LIFE CYCLE COST-BASED RISK MODEL FOR ENERGY PERFORMANCE CONTRACTING RETROFITS

By

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ABSTRACT

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Buildings account for 41% of the primary energy consumption in the United States, nearly half of which is accounted for by commercial buildings. Among the greatest energy users are those in the municipalities, universities, schools, and hospitals (MUSH) market. Correctional facilities are in the upper half of all commercial building types for energy intensity. Public agencies have experienced reduced capital budgets to fund retrofits; this has led to the increased use of energy performance contracts (EPC), which are implemented by energy services companies (ESCOs). These companies guarantee a minimum amount of energy savings resulting from the retrofit activities, which in essence transfers performance risk from the owner to the contractor.

Building retrofits in the MUSH market, especially correctional facilities, are well-suited to EPC, yet despite this potential and their high energy intensities, efficiency improvements lag behind that of other public building types. Complexities in project execution, lack of support for data requests and sub-metering, and conflicting project objectives have been cited as reasons for this lag effect. As a result, project-level risks must be understood in order to support wider adoption of retrofits in the public market, in particular the correctional facility sub-market.

The goal of this research is to understand risks related to the execution of energy efficiency retrofits delivered via EPC in the MUSH market. To achieve this goal, in-depth analysis and improved understanding was sought with regard to ESCO risks that are unique to EPC in this

market. The proposed work contributes to this understanding by developing a life cycle cost-based risk model to improve project decision making with regard to risk control and reduction. The specific objectives of the research are: (1) to perform an exploratory analysis of the EPC retrofit process and identify key areas of performance risk requiring in-depth analysis; (2) to construct a framework describing the sources of and mitigation strategies employed for assessing key risks in EPC retrofits; (3) to develop a strategy for analyzing and evaluating risks for EPC retrofits focused on managing expected costs throughout the project life cycle, and use data collected through this strategy to develop and parameterize a risk model; and (4) to demonstrate the applicability of the proposed life cost-based risk model through a pilot application to a case study site.

Five major contributions to the body of knowledge resulting from the research include: (1) a consensus-based assessment of ESCO risk management; (2) characterization of EPC retrofit risks borne by ESCOs; (3) an empirical evaluation of scenario failure mode and effects analysis and its application to this domain; (4) development and pilot application of a life cycle cost-based risk model; and (5) future expansion of the research approach to other domains.

The researcher envisions that full implementation of the research will further encourage the growth of the energy services industry, and support focused retrofits in complex building types that typically can benefit the most from such work. Ultimately, this will reduce the energy consumption of public sector buildings to levels that are more fitting with the global principles of sustainability and responsible management of constrained resources.

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TABLE OF CONTENTS

CHAPTER 5

CHAPTER 7
SUMMARY AND FUTURE RESEARCH....................314

LIST OF TABLES

LIST OF FIGURES

KEY TO ABBREVIATIONS

BBN	Bayesian Belief Network
BTU	British Thermal Unit
C&I	Commercial and Industrial
CBECS	Commercial Buildings Energy Consumption Survey
CCF	Hundred Cubic Feet
CDD	Cooling Degree Days
D	Detection
EC	Expected Cost
EC_{PV}	Expected Cost Based on Present Value
ECM	Energy Conservation Measures
ELCV	Expected Life Cycle Value
ELC_{PV}	Expected Life Cycle Value Based on Present Value
EPC	Energy Performance Contract
ESCO	Energy Service Company
ESPC	Energy Savings Performance Contract
FEMP	Federal Energy Management Program of the U.S. Department of Energy
FMEA	Failure Mode and Effects Analysis
HDD	Heating Degree Days
IGA	Investment Grade Audit
IPMVP	International Performance Measurement and Verification Protocol
KBTU	Thousand BTUs

kVA	Kilo Volt Ampere
kW	Kilowatt
kWh	Kilowatt Hours
LCCA	Life Cycle Cost Analysis
M&V	Measurement and Verification
MMBTU	Million BTUs
MUSH	Municipalities, Universities, Schools, and Hospitals
NEB	Non-Energy Benefit
O	Occurrence
O&M	Operations and Maintenance
OPR	Owner’s Project Requirements
P_{cause}	Probability of the Cause of a Risk Scenario
P_{effect}	Probability of the End Effect of a Risk Scenario
RM	Risk Management
RPN	Risk Priority Number
S	Severity
SFMEA	Scenario-Based Failure Mode and Effects Analysis
SPV	Single Present Value

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

High performance sustainable buildings (HPSB) are a part of the broader green building market and defined as those buildings that utilize integrated design, are highly efficient in their use of energy and water, improve indoor environmental quality for building occupants, and minimize the negative environmental impacts of material consumption and use (U.S. Department of Energy 2008). These buildings result in reduced life cycle costs for building operation and maintenance and reduced energy and water consumption, leading to increased demand for such buildings. With 40% of total energy use in the United States coming from the buildings sector (U.S. Department of Energy 2011a; Morganstern et al. 2008), significant economic advantages exist for buildings that exhibit high standards of energy efficiency. Energy efficient building practices have been identified as one of the most cost effective measures for controlling operating costs in buildings (Drumheller and Wiehagen 2004; Dong et al. 2005; Harvey 2009). The U.S. non-residential green building market is projected to triple from approximately \$43-\$54 million in 2010 to \$145 billion by 2015; major retrofit and renovation projects are expected to experience a three to fivefold increase to \$18 billion during that same time. Energy efficiency is expected to be a key element of up to two-thirds of these retrofit projects between 2010 and 2015 (Russo 2011).

Commercial buildings account for nearly half of the primary energy consumption in the United States (U.S. Department of Energy 2011a). Among buildings with the greatest energy intensity (measured by British Thermal Units [BTUs] consumed per square foot of building area) are hospitals, nursing homes, food service and sales facilities, educational, and public safety facilities. While the U.S. Department of Energy (DOE) does not further disaggregate its Commercial Building Energy Consumption Survey (CBECS) data beyond the building types mentioned above, an analysis of the data reveals that prison and jail facilities are in the upper half of all commercial building types for energy intensity (U.S. Department of Energy 2011a). Average energy intensities between 120,000 and 221,100 BTUs per square foot were recorded for buildings of the “public order and safety” type in the CBECS survey (U.S. Department of Energy 2011b). Correctional facility data, obtained from California and Wisconsin, shows these facilities had average energy intensities between 163,000 BTU/sf (California Department of General Services 2011) and 193,400 BTU/sf (Wisconsin Department of Administration 2011) respectively, thereby confirming the CBECS data. Energy efficient retrofit is a growing and important part of both the construction and energy economies – utilities spent \$6.7 billion on demand-side management programs in 2011 (Forster et al. 2013), which is projected to increase to between \$6.5 and \$15.6 billion by 2025 (Barbose et al. 2013). These utility expenses, along with owner-financed improvements, had a net impact of \$574 billion to the U.S. economy in 2010, which was three times the investment made in conventional energy generation capacity (Laitner 2013).

Despite high energy intensities, many public agencies have reduced capital budgets to fund retrofit programs, even among projects which enhance efficiencies and thus save funds (Bharvirkar et al. 2008). The continued operation of inefficient mechanical, electrical, and plumbing equipment can lead to increased utility costs, thereby exacerbating this situation

(Bhattacharjee et al. 2010). These factors have contributed to the increased use of energy performance contracts (EPCs), particularly in what has been termed the MUSH (municipalities, universities, schools, and hospitals) market (Hopper et al. 2005).

1.1.1 Energy Performance Contracting (EPC)

Energy performance contracting is a project delivery mechanism that finances retrofits using projected utility savings gained through improved energy efficiency. As a result, capital is not required at project startup; rather, the work can be financed over a period of years, termed the contract performance period. EPCs are generally executed by an energy service company (ESCO), which performs the work and receives payment as a result of accumulated utility savings which exceed baseline consumption. ESCOs are defined as businesses that provide a full-range of energy efficiency services and include performance contracting as a core component of the energy efficiency business (Goldman et al. 2005; Hopper et al. 2007).

Businesses cannot be classified as ESCOs in the absence of engaging in performance contracting. This is an important concept, because it implies that ESCOs, by definition, guarantee some level of performance in their energy efficiency services, which in turn creates inherent risks to the ESCO throughout the EPC delivery process. The level to which these firms can manage and mitigate these risks defines a successful ESCO. As a result, the concepts of risk analysis, risk management, decision-making under uncertainty, and EPCs are interrelated and must be treated as such.

Energy service company revenues have grown significantly in the United States over the past 20 years, with annual growth rates of approximately 9% between 2009 and 2011, (Figure 1-1a), with a projected doubling to between \$10.6 and \$15.3 billion by 2020. This growth outpaced the U.S. Gross Domestic Product, and its continued growth despite the economic recession indicates that the EPC model may in fact be somewhat insensitive to the economy due to its ability to deliver capital improvements with little-to-no up-front investment (Stuart et al. 2013). Approximately 85% of ESCO revenue in 2011 was the result of energy efficiency projects, thereby providing an analogous measure to the size of the EPC industry at that point in time.

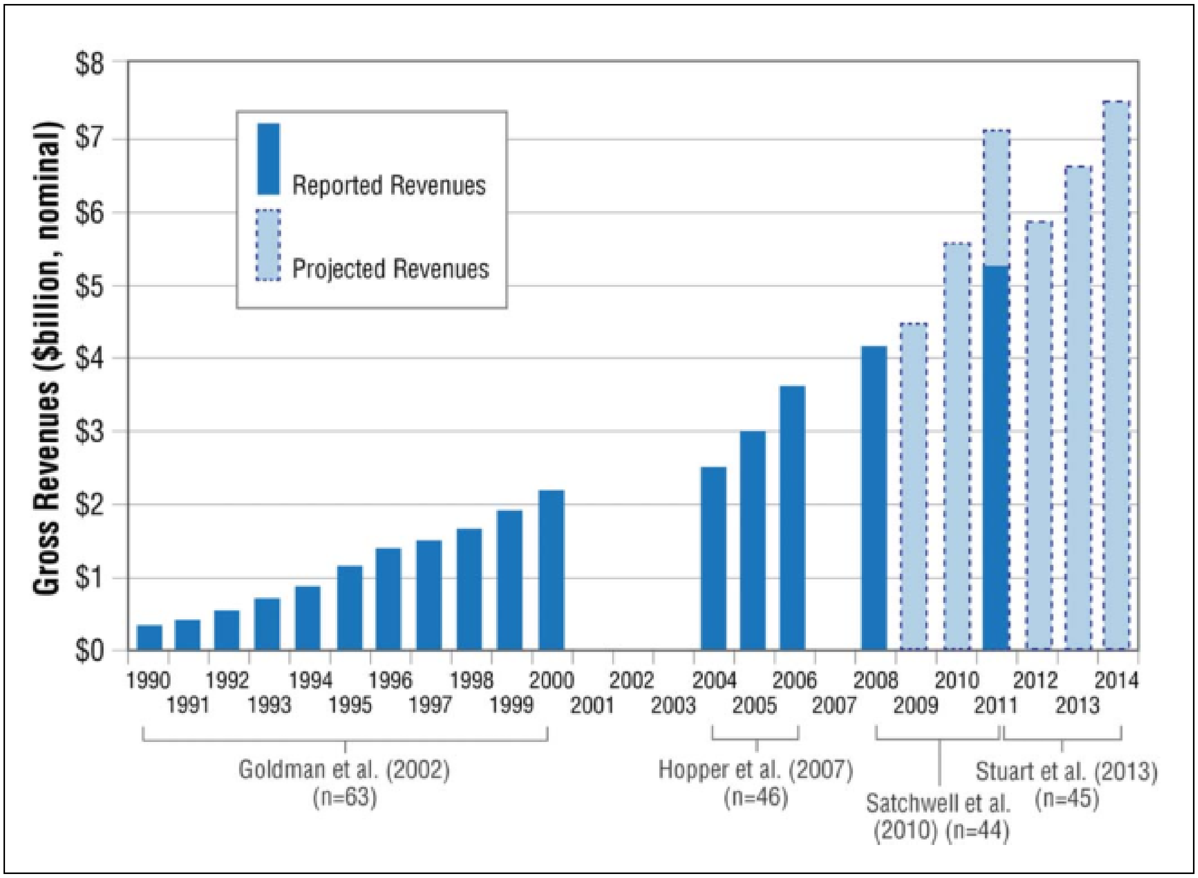


Figure 1-1a. United States ESCO – 1990 Projected Through 2014
(Source: Stuart et al. 2013)

The MUSH market is the dominant sector for EPC retrofits, representing a 63% share of total energy ESCO revenue in 2011, a 9% growth since 2006 (Figure 1-1b) (Satchwell et al. 2010). While this market sector has been characterized as being mature, Stuart et al. (2013) reported remaining market potential of between $52 and $94 billion as of 2012, which represents potential annual energy savings of 211-311 trillion BTUs.

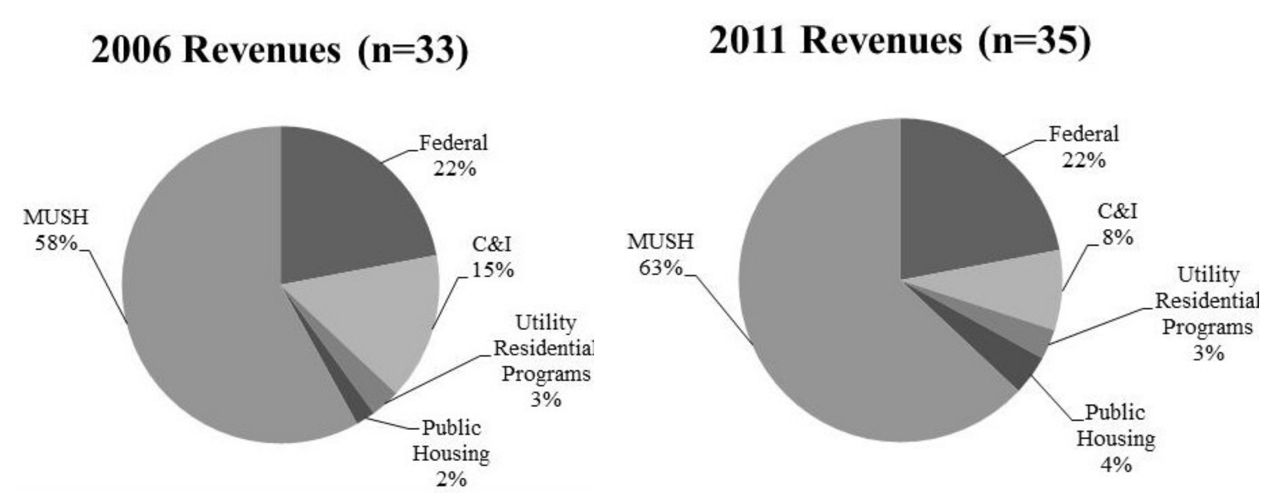


Figure 1-1b. ESCO Revenues by Market – 2006 and 2008
(Source: Larsen et al. 2012a; Stuart et al. 2013)

1.1.1.1 Correctional Facilities and Energy Performance Contracting

Correctional facility retrofit projects are well-suited to EPCs, as indicated by a framework developed by the Australian Energy Performance Contracting Association (AEPCA 2000). These projects are characterized by centralized buildings in a discrete location, typically consisting of 50 or fewer buildings (often less), large gross square footages (>250,000 SF), high energy bills ($500,000-$1,000,000/year are not uncommon), facilities that are generally more than 20 years old, and due to capital constraints, more than 10-15 years have passed since their last upgrade.

Projects may be procured using a single-phase or multi-phase approach. In the former, the request for proposals (RFPs) leads to selection of an ESCO to conduct all phases of work; in the latter, two RFPs are issued – one for selecting an ESCO at the design phase and preparation of the technical audit and a second one for the investment grade audit (IGA), energy savings guarantee, construction, and measurement and verification (M&V). Some RFPs include all phases of work in a single contract while others divide the scope into separate work packages for the audit, construction, and M&V, regardless of whether the work packages are bid separately. The energy savings guarantee and M&V portion of the contract (or separate contract, if used) generally includes provisions for the annual calculation of savings and may include a designated time period (two to three years) of intense M&V activity after completion of construction, upon which further annual savings are based. Some contracts may stipulate different calculation methods during the construction phase, due to incomplete installation of energy conservation measures (ECMs) and intense utility consumption due to construction activity. Additionally, savings may be stipulated, where both parties agree to performance levels of individual ECMs during project development or they may be measured and verified following options in the International Performance Measurement and Verification Protocol (IPMVP) (EVO 2012). The IPMVP is discussed in greater detail in Chapter 2.

1.1.1.2 Contractual Forms of Energy Performance Contracting

There are two predominant contractual forms of EPCs: (1) shared savings and (2) guaranteed savings (Figure 1-2a). In the shared savings model, the ESCO shares the value of energy savings with the project owner under a pre-determined arrangement that is dependent on project-specific factors. Under this model, the ESCO typically secures financing from a third-party entity, meaning that both parties bear some degree of credit and performance risk. Since the ESCO's share of the savings is the only form of payment they receive, their share of the savings is typically higher in the early stages of the project when design and construction costs are incurred, and decrease over the project life cycle (Hopper et al. 2005; Bertoldi et al. 2006; CCI 2009a; Larsen et al. 2012a).

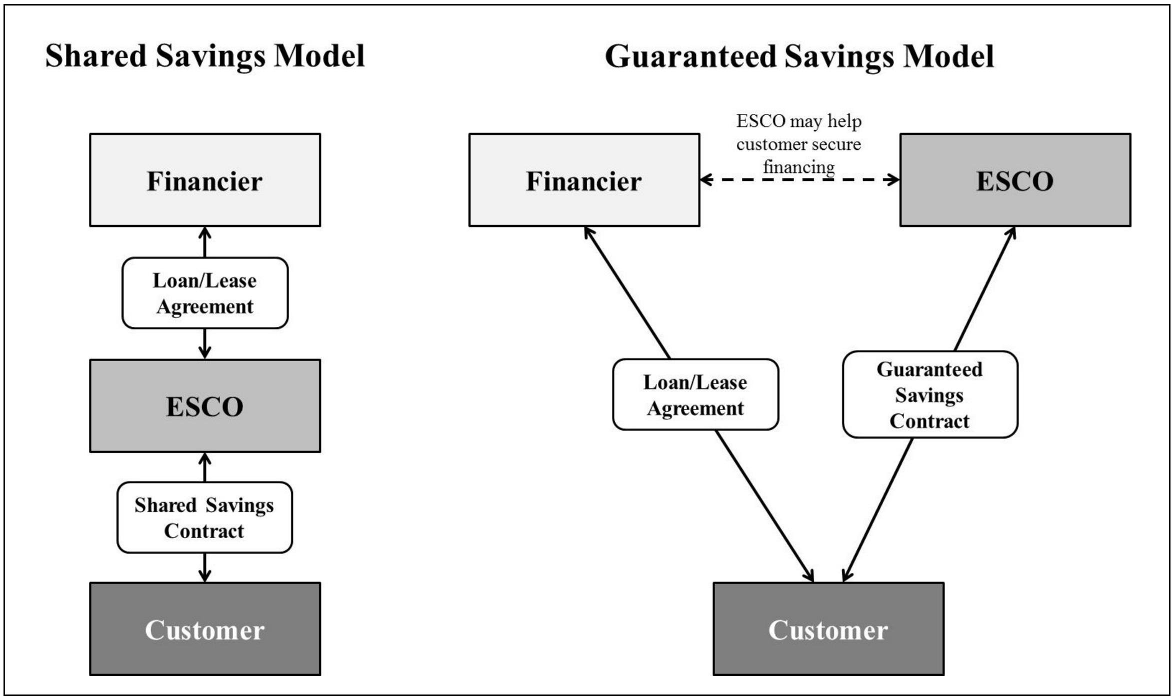


Figure 1-2a. Comparison of Shared Savings and Guaranteed Savings EPC Models
(Source: Hopper et al. 2005)

Under the guaranteed savings approach, the ESCO guarantees the customer a certain quantity of energy savings via the guaranteed savings contract, ensuring that the associated value of those savings is enough to repay lease costs to the financier and to pay for the cost of the retrofit work itself (Deng 2011). When using this model, the ESCO generally grants all excess savings to the project owner, and agrees to be liable for any shortfalls in actual energy savings. In the guaranteed savings model, the owner typically secures funding directly from a third-party lender (although the ESCO may assist with securing financing), which eliminates credit risk for the ESCO; however, in this model the ESCO retains project performance risks via the guaranteed savings contract (Larsen et al. 2012a).

The dominant contractual form in the United States is the guaranteed savings model. According to Goldman et al. (2005), 67% of public sector performance contract projects reviewed over a 15 year period utilized guaranteed savings (Figure 1-2b). According to the authors, public project owners reported that they preferred the stronger savings guarantee, and ESCOs preferred the lower financing costs for public projects and the ability to place more focus on matters directly related to project performance. This is reversed in the developing world and in countries with nascent ESCO markets, where the stronger preference is to execute shared-savings contracts. This frees project owners from bearing any financial risk, and frees banks from retaining credit risk, often in countries that have poorly-established banking infrastructures (Okay and Akman 2010).

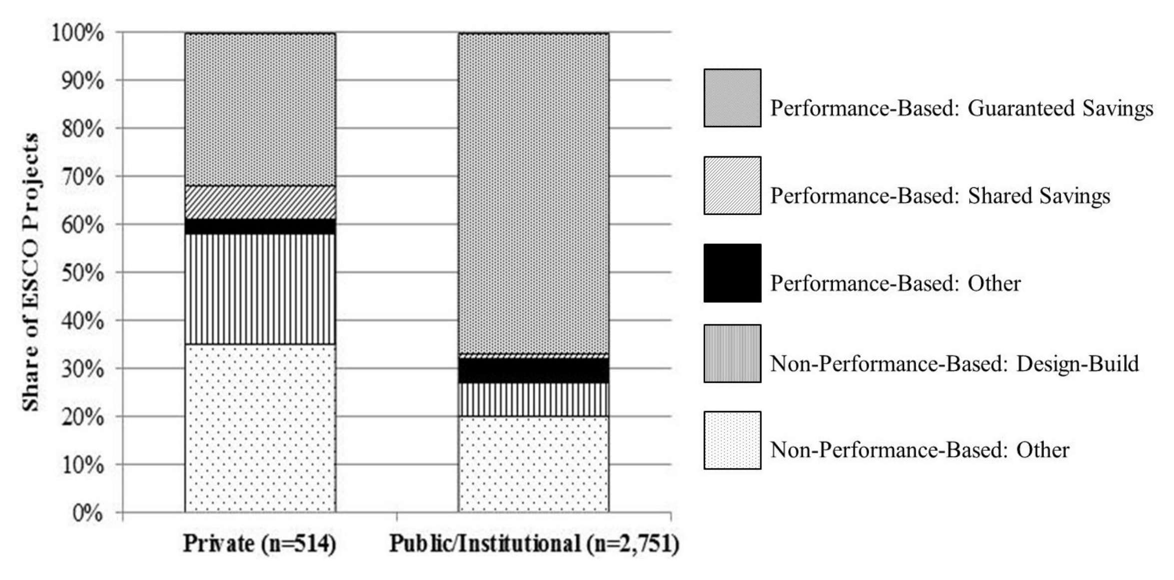


Figure 1-2b. EPC Contractual Models in Private and Public Sector Projects
(Source: Larsen et al. 2012a)

As stated above, the guaranteed savings model allocates a larger share of performance-related risk to the ESCO. These risks occur throughout the project life cycle and result primarily from three sources: (1) development phase concerns related to customer and project characteristics as well as potentially unrecoverable costs during this time; (2) the financial guarantee proffered by the ESCO which results from actual levels of energy performance versus guaranteed levels of performance; and (3) the lack of ESCO-initiated change orders in such projects, which make additional costs difficult or impossible to recover (Kansas Corporation Commission, Energy Division 2014; Oregon Department of Energy 2014). These risks are discussed in greater detail in sections 1.2.1 and 1.2.4, and serve as a key underpinning of the need for this research.

1.1.2 Energy Characteristics of Relevant MUSH Sector Building Types

As defined above, the MUSH market includes municipalities, universities, schools, and hospitals. These four sub-markets comprise a wide variety of building types and include correctional facilities. These buildings are neither well-described nor well-represented in existing energy consumption data sets, such as CBECS (U.S. Department of Energy 2013a). The CBECS data can be queried by principal building activity and government ownership to identify buildings that are representative of the MUSH market, to include other public order and safety, nursing home, hospital, outpatient health, office, education, public assembly, and non-refrigerated warehouse facilities. The “other public order and safety” buildings were queried based on 24-hour operation to generate a data set that is analogous to correctional facilities and jails. Building type descriptions are provided in Table 1-1, and illuminate some limitations of this highly-aggregated data set; however, CBECS data provides a framework for understanding energy intensities and enegy end-uses of a variety of building types despite its limitations.

Table 1-1. CBECS Building Types, Definitions, and Sub-Categories

Building Type	Summary Definition	Example Sub Categories
Education	Buildings used for academic or technical classroom instruction, such as elementary, middle, or high schools, and classroom buildings on college or university campuses.	• Preschool or daycare • Elementary/middle/high school • College or university • Career or vocational training
Healthcare (Inpatient)	Buildings used as diagnostic and treatment facilities for inpatient care.	• Hospital • Inpatient rehabilitation
Healthcare (Outpatient)	Buildings used as diagnostic and treatment facilities for outpatient care.	• Medical office • Clinic or other outpatient health care
Non-Refrigerated Warehouse	Buildings used to store goods, manufactured products, merchandise, raw materials, or personal belongings (such as self-storage).	• Non-refrigerated warehouse
Nursing home	Buildings used to offer multiple accommodations for long-term residents involving skilled nursing.	• Nursing home • Assisted living or other residential care
Office	Buildings used for general office space, professional office, or administrative offices. Medical offices are included here if they do not use any type of diagnostic medical equipment (if they do, they are categorized as an outpatient health care building).	• Government office • City hall or city center • Administrative office • Mixed-use office • Bank or financial institution • Contractor's office • Non-profit or social services
Other public order and safety – 24 hour operation	Buildings used for the preservation of law and order or public safety.[a]	• Jail or penitentiary
Public assembly	Buildings in which people gather for social or recreational activities, whether in private or non-private meeting halls.	• Social or meeting space • Recreation • Library • Armory
Service	Buildings in which some type of service is provided, other than food service or retail sales of goods.	• Vehicle storage/maintenance • Post office or postal center • Copy center or printing shop • Kennel

Notes:

a\ “Other public safety” is a sub-set of the “public safety” building type that excludes police and fire stations. Facilities operating 24-hours per day were queried to provide an analog for correctional facilities, since that building type cannot be disaggregated from CBECS data.

(Data source: U.S. Department of Energy 2003 Commercial Buildings Energy Consumption Survey [CBECS])

Energy intensities varied by building type, from 67,112 BTU/sf (non-refrigerated warehouse) to 258,819 BTU/sf (healthcare-inpatient), with an average of 122,282 BTU/sf (U.S. Department of Energy 2011b). As might be expected, end-use energy intensities among these building types are dominated by heating, ventilation, and air conditioning (HVAC) (average 72,000 BTU/sf; 56% of building energy intensity), lighting (average 19,369 BTU/sf; 17% of building energy intensity), and water heating (average 14,274 BTU/sf; 13% of building energy intensity). End-use energy intensities for various MUSH market building types are depicted in Figure 1-3.

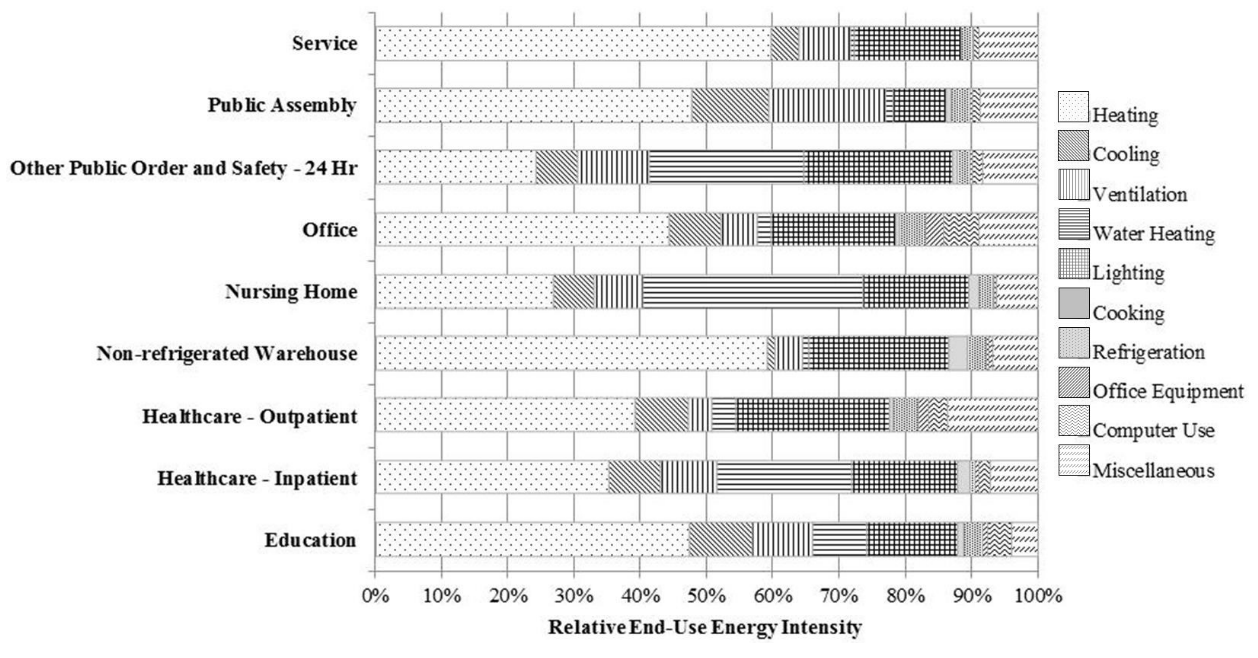


Figure 1-3. Relative End-Use Energy Intensities Among MUSH Sector Building Types
(Source: U.S. Department of Energy 2003 Commercial Buildings Energy Consumption Survey)

Given the limited available data on energy consumption and a very small amount of literature focused on energy efficiency in correctional facilities, the CBECS data were reviewed to find other building types with similar energy end-use intensities of the "other public order and safety" type. Nursing home and hospital building types were found to have the most similar end-use intensities among dominant energy uses. Additionally, healthcare buildings are an important part of the MUSH sector, due to their ubiquity in the built environment and the high energy intensities of these buildings. A relatively rich literature is also available for hospital energy efficiency that helps establish the context for the development of the proposed risk framework in the context of correctional facilities. Key elements of this literature that are relevant to the subject work include:

- Energy efficiency frameworks, such as the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Advanced Energy Design Guide (AEDG) for Large Hospitals (ASHRAE 2012), the Advanced Energy Retrofit Guide for Healthcare Facilities (U.S. Department of Energy 2013b), the 2007 Sustainable Healthcare Energy Challenge (Burpee et al. 2009), and the Green Guide for Healthcare (Burpee et al. 2009).
- Suggested energy targets for various building systems (ASHRAE 2012)
- Research-based approaches to energy efficiency retrofits in hospitals that can be directly transferred to correctional facility retrofit frameworks, to include life cycle cost-based technical approaches (Kolokotsa et al. 2012).

While not the focus of this research, healthcare facility energy efficiency research can be used to inform the development of this research framework, given the similarity in energy consumption and operational profiles of these buildings and correctional facilities.

1.1.3 Energy Consumption and Efficiency in Correctional Facilities

Less attention has been focused specifically on guidelines for reducing energy consumption in correctional facilities; however, drivers for such work have been given as: (1) reducing recidivism through inmate job training related to sustainability activities and (2) reducing operating costs (Morgan 2010; Webster 2010; Sheldon and Atherton 2011; Sheldon et al. 2011). These reduced costs have been equated to saving $1,000 to $1,250 per inmate per year (CEC and CBC 2001; Sheldon et al. 2011), which can be equated to $44 to $55 million in annual operational savings in Michigan alone. A small body of research has focused on the effects of design and engineering on inmate behavior (e.g., violence level, health effects) due to indoor environments; energy efficient and sustainable retrofits may provide such facility improvements which can consequentially lead to improved inmate behavior (Moore 1980; Al-Hosany and Elkadi 2002; Nalbone 2004; McMillan 2010; Wener 2012). Such practices were codified in 2010, when the American Correctional Association (ACA) amended its correctional facility accreditation standard through the inclusion of the "ACA Standard on Sustainability" and the attendant "Public Correctional Policy on Environmentally Responsible and Sustainability-Oriented Practices" (American Correctional Association 2012).

Despite this body of research and recent attention provided by a new accreditation standard, limited literature exists related to design and retrofit concepts related to energy consumption (and efficiency) and guidelines to promote efficient construction and retrofit practices in correctional facilities. The National Institute of Justice released the first national comprehensive guidance on implementing sustainable technologies in correctional facilities, titled the "Greening Corrections Technology Guidebook" in 2011 (Sheldon and Atherton 2011). This guidance document focuses on sustainability practices in seven key systems, four of which directly impact energy consumption: (1) lighting; (2) HVAC; (3) plug-in appliances, to include pumps and motors; and (4) energy, to include renewable energy, passive cooling, and transportation considerations, as well as one system, water efficiency, which has mediating effects on energy consumption. This document does not specifically address technical solutions to achieve these sustainability goals; however, management, implementation, and funding issues are addressed, including a discussion about the role of EPC in procuring projects which have inadequate capital funding.

Two example guidelines for assessing the environmental performance of correctional facilities are the “Energy Efficiency Design Guide for California Detention Facilities,” first published in 1990 (CEC and CBC 2001), and the Building Research Establishment’s Environmental Assessment Method (BREEAM) Prisons scheme document, first published in 2008 (BRE Global 2012). The California document provides guidance for three primary building systems (building envelope, lighting systems, and mechanical systems) with a fourth category devoted to ongoing considerations, to include transformers, commissioning, and maintenance. Security concerns are included with regard to minimum interior and exterior lighting levels, ingress and egress control with skylights, and the location within the facility of mechanical plant components.

BREAAM Prisons addresses similar systems, although it places more emphasis on carbon dioxide emissions, low- or zero-carbon emission strategies, sub-metering, acoustics, and occupant comfort. It provides less technical implementation detail than the California guidance; however, it places significant emphasis on security considerations, integrating these concerns into nearly every category and issue.

1.1.4 Life Cycle Cost Analysis and Energy Performance Contracting

Life cycle cost analysis (LCCA), and a related cash flow analysis, are critical elements of the

IGA performed in conjunction with the planning phase of an EPC (Hansen 2006). The U.S. DOE has created specific guidance for the use of LCCA in federal projects in accordance with Executive Order (EO) 13123, calling for the comparison of existing equipment costs against ECMs specified through an EPC project (Fuller 2005). The DOE guidance utilizes the EO 13123 definition of life cycle costs, "…the sum of present values of investment costs, capital costs, installation costs, energy costs, operating costs, maintenance costs, and disposal costs over the life-time of the project, product, or measure." This is a relatively traditional definition of built environment LCCA and does not include the large array of non-energy benefits (NEBs) in which may be included in EPC retrofits. Non-energy benefits have the potential to positively affect the financial performance of EPC projects; however, their use and calculation has been the subject of considerable debate.

A small number of studies over the past 8-10 years have focused on NEBs. In a survey of ESCOs and building managers conducted by Birr and Singer (2008), 93% of respondents felt that building maintenance and operation costs savings were either significant or extremely significant in motivating their organization to consider entering into an EPC. A survey conducted by Jennings and Skumatz (2006) focused on additional benefits from the commissioning process found that the primary benefits related to similar life cycle cost activities – finding and correcting operational deficiencies, increasing operations and maintenance staff knowledge, and addressing equipment maintenance considerations.

The ability to incorporate NEBs into LCCA varies across public projects. The federal energy savings performance contract (ESPC) program is not clear about permitting eligible savings from operations and maintenance and avoided capital costs (Larsen et al. 2012b). Larsen et al. (2012b) examined legislation from six states (Florida, Hawaii, New Jersey, New Mexico, Pennsylvania, and Virginia) to ascertain whether they permit the inclusion of NEBs in energy efficiency projects. All six states permitted the inclusion of operations and/or maintenance benefits and five permitted the use of avoided capital costs; however, only two of the six states (New Jersey and Pennsylvania) allowed the inclusion of other NEBs, and two states limited the amount and type of NEBs that may be included in a project.

Michigan's Public Act 625 of 2012 allows for the inclusion of a variety of NEBs in energy performance contracts issued for state facilities, to include measures that reduce capital avoidance costs, capital improvement costs, maintenance costs, and operating costs (Cost-Effective Governmental Energy Use Act 2012). Examples provided in the law include:

- Water consumption and sewage reduction devices and practices to include water-conserving equipment, low-impact landscaping features, equipment that permits recycling of water, to "treated municipal effluent," condensate and grey water recapture devices, and water system sub-metering.
- Operation and maintenance practices.
- Indoor air quality improvements.
- Life safety measures that lead to long-term operating cost reductions, including those measures related to compliance with the Americans with Disabilities Act.
- Any other building infrastructure improvement that leads to utility or operational cost savings.

Hughes and Muessel (2000) identified an important life cycle cost consideration in executing federal ESPCs under the Federal Energy Management Program (FEMP) – the need to calculate life cycle costs and benefits of the entire package of ECMs, not just on an individual ECM-by-ECM basis, as included in early versions of technical guidance for the FEMP (Fuller and Petersen 1995). This not only ensures that ECMs provide maximum benefits to the building system, but also increases the potential to find synergies among them (e.g., envelope and lighting changes can result in decreased cooling loads, thereby requiring a smaller HVAC system).

Since LCCA and the long-term energy savings guarantee feature of EPC projects are so closely-related, it is reasonable to conclude that a complete understanding of life cycle costs of the portfolio of ECMs installed in such projects is critical to overall project success. Despite the important role that LCCA plays in making retrofit decisions utilizing EPC, historically there have been challenges with the method. These challenges center on the lack of data for maintenance and replacement costs as well as the presence of uncertainty and risk in many LCCA elements, and their attendant lack of inclusion in analysis (Kishk et al. 2003; Brink 2012). LCCA methods must give appropriate consideration to uncertain or incomplete data as well as risk factors inherent with system inputs in order to provide a complete analysis. This is particularly important in the case of EPC, where the performance guarantee is based on energy use reductions over the performance period of the contract.

1.2 NEED STATEMENT

The use of EPCs is growing in popularity among MUSH market owners, with overall industry growth rates increasing rapidly in the past several years. This represents a marked increase from the slowing growth trend observed during the late 1990s and early 2000s (Mills et al. 2006; Satchwell et al. 2010). This actual and projected growth over the past five years exists despite the downturn observed in the buildings sector and restricted lending as credit rules were temporarily tightened. Much of this optimism resulted from the American Recovery and Reinvestment Act, which had significant focus on public sector building retrofit funding (Satchwell et al. 2010).

Despite growing use of EPCs in the MUSH market, a relatively limited body of related literature restricts the ability for research to inform practice in this important sector of the built environment. Since performance contracting is essentially a mechanism to transfer energy efficiency performance risks from the owner to the ESCO, project-level risks specific to ESCOs must be better-understood. This need has been noted by Hansen (2006), and confirmed by Hansen (2013), in providing a list of broad risks that ESCOs should be particularly attune to; however, this work does not provide an evaluative framework for the assessment and evaluation of risk in EPCs. A small body of literature identifies other risks in performing EPCs, but like the previous work, the majority of the effort is directed to risk identification. A comprehensive risk assessment framework for ESCOs is required to fully understand and implement EPC, particularly in emerging markets and sub-markets, such as correctional facilities.

The confluence of the increased use of EPCs in the MUSH market with the need to better study the management of ESCO risk leads to the following four premises which guide the need for this research.

1.2.1 Premise #1 – Construction and Energy Efficient Retrofits Carry Risks for Contractors

During the life cycle of an EPC retrofit, traditional construction project-related risks combine with the unique risks borne by the ESCO in achieving the performance guarantee to create a unique situation that merits further study. As a result of this risk convergence, the construction, technical, and performance risks are transferred from the owner to the ESCO in an EPC, therefore making this arrangement inherently risky for the ESCO.

Construction is an inherently risky enterprise due to the unique nature of projects as well as their size and complexity, and numerous contractual and management interactions among diverse stakeholders, which all occur in an environment with distinct political, economic, and social factors (Zavadskas et al. 2010; Banaitiene and Banaitis 2012). As a result, project risks have been well-studied in the literature, at the level of overall project risks (Tah and Carr 2000; Tah and Carr 2001; Zavadskas et al. 2010; Banaitiene and Banaitis 2012; Goh and Abdul-Rahman 2013) and at the level of individual project phases, elements, and critical success factors such as the project planning phase (Diab 2012), time and cost (Doloi 2012), safety (Hallowell and Gambatese 2010), and delay (Assaf and Al-Hejji 2006). Willis (2008) suggested that a specific risk assessment method is needed for the specification of ECMs, resulting from the identification of twelve emerging technologies that did not perform as expected, and in many cases actually consumed more energy and caused damage to other equipment in linked systems. This assertion is of direct concern to ESCOs, as ECM failure potentially means that the performance guarantee will not be obtained. As a result, an understanding of contractor risk in the EPC process is warranted.

Hansen (2006) proposed a framework for identifying and mitigating the unique risks in EPC projects. While not explicitly defined elsewhere in the literature, several studies support and expand upon various elements of this proposed framework, which includes ten risk categories for ESCOs to consider when undertaking EPCs (eight from Hansen 2006; two additional from the literature that were not identified by Hansen). Since the primary risk category for ESCOs undertaking EPCs is failing to achieve guaranteed performance, this framework can be considered a first step toward identifying critical risk categories for ESCOs in this regard. These risks are discussed in greater detail in Chapter 2, but are identified briefly, as follows:

- Customer Pre-Qualification – includes concerns related to the building owner, building-specific features, and possible future building reuse and/or repurposing (AEPCA 2000; Walker and Dominick 2000; Bertoldi and Rezessy 2005; Shonder and Hughes 2005; Hansen 2006; Mills et al 2006);
- Project Development (Hansen 2006);
- Energy Audit Quality (Mozzo 2001; Hansen 2006; Mills et al 2006; Sankey 2007);
- Equipment Selection and Installation – includes differential risks among passive (e.g., building envelope) and active (e.g., mechanical system, lighting) retrofit strategies. (Shonder and Hughes 2005; Hansen 2006; Mills et al 2006; Shang et al. 2008; Wang and Chen 2008; Willis 2008; Jinrong and Enyi 2011);
- Commissioning (Stum 2000; Hansen 2006; Sankey 2007);
- Operations and Maintenance Practices (AEPCA 2000; Hansen 2006; Mills et al 2006);
- Measurement and Verification of Savings – includes the behavioral and systems implications of the “rebound effect” (Hertwich 2005; Herring and Roy 2007; Strand 2011) and risks related to external conditions, such as variations in weather during the

performance period (Schweitzer et al. 2000; Hansen 2006; Mills et al 2006; Mozzo 2006; Shang et al. 2008; Larsen et al 2012a);

- Project Management Over the Project Life Cycle (Hansen 2006);
- Construction-Specific Concerns (Smith and Ferber 1996; AEPCA 2000; Sankey 2007; Silberman 2010); and
- Volatility of Energy Prices (Bertoldi and Rezessy 2005; Shonder and Hughes 2005; Mills et al 2006; Shang et al. 2008; Wang and Chen 2008; Berghorn 2012).

1.2.2 Premise #2 – There is a Need for Energy Efficient Retrofits in the MUSH Market

Sixty three percent of ESCO revenue is derived from MUSH market projects, and another 22% of ESCO revenue has been attributable to federal government projects (Stuart et al. 2013). Several factors make this market particularly attractive to EPC-driven work, including high rates of owner occupancy, which eliminates the split incentive problem; the relatively low financial risk of MUSH market clients; legislation-driven energy efficiency mandates that increase motivation to perform such work; and constrained capital budgets that often demand alternative financing strategies to fund retrofits (McCabe 2011). While ESCOs have been active in the MUSH market for over two decades, there is significant remaining market potential for energy efficiency retrofit. An analysis conducted by the Lawrence Berkeley National Laboratory in 2010 estimated that unmet energy efficiency retrofit opportunities in larger MUSH market facilities could yield annual energy savings of 160 million MMBTU and lifetime savings of 2.4 billion MMBTU, which would require approximately $35 billion in additional ESCO investment (Satchwell et al. 2010).

The primary motivation for the use of EPC retrofits in the MUSH market is the lack of capital financing, which often manifests as a challenge to address a broader range of capital investment needs beyond energy efficiency (Hopper et al. 2004). This is seen by the typical inclusion of more lighting retrofits and non-energy improvements (e.g., building envelope, environmental remediation) in MUSH market projects than what is typically found in federal markets (Hopper et al. 2004). The authors further identified important barriers to increased EPC implementation in the MUSH sector. The primary barrier identified was the lack of enabling legislation in certain states, particularly that which is well-designed or strongly supported. Legislatively-limited contract lengths were noted as a barrier to fully realizing the opportunities available through EPCs by limiting technical work packages to only those with relatively faster paybacks. Other barriers included poor project performance history, which has led some states to avoid exploring or expanding EPC work, the need to educate customers, and a sense that "the low-hanging fruit is already picked" – meaning that the least-risky and easiest to implement retrofit strategies have already been implemented (Hopper et al. 2004).

Energy consumption and efficiency potential in the MUSH market is difficult to understand due to limitations in available datasets. For example, CBECS data is categorized by building type, ownership, and occupant type, potentially leaving a gap in the knowledge of whether an office building would be considered part of the MUSH market or not. This is an important distinction because MUSH market buildings are often the most energy-intensive among similar structures because they are typically older and they are generally significant energy users owing to the unique and mission-specific function of many of these facilities. Water utilities and wastewater treatment facilities account for up to 33 percent of municipal energy use, and the healthcare sector operates continuously (e.g., around the clock) and abides by strict health and safety requirements which can require specialized air filtration and increased air flow and exchange rates (Irwin et al. 2011).

Irwin et al. (2011) identified over 137,000 MUSH organizations in the United States. The CBECS 2003 survey identified 386,000 education buildings, 129,000 healthcare buildings, and 71,000 public order and safety buildings (U.S. DOE 2011b). The survey also identified 1.77 million buildings in the office, public assembly, warehouse, and other types. Applying the U.S. Department of Energy estimate that 24% of commercial floor space is under government ownership or management (Irwin et al. 2011), there are an estimated 426,480 office, public assembly, warehouse, and other building types under government control. When added to the number of education, healthcare, and public order and safety buildings, the MUSH market can be assumed to comprise 1.01 million buildings. Subjecting square footages from the CBECS survey to a similar analysis yields an estimated 20.8 billion square feet of floor area exists in the national MUSH market (32.2% of the national commercial building stock floor area). This square footage has been estimated to use between 2.08 quadrillion (analysis of CBECS data) and 3.87 quadrillion (Irwin et al. 2011) BTU per year, which costs between \$21.9 and \$40.7 billion annually.

Savings from energy efficiency retrofits executed under performance contracts in the MUSH sector have historically been approximately 20 percent of the utility bill baseline (Hopper et al. 2005). The MUSH market could realize annual energy savings of between \$4.4 and \$8.1 billion if the entire building inventory was retrofitted using performance contracting to achieve 20 percent savings, thereby highlighting the significant potential in this market that might be realized through improved understanding of EPCs.

1.2.3 Premise #3 – An Energy Efficiency Gap Exists in Correctional Facilities

The United States has more correctional facilities today than at any other time in history. The number of prisons nearly doubled between 1974 and the turn of the 21st Century (Lawrence and Travis 2004), and there are currently 1,292 state, federal, and private prisons in the United States (Stephan 2008), with the vast majority built before 1961 (Baker and Forbes 1997). This aging infrastructure requires a management decision to either retrofit existing facilities or undertake new construction. After significant growth throughout the mid-1900s, new construction of prisons began to slow down in the late 1990s, with limited "hot-spots" of new construction in just a few states; however, the number of retrofit projects increased 35% between 1995 and 1997 (Dallao 1997).

The nationwide incarceration rate increased during the same time period (1980s to present), leading to overcrowded facilities and added pressure on facility infrastructure (GAO 2012). Negative impacts on infrastructure such as increased water and electricity consumption, increased wear on plumbing and food service equipment, and increased needs for general facility maintenance have been reported. The U.S. Bureau of Prisons (BOP) reported a 15% increase in maintenance costs between 2006 and 2011 and a 37% increase in electricity costs, across all ages of facilities, to include even those most recently constructed (GAO 2012). This has had a negative impact on total operating budgets for state and federal correctional agencies, which typically direct a significant portion of their budgets to supervision activities. As of February

2012, the BOP reported 150 unfunded major repair projects at a total cost of approximately $346 million – some of which have implications for energy efficiency, such as roof repairs (GAO 2012).

The last several years have seen reductions in public corrections agency budgets which have significantly outpaced relatively small reductions in incarceration rates (Scott-Hayward 2009; Glaze and Parks 2012). Some states have experimented with early release initiatives as a cost-savings measure; however, these programs are often fraught with social, economic, and political challenges. This environment has created challenges for funding new capital projects, including those projects designed to improve aging infrastructure and save operational costs. Nationally, state correctional expenses for capital projects decreased from a 28 year high of 13.6% of the aggregate overall corrections budget in 1986 to a low of 2.7% in 2010 (the last year of the study period) (Kyckelhahn 2012).

The above-referenced conditions have created a “perfect storm” for the retrofit of correctional facilities. Aging facilities, higher occupancy rates, deteriorating infrastructure, reduced capital budgets, and increased utility consumption along with attendant utility rate increases mean that retrofit projects can provide significant benefits by reducing operational costs, reducing end-use utility intensities, and maximizing the overall facility benefit of such projects conducted under constrained capital budgets. Limited research has been conducted related to correctional facility retrofits and construction in general – as a result, a new approach is required to study this work and develop a model for understanding and expanding work in this MUSH sub-market.

EPC has been used to fund retrofit projects in correctional facilities despite the presence of budgetary restrictions by leveraging operational budgets to pay for construction and equipment costs through annualized utility savings. The use of this financing mechanism has been growing among correctional facility retrofit projects, and they have demonstrated the ability to return or exceed the guaranteed savings amount among recent projects (Berghorn and Vallad 2013). At the same time, EPC implementation has been growing across the U.S. construction market (Satchwell et al. 2010). Despite these favorable conditions, energy intensity reduction efforts among corrections departments often lag behind those of other public agencies.

The State of Connecticut undertook a benchmarking program for 110 of its state facilities between 2005 and 2008, utilizing the Energy Star Portfolio Manager (U.S. Environmental Protection Agency 2014). Twenty one percent of the benchmarked buildings had a benchmark score of 75 or above, thereby making them eligible for Energy Star recognition – 15% of these buildings scored in the next lowest quartile (scores of 50-74). One hundred percent of the 15 Department of Corrections buildings included in this program fell at or below scores of 49, with nearly 87% of their facilities scoring 24 or less (Commission on Enhancing Agency Outcomes 2010). This trend in correctional facilities has been seen in other states as well. Correctional facilities in California reduced their energy intensities between 2003 and 2010; however, their net reduction of 2.0% lagged behind the statewide facilities average of 6.3% (California Department of General Services 2011). A similar trend has been observed in Wisconsin. Between 2005 and 2010, state facilities experienced a 9.8% decrease in energy intensity, while the Department of Corrections reduced energy intensity by 3%, when adjusted for weather (Wisconsin Department of Administration 2011).

The Connecticut data illustrates that correctional facilities may inherently consume more energy per square foot than many other state-owned building types, which have been addressed with some level of success by energy efficiency retrofits. As the data show, while correctional facilities have undertaken retrofit projects, they have not led to the same level of savings as those realized elsewhere in the public sector. This gives rise to the notion of an "energy efficiency gap" within such facilities. Several reasons have been given for this gap, to include additional pressure on limited capital project funding, complexities in project execution, lack of support for data requests and sub-metering, and technical scope considerations and conflicting objectives.

Four possible reasons for this observed energy efficiency gap are: (1) additional pressure on limited capital project funding, (2) complexities in project execution, (3) lack of support for data requests and sub-metering, and (4) technical scope considerations and conflicting objectives. These reasons are discussed below, and explain unique aspects of correctional facilities that may contribute to the perceived energy efficiency gap in such facilities.

1.2.3.1 Additional Pressure on Limited Capital Project Funding

Reductions in public budgets have had the effect of limiting the ability to finance capital projects. While this is likely a constant condition across multiple agencies, corrections agencies face additional pressure from rising costs due to an increased number of incarcerated persons and the attendant operational and utility costs of such increases in occupancy (GAO 2012).

Additionally, higher facility occupancy reduces the serviceable life of infrastructure and leads to increased pressure on maintenance budgets. This combination of factors has led public entities to seek alternative project financing and delivery models, such as EPCs (Commission on Enhancing Agency Outcomes 2010; Wisconsin Department of Administration 2011).

1.2.3.2 Complexities in Project Execution

The use of effective construction management practices has been cited as one way that ESCOs can ensure successful EPC performance (McQuade and Piotrowski 1993; Hansen 2006). Among the critical roles highlighted for the construction manager is the ability to keep the project on schedule by minimizing delays and reducing the costs attributable to such delays. Construction and retrofit projects taking place at operational secure facilities must place a primary emphasis on the safety and security of the facility and general public (Ginoza et al. 2003); however, required security activities can have a negative impact on the project schedule if not managed properly.

An example of required security measures can be found in the Oklahoma Department of Corrections Facility Construction Security Standards (Oklahoma Department of Corrections 2012). This standard requires daily check-in and check-out of all contractors at the facility's central control station; weekly or more frequent compliance inspections of equipment storage areas, vehicles, and the construction site; and interviews of construction personnel for knowledge of information contained in the standard. Additionally, daily tool inventories during mobilization and demobilization are required, the worksite may require physical isolation from the rest of the facility, and employees may be subject to regular searches. All of these factors can add significant time to the project by reducing the number of work hours available in a scheduled work day.

1.2.3.3 Lack of Support for Data Requests and Sub-Metering

Vanneste (2010) reported that funding to support data needed to plan and implement sustainability-related capital projects was largely unavailable. This specifically limited the ability of the Washington Department of Corrections to report energy use for each facility in the Energy Star Portfolio Manager, which was mandated by new legislation in 2009-2010. The author also identified that current funding levels effectively prevented the installation of sub-meters at facilities, thereby limiting data collection to the campus-level. This highly aggregated data hampers efforts to analyze energy performance at the building level, and would likely need to be considered during the procurement of an EPC project, in order to facilitate proper measurement and verification activities. This can be a state-by-state issue; recently-passed legislation in Michigan allows for sub-meter installation as well as data collection and reporting activities to be included in EPCs (Cost-Effective Governmental Energy Use Act 2012).

1.2.3.4 Technical Scope Considerations and Conflicting Objectives

In addition to factors common to all construction projects (e.g., safety, quality, schedule management), correctional facility construction projects must consider four specific issues: (1) technology, (2) security, (3) accessibility, and (4) sustainability (Phillips and Griebel 2003). While there are numerous potential design, engineering, and construction challenges with each of these areas, a key concern is the interaction among these elements. Technology and security, if considered alone, may dominate other important design elements (Phillips and Griebel 2003). Conflicting objectives, specifically related to ECMs that pose concerns for security, can potentially add costs and limit overall energy performance.

EPC projects must also consider the relationships between first costs and life cycle costs. While this is not an attribute specific to corrections projects, it is particularly important when evaluating design alternatives in this sector given the exceptionally high operating costs of prisons as compared to their first costs (GAO 1991).

1.2.4 Premise #4 – Uncertainty and Risk Must be Understood and Managed

The limited literature focused on ESCO risks in EPC retrofits was briefly summarized in section 1.2.1. Figure 1-4 graphically depicts potential risk instances for ESCOs undertaking an EPC retrofit. It is based on a prototype EPC which was procured using a single-phase approach with separate contracts for two individual work packages: (1) technical audit and (2) energy services performance contract (construction and M&V), with annual reviews of savings. The EPC project flowchart is developed primarily from Hughes et al. (2003) and Energy Services Coalition (2011). The numbered instances of ESCO risk are based on the risk categories described in section 1.2.1. These are further expanded upon in Table 1-2, which is a companion to Figure 1-4.

Despite the knowledge represented in Figure 1-4 and Table 1-2, the interrelationships among these risks are still relatively unknown, a comprehensive risk management framework for ESCO risks in EPC retrofits does not exist, and specific applications of a risk framework to correctional facility retrofits is lacking. This requires an approach that connects the sources of risk with the decisions made under conditions of risk and uncertainty, in light of the information used by ESCO professionals when making critical project decisions.

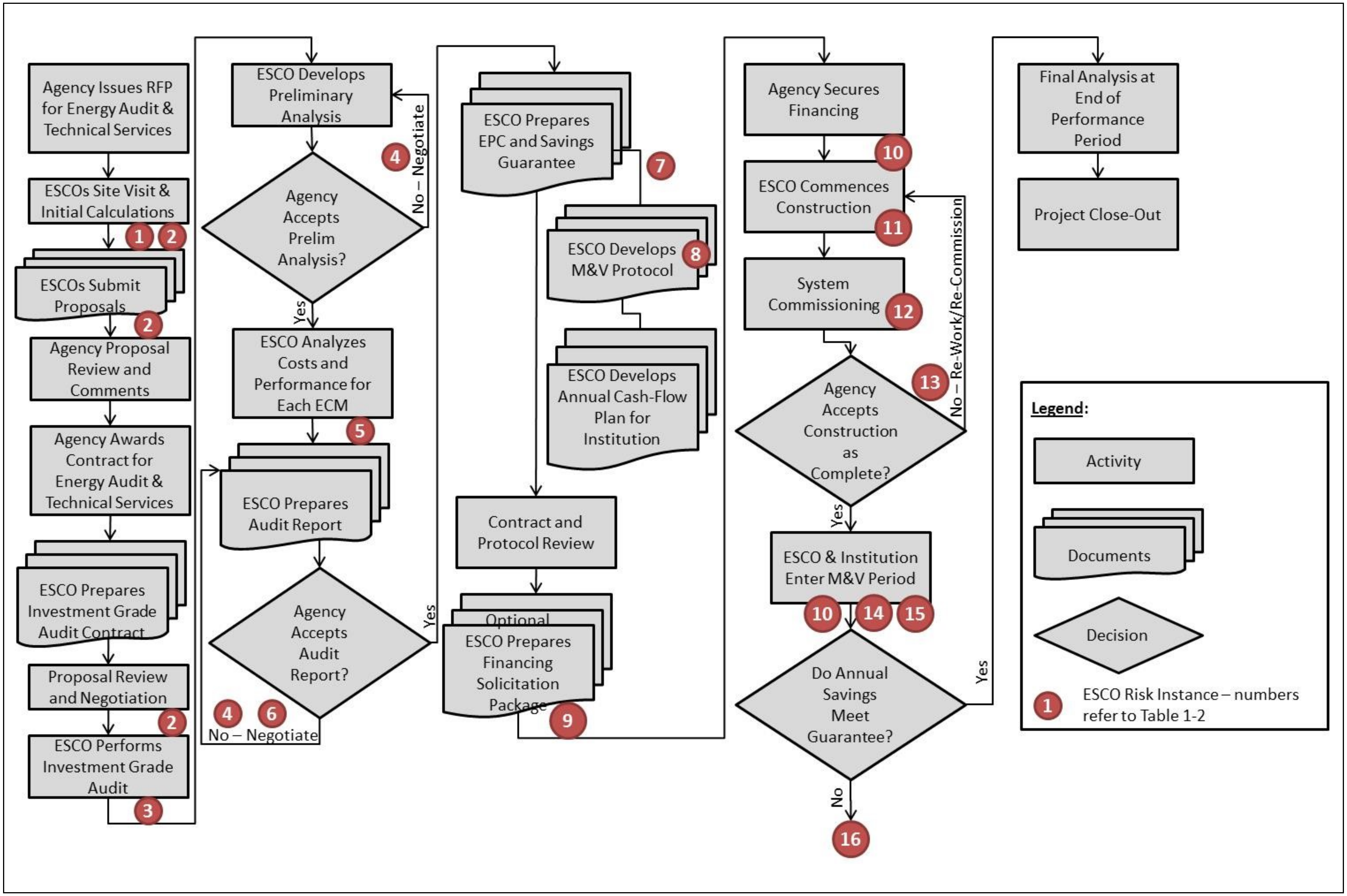


Figure 1-4. Energy Performance Contract Flowchart with Instances of Contractor's Risks
(Based on Hughes et al. 2003 and Energy Services Coalition 2011)

Table 1-2. Instances of ESCO Risk During the Performance Contracting Process

#	Risk Category	Risk
1	Client Selection Factors	Mandated short performance periods may limit technical approach; ESCO may not get all necessary information from owner; Current building uses/occupancies may not reflect future uses/occupancies; Unknown latent conditions may exist.
2	Project Development	Overhead rates used for bidding may not be feasible once technical approach is developed; Up-front costs may be difficult to recover once technical approach is developed.
3	Energy Audit Quality	The IGA must include a thorough risk assessment; Improperly-established or disputed baseline can give rise to conflict and result in improper M&V.
4	Project Development	Negotiated terms may impact results of technical analysis and require re-work to accurately reflect new conditions.
5	ECM Selection and Installation	Individual ECM performance must be considered as a part of overall portfolio performance; Allowable non-energy benefits may be difficult to quantify; Lack of risk-based LCCA may limit robustness of findings.
6	ECM Selection and Installation	Additional costs incurred to renogetiate ECM portfolio; Contract may be terminated after the IGA if it reveals that desired performance levels cannot be obtained.
7	ECM Selection and Installation	Uncertainty in economic parameters (energy cost escalation, discount rate, inflation rate) may limit robustness of findings ; ECMs may not perform as expected; ECM portfolio does not reflect future building uses/occupanices.
8	Measurement & Verifiation	Poorly-developed M&V plans increase technical and financial risk to ESCOs; Poorly-designed M&V sampling protocols may not properly represent performance of installed ECMSs; M&V protocols that do not include non-energy benefits may understate system performance; Failure to include O&M may lead to missed savings opportunities.
9	Client Selection Factors	Client is unable to secure financing.
10	Project Management Over the Project Life Cycle	Hand-offs between project phases lead to information loss and loss of continuity by ESCO team.
11	Construction-Specific Concerns	Schedule and cost growth resulting from delays – likely to impact financial analysis that the technical audit and EPC scope of work is based on; Delays may result from latent site conditions, site access restrictions, and re-work.
12	Commissioning	Failure to commission systems may result in unknown sub-optimal system performance conditions; Failure to commission may miss opportunities to verify performance; Commissioning may lead to re-work if systems are not installed properly – this may lead to schedule and cost growth.

Table 1-2 (cont'd)		
#	**Risk Category**	**Risk**
13	Construction-Specific Concerns	Failure to deliver the project as stated in the scope of work may lead to re-work, ultimately resulting in schedule and cost growth.
14	Operations and Maintenance Practices	Poorly understood responsibilities by each party if the O&M plan is unclear; The institution may not perform O&M work to specification; Institution self-performance or contracted O&M may reduce potential revenue for ESCO.
15	Measurement & Verification	Poorly-developed M&V plans and sampling protocols can create additional risk for the ESCO (see item # 9); Failure to include O&M in the M&V plan may lead to missed savings; Disputes in establishing the initial baseline and procedures and conditions for recalculating the baseline may add risk to the ESCO; Behavioral factors lead to a "rebound effect" in the performance of installed ECMs
16	Measurement & Verification	Annual savings less than costs require the ESCO to cover the difference and thus lose revenue.

Understanding decisions under uncertainty and risk requires a hybrid approach of quantitative and qualitative approaches. Quantitative information typically comes from energy models, system design tools (e.g., Trane Trace), and building system energy consumption data, which are key elements of the IGA. Qualitative information is represented by the expertise of decision makers, realized through severity assessments of risks and their associated mitigation strategies, as well as understanding owner's project objectives and requirements. This hybrid qualitative-quantitative approach provides a more complete assessment of risks. Automated systems such as energy models cannot by themselves replace the need for expertise in making decisions, such as the designer's role in optimizing energy performance, owner's requirements, constructability, and facility operating parameters (Abaza 2008). This information must be provided by technical experts and decision-makers in order to make quality decisions about sustainability-related challenges (Cash et al. 2003). These factors make knowledge-based approaches appropriate to building energy design problems, because numerical methods do not provide designers with a quick means to assess options, whereas analytical methods do not deal well with the multitude of variables inherent in these problems (Kalogirou 2009). Therefore a method that combines both types of information must be considered in developing an ESCO risk model.

Decisions made under conditions of uncertainty and risk can lead to poorly-performing project outcomes over lengthy life cycles, as exist in EPC retrofits. A body of research has developed around incorporating uncertainty analysis into LCCA (Reigle and Zaniewski 2002; Kapp and Girmscheid 2005; Pan et al. 2012) at the model parameter level (Reigle and Zaniewski 2002; Dell'Isola and Kirk 2003) and project level (Pan et al. 2012).

Pan et al. (2012) identified key project-level risks by life cycle phase, which underscores the need to develop a framework to understand and ultimately analyze risks in relation to project life cycle phases:

- Design and Purchase – price fluctuations, technical innovation, quality of data regarding the project, site investigation quality and results.
- Installation – latent conditions, schedule and cost growth factors.
- Facility Operation – fluctuations and changes in human costs and energy prices, operational risks.
- Maintenance – uncertainties in O&M parameters, variations between planned and executed O&M activities.
- Disposal – risks related to the approval of disposal options and the costs of inactive facilities.

Based on the foregoing discussion, there is therefore a need to understand risk at the project level. EPC projects in general have been shown to contain certain inherent risks, and MUSH market (specifically correctional facilities) retrofit work has the potential to add to the project risk profile. Reducing risk in EPCs is particularly important given the tremendous potential for energy efficient retrofit represented by the MUSH market. Corrections, as a sub-market of MUSH, may have some of the greatest potential for retrofit due to continuous facility operation, above average energy intensities among MUSH market buildings, unique project parameters, and financial and systems constraints on additional capital investment. This potential must be balanced with the development of a framework to understand the factors contributing to contractors risk when undertaking EPC projects at such facilities.

1.3 RESEARCH GOAL AND OBJECTIVES

The main goal of this research is to understand risks related to the execution of energy efficiency retrofits delivered via EPC in the MUSH market through the development of an integrated risk model with focus on correctional facilities. Research objectives have been developed to support the achievement of the research goal, and they are described below and in Figure 1-5.

1.3.1 Objective 1: Energy Performance Contract Retrofit Process

To perform an exploratory analysis of the energy performance contract retrofit process and identify key areas of performance risk requiring in-depth analysis.

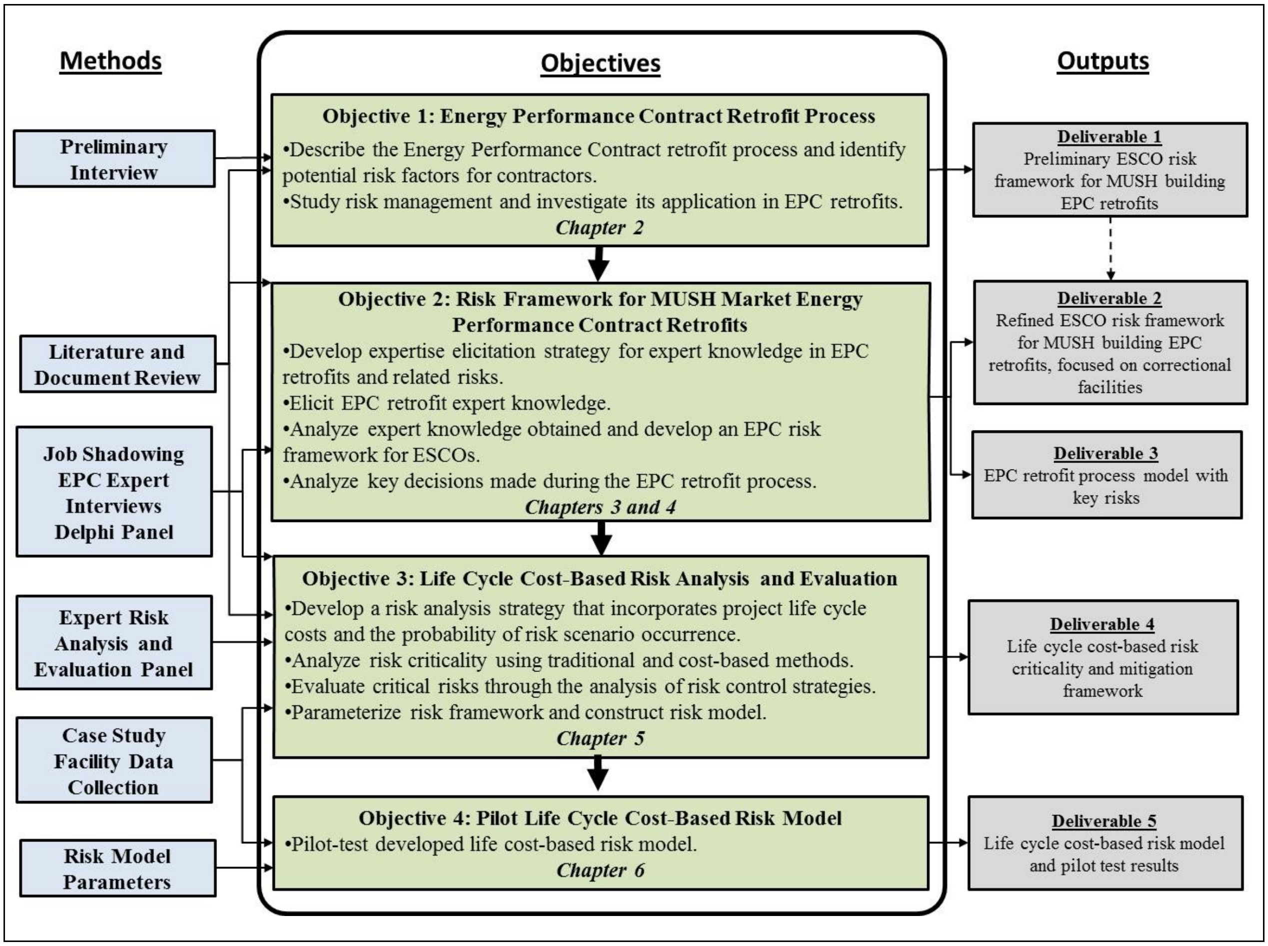


Figure 1-5. Research Objectives, Methods, and Outputs

1.3.2 Objective 2: Risk Framework for MUSH Market Energy Performance Contract Retrofits

To construct a framework describing the sources of and mitigation strategies employed for assessing key risks in energy performance contract retrofits.

1.3.3 Objective 3: Life Cycle Cost-Based Risk Analysis and Evaluation

To develop a strategy for analyzing and evaluating risks for energy performance contract retrofits focused on managing expected costs throughout the project life cycle, and use data collected through this strategy to develop and parameterize a risk model.

1.3.4 Objective 4: Pilot Application if the Life Cycle Cost-Based Risk Model

To demonstrate the applicability of the proposed life cost-based risk model through a pilot application to a case study site.

1.4 RESEARCH METHODS

A complete discussion of the structured methods used to decompose the research goal and objectives into logical and related research steps is provided in Chapter 3. An overview of methods is provided in this section, with the conceptual research model depicted in Figure 1-5.

1.4.1 Objective 1: Energy Performance Contract Retrofit Process

To perform an exploratory analysis of the energy performance contract retrofit process and identify key areas of performance risk requiring in-depth analysis.

Step 1 - Describe the Energy Performance Contract retrofit process and identify potential risk factors for contractors: The primary focus of this objective is to compile information about the EPC process as it is currently used in the United States with greater attention given to the MUSH market, specifically correctional facility retrofits. Information was compiled about the history and use of EPCs in the United States, the dominant contractual forms of EPC and related savings models, and financial considerations related to performance periods and the disposition of excess savings. This information was obtained from published literature (refereed journals and EPC-related books), government reports on state and federal EPC projects, government (primarily from the Lawrence Berkeley Laboratory) and industry reports, one identified Master's thesis and one identified PhD dissertation, and a review of contracts, audits, and final reports prepared by ESCOs, evaluated using the content analysis procedure described by Molenaar et al. (2009).

Additionally, a preliminary interview was conducted with an internationally-experienced EPC professional, in order to refine the scope of the research, to obtain confirmation of some of the identified risks, and to identify additional risks not apparent from the literature and document review. This work served as the basis for developing the conceptual risk framework which was used when developing questionnaires for later research objectives. That preliminary risk framework is the deliverable resulting from this work step and is presented in Chapter 2.

Step 2 - Study risk management and investigate its application in EPC retrofit projects: The intent of this step was to understand formal and informal risk management processes used in construction engineering and management (CEM). In conjunction with understanding the EPC retrofit process in Step 1, this information was used to better define risk management methods that could be applied to this research. A comprehensive literature review of risk management techniques deployed in CEM research related to EPC, build-operate-transfer (BOT), and public-private partnership (PPP) projects was conducted to identify appropriate methods for further study. Due to the limited amount of literature directly related to EPC retrofits, research conducted on BOT and PPP projects was examined as these project types share common features with EPC, to include unique financing mechanisms, a partnership between the owner and contractor, often lengthy performance periods, and contractually-guaranteed levels of performance of the completed project. The conceptual risk framework developed in Step 1, along with the literature review of risk management methods conducted in this step, resulted in the selection of a risk management strategy for this research, as discussed in Chapters 2 and 3.

1.4.2 Objective 2: Risk Framework for MUSH Market Energy Performance Contract Retrofits

To construct a framework describing the sources of and mitigation strategies employed for assessing key risks in energy performance contract retrofits.

Step 3 - Develop expertise elicitation strategy for expert knowledge in EPC retrofits and risk: Expert knowledge was a significant source of data for this research. As a result, a strategy was needed to first identify domain experts and then to elicit such expertise from these selected professionals. Methods for expertise elicitation were obtained through a literature review, in particular a review of the techniques developed by Duah (2014), which was a complementary research project conducted in the same laboratory at Michigan State University.

Step 4 - Elicit EPC retrofit expert knowledge: Using the strategy developed in Step 3, relevant expertise was elicited from qualified EPC retrofit experts in order to yield data related to four specific areas of focus, which divided the survey into four distinct parts: (1) risk behavior and tolerance, (2) professional experience, (3) risk management process, and (4) life cycle cost analysis.

Expertise was elicited through the use of a questionnaire, which collected data in the four categories listed above. In part three of the questionnaire (risk management process) elicitation was directed toward: (1) identification of risk categories and risks related to not meeting the performance guarantee in EPC retrofit projects; (2) parameters, uncertainties, and risks inherent in conducting LCCA as part of the EPC retrofit process; (3) a rapid assessment of the relative importance of identified risk categories, and (4) risk mitigation strategies. Methods employed in steps 3 and 4 are discussed in greater detail in Chapter 3.

Step 5 - Analyze expert knowledge obtained in Step 4 and develop an EPC risk framework for ESCOs: Elicited expertise was used to refine the preliminary ESCO risk framework developed in Step 1. Additionally, participants were asked to provide a rapid assessment of the risk categories that are the most important in terms of their potential negative impact when developing and executing EPC retrofits. There was an *a priori* assumption that many of the risks contributing to not attaining the performance guarantee were related to the selection, installation, and operation of ECMs. The nature of EPC retrofits bases the performance guarantee on realized energy savings resulting from the installed ECM package. It was therefore reasonable to expect that risk management processes would be heavily-focused on ECM selection and installation; however, other important risk categories were also identified. This refined risk framework (described in Chapter 4) included the following improvements to the conceptual risk framework:

- Confirmation or elimination of risk categories and risks based on elicited expertise;
- Addition of risk categories and risks;
- Two measures of importance for each risk category in EPC retrofits; and
- Identification of risk causes and mitigation strategies.

Step 6 - Analyze key decisions made during the EPC retrofit process: The expert knowledge that was elicited was used to map the decisions made during the EPC retrofit process based on the risk framework developed in Step 5. As a result, an EPC retrofit process (EPC-RP) model, presented in Chapter 4, was developed to identify information requirements, key decisions, and related risks throughout the life of often lengthy EPC projects.

1.4.3 Objective 3: Life Cycle Cost-Based Risk Analysis and Evaluation

To develop a strategy for analyzing and evaluating risks for energy performance contract retrofits focused on managing expected costs throughout the project life cycle, and use data collected through this strategy to develop and parameterize a risk model.

Step 7 - Develop a risk analysis strategy that incorporates project life cycle costs and the probability of risk scenario occurrence: Based on the risk management method selected in Step 2, complementary methods were sought that would permit analysis of risk-related costs and understanding of risks throughout a project's life cycle. A risk analysis method was sought that could be conducted using a workshop or panel format, continuing the ability to elicit expertise from ESCO professionals through this phase of the research.

Step 8 - Analyze risk criticality using traditional and cost-based methods: The risk analysis strategy developed during Step 7 was deployed in this work step and permitted the researcher to gain an in-depth understanding of the heuristics used by experts when making project decisions under conditions of known or suspected risk. This aspect of the risk analysis approach was important to the development of the risk model, represented by Step 10.

Risk analysis was focused on finding relative measures of risk criticality. A risk analysis panel was convened for this work step, which also provided focus for the risk evaluation process in Step 9, and risk model development and parameterization in Step 10. Additionally, traditional and cost-based risk criticality measures were developed by the panel to allow the researcher to determine the relationships among different risk analysis approaches.

Step 9 - Evaluate critical risks through the analysis of risk control strategies: The same risk analysis panel from Step 8 was used to provide further evaluation of the most critical risks by identifying relevant mitigation strategies. These strategies were evaluated for their cost and likelihood of success in order to construct cost-benefit relationships among the analyzed risks and the control measures identified in this work step. This information was used as an input to Step 10. Results of the risk analysis (Step 8) and risk evaluation are provided in Chapter 5.

Step 10 - Parameterize risk framework and construct risk model: Risks and their mitigation strategies, along with their attendant costs and likelihoods of occurrence and successful control were mapped, along with important facility and project factors along with heuristics and expertise used by risk panelists in order to develop a framework for the creation of a life cost-based risk model. This model framework and parameterization is provided in Chapter 5.

1.4.4 Objective 4: Pilot Life Cycle Cost-Based Risk Model

To demonstrate the applicability of the developed life cost-based risk model through a pilot application to a case study site.

Step 11 - Pilot-test proposed life cost-based risk model: The risk model framework developed in Step 10 was fully developed in this step and implemented through application to a case study. The risk tool was further refined based on results of this pilot application. The case was a representative example of a recently-conducted correctional facility EPC retrofit and included analysis of facility-specific characteristics, results of the IGA, the energy guarantee, and installed ECMs and retrofit measures. The purpose of the pilot was to evaluate the applicability of the research in evaluating significant risks faced by ESCOs when conducting EPC retrofits, through a method that reflects the decision-making process utilized by ESCO professionals, utilizing the case study method.

1.5 RESEARCH SCOPE AND LIMITATIONS

1.5.1 Research Scope

The scope of this research is the creation of a life cycle cost-based risk model for understanding long-term risks associated with project-level factors. The contextual focus of this work is MUSH market buildings, with an emphasis on correctional facilities. While the first two objectives of the research are focused on understanding the EPC retrofit process and risk identification for the entire project life cycle, this project does not undertake a complete risk analysis and evaluation of all elements of ESCO risk in such projects. Instead, project phases and risk categories that were shown to have the greatest potential impact on project performance were the focus of the latter two objectives. Additionally, this research is premised on the notion that risks can best be controlled during the earliest project phases, when the costs of change are lowest and the potential impact of those changes is the greatest (Kmenta and Ishii 2001; Horsley et al. 2003;

Kishk et al. 2003). As a result, risks related to project execution are not considered, except in the context of their upstream effects on risks that occur in earlier project phases.

1.5.2 Research Limitations

Limitations of this research include:

- The scope of the risk identification model is limited to project failure based on failure to achieve guaranteed performance;
- This research examines risk from the perspective of the ESCO (contractor's risk); client-only risks are not considered; and
- The risk management process used in this research was not intended to be used as a design tool to select among multiple retrofit measures or to optimize risk and energy performance. Instead, the focus of this research was to obtain a comprehensive understanding of project-level risks and conduct a thorough evaluation of the most critical risk categories by understanding cost-related impacts of risks and their associated mitigation strategies. This information is used to inform the risk management approach taken by ESCOs for a given design or set of design alternatives before their contract is finalized, when changes to the work scope and delivered costs are still possible.
- While acceptable for the selected method, the size of the risk analysis and evaluation panel did not permit statistical analysis or modeling of results, thereby limiting cross-case comparisons among individual panelists and the ability to predictively model panelist results.

1.6 PROJECT OUTPUTS/RESEARCH CONTRIBUTIONS

The primary output of the research is the development of a life cycle cost-based risk model for evaluating the most significant ESCO risks in the development and execution of EPC retrofit projects in MUSH market buildings, particularly correctional facilities. This primary output is supported through the development of the following intermediate outcomes:

- Preliminary ESCO risk framework for MUSH building EPC retrofits;
- Refined ESCO risk framework for MUSH building EPC retrofits, focused on correctional facilities;
- EPC retrofit process model with key risks;
- Life cycle cost-based risk criticality and mitigation framework; and
- Life cost-based risk model and pilot test results.

1.7 DISSERTATION ORGANIZATION

The dissertation is organized into seven chapters. This chapter provided an introduction to the research, to include background on the problem, key premises underlying the research, and goals and objectives of the work. Chapter 2 provides a review of the relevant literature in three key areas – (1) energy performance contracting and the selection of energy conservation measures, (2) risk in construction and energy performance contracting, and (3) project life cycle risk analysis. The research methodology, developed in part through the literature review, is presented in Chapter 3. The contractor’s EPC risk framework and EPC retrofit process model are presented in Chapter 4 and the life cycle cost-based risk model is presented in Chapter 5. Implementation of the model through a pilot application to a case is described in Chapter 6, and the research summary, conclusions, and directions for future research are provided in Chapter 7.

1.8 CHAPTER SUMMARY

This chapter provided the project overview and a discussion of the need to undertake this research. The project goal and objectives were described, along with research methods supporting the completion of each goal. The scope of the research along with its limitations were presented, as was a discussion of the key outputs and contributions to the body of construction management and energy retrofit knowledge made by this project.

CHAPTER 2

LITERATURE REVIEW AND PRELIMINARY RISK FRAMEWORK

2.1 INTRODUCTION

This chapter presents a review of literature providing the context for this research with regard to decision making in energy performance contract (EPC) retrofits and related concepts of risk management in construction and engineering and the life cycle cost implications of retrofit projects with lengthy contracts. The literature review has been organized around three broad categories: (1) energy performance contracting, (2) risk in construction, and (3) life cycle cost analysis (Figure 2-1). Understanding these three related categories of literature is essential to understanding the EPC retrofit decision making process, the sources and nature of risks to energy service companies (ESCOs), and the tools available to help identify and manage these risks.

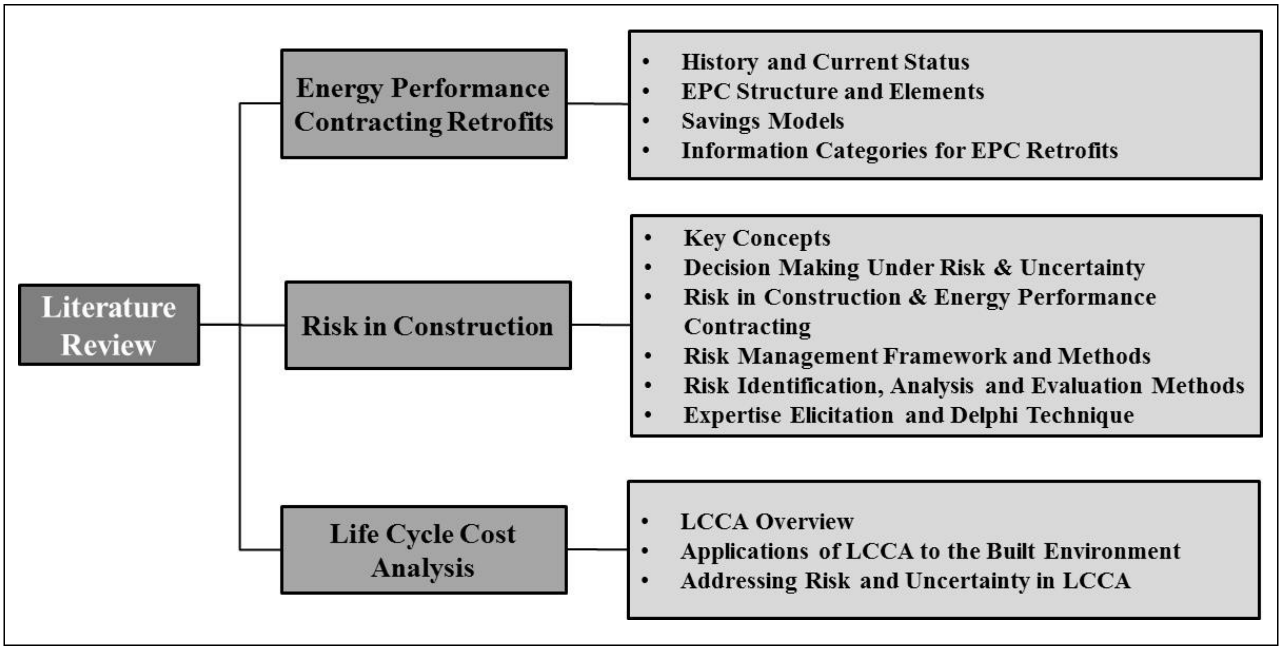


Figure 2-1 Literature Review Categories

The literature from the first two categories is presented later in this chapter as a preliminary risk framework for ESCOs undertaking EPC retrofits. The purpose of this a priori framework is to organize the relatively small and disperse literature related to EPC risks to assist with the development of the primary data collection instrument in Chapter 4. This also represents the first deliverable from this research.

2.2 ENERGY PERFORMANCE CONTRACTING RETROFITS

This section reviews the history and current state of EPC retrofit projects, with a focus on the municipalities, universities, schools, and hospitals (MUSH) market. The guaranteed savings model is described, as it is the predominant model used in the United States and among MUSH market projects. Finally, information needs for making retrofit decisions under the EPC contracting method are discussed with particular attention focused on the notion of ESCO risk and the types of information used to make risk-based decisions.

2.2.1 History and Current Status

Energy performance contracting dates back over 100 years; however, in its modern form the concept gained significant traction globally in the mid-1980s following the OPEC oil crisis (Hansen 2006; ICF and NAESCO 2007; Larsen et al. 2012a; Deng et al. 2014). The earliest form originated from government mandates that required utility companies to provide energy services to their customers – ESCOs contracted these services to the utilities. This continued through the late 1980s when energy prices fell dramatically and the construction cost for new energy generating technologies became more expensive (Hansen 2006; ICF and NAESCO 2007).

As a result of reduced energy prices, project values decreased and ESCOs were finding it more difficult to meet their long-term project guarantees. As a result, they began to default on their payments and their shared savings guarantees and the industry shifted away from shared savings to guaranteed savings as a means to reduce uncertainty and risk for financiers, equipment suppliers, and owners by decoupling performance from energy prices (Hansen 2006). Between 1982 and 1996, 27% of the EPC projects in the National Association of Energy Service Companies (NAESCO) database utilized shared savings; that number dropped to 3% between 1996 and 2000 (Goldman et al. 2002).

These changes in contractual savings have come as the ESCO industry has experienced significant growth. Industry revenues have grown significantly over the past 20 years, from less than $500 million in 1990 to an estimate of over $15 billion in 2020 (Stuart et al. 2013).

The retrofit strategies employed on institutional sector EPC projects changed between 1990 and 2008. The greatest increase in retrofit measures over that time was the use of non-energy related strategies, growing from 3% of all projects in 1990 to 24% in 2008 (Larsen et al. 2012a). The use of distributed generation also increased over that time, from 3% to 8% of projects. Lighting only retrofits decreased from 25% in 1990 to 3% in 2008, indicating that much of the “low hanging fruit” was already “picked” and more comprehensive retrofits are becoming the norm.

The increasing complexity of EPC retrofits is supported by the fact that the number of retrofit measures used on institutional EPC retrofits approximately doubled between 1990 and 2008, the mean investment per square foot more than doubled over that time, and 60% of survey respondents reported increased project installation costs (Larsen et al. 2012a). Additionally, over 50% of projects used total facility consumption data to develop project baselines; less than 12% of projects used end-use targeted measures.

The value of annual savings per square foot increased approximately 25% between 1990 and 2008 and the simple payback period length increased approximately 50% (Larsen et al. 2012a). However, during this same time period, the number of institutional projects with excess savings decreased significantly. This may be the result of limited incentives for ESCOs to exceed the savings guarantee (Larsen et al. 2012a). In an earlier study, Hopper et al. (2005) reported that 19% of 517 EPC projects examined experienced savings shortfalls; Larsen et al. (2012a) observed that approximately 16% of the 436 EPC projects they examined experienced a savings shortfall.

While the ESCO market and the demand for EPC retrofits have grown significantly over the past 20 years, there are still issues to be addressed as this market matures. The MUSH market accounts for approximately 69% of EPC revenues; however, penetration of EPC projects into this market has been limited. As described in Chapter 1, an additional \$4.4 to \$8.1 billion of energy savings (at a 20% target energy efficiency rate) is possible on an annual basis from the MUSH market alone. Additionally, further work is required to investigate the monetization and inclusion of non-energy benefits in EPC retrofits to create additional opportunities for owners and ESCOs alike (Jennings and Skumatz 2006; Birr and Singer 2008; Larsen et al. 2012b).

2.2.2 Energy Performance Contract Structure and Elements

Energy performance contracting is a project delivery and financing method that provides turnkey service to deliver a set of energy efficiency-related upgrades to an owner, typically via a performance guarantee issued by the ESCO, which is financed through the annual energy savings that result from the retrofit work (ICF and NAESCO 2007; Appleman et al. 2010; Seeley 2012). The retrofit work is essentially completed using a design-build approach (ICF and NAESCO 2007). Because the work is financed through the accrual of operational cost savings during the length of the project performance period (Figure 2-2), owners are typically not required to provide significant up- front capital to finance the work and instead can access operations and maintenance funds (e.g., budgets for utility payments, equipment replacement) for project financing.

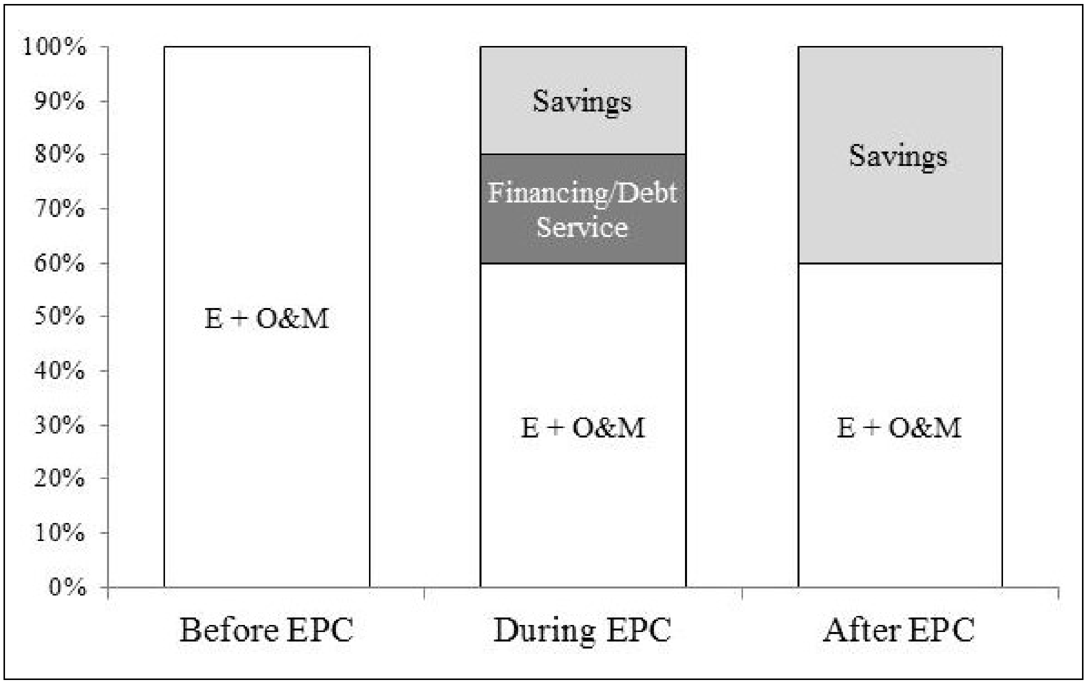


Figure 2-2 Energy Performance Contracting Cash Flow and Savings Model
(Source: Shonder et al. 2010)

In the idealized EPC cash flow and savings model presented in Figure 2-2, operational costs, such as utility bills, equipment maintenance, and equipment replacement burden 100% of available capital before the EPC retrofit begins. During the project performance period, annual savings from efficiency upgrades are first used to offset debt service (e.g., loan payments for financing the project); any remaining savings are then available to the owner. Debt service payments are completed by the end of the performance period; at that point, the owner retains all savings obtained through the EPC retrofit work, and experiences an overall reduction in operational costs.

2.2.2.1 Energy Performance Contracting Elements

EPC retrofits are typically conducted by ESCOs, which are defined as businesses that provide a full-range of energy efficiency services and have performance contracting as a key element of their energy efficiency offerings (Goldman et al. 2002; Hopper et al. 2005; ICF and NAESCO 2007; Larsen et al. 2012a; Stuart et al. 2013). The inclusion of performance contracting as a key business element is important because the guarantee offered through EPC means that ESCOs inherently retain risks throughout the performance contracting retrofit delivery process.

The provision of the performance guarantee is one of four key elements of EPC retrofits recognized by the ESCO industry (ICF and NAESCO 20070). These elements include: (1) turnkey service, (2) comprehensive retrofit measures, (3) project financing, and (4) performance guarantee. These elements essentially define the ESCOs scope of work during the EPC retrofit process, and provide a working definition for the comprehensive nature of the work conducted as part of an EPC.

Through EPC, an ESCO typically provides a complete suite of services (i.e., turnkey service) to include an energy audit (preliminary audit and investment grade energy audit), engineering and architectural design, construction management, and commissioning, as well as assistance with securing financing. Operation and maintenance (O&M) services may also be provided during the performance period; however, this is variable depending on the project goals and complexity, owner ability to self-perform O&M, and contractual provisions. Similarly, while measurement and verification (M&V) is an important part of an EPC project, it may or may not be included as part of the turnkey services provided by the ESCO. Projects that are measured and verified through stipulation do not require comprehensive M&V. Additionally, less-comprehensive retrofits such as lighting-only retrofits typically only develop the baseline using equipment-targeted metrics (Larsen et al. 2012a).

Typical EPC projects include a comprehensive suite of retrofit measures, also called energy conservation measures (ECMs) that address the owner’s project requirements (OPR). Larsen et al. (2012a) identified 26 different categories of retrofit measures installed in private, K-12 school, and other public EPC retrofits (Figure 2-3). The most commonly installed measures include lighting, controls, distribution and ventilation, boilers, water conservation, chillers, and improvements to the building envelope.

ESCOs often provided funding early in the history of EPC retrofits in the United States, primarily due to the unwillingness of financial institutions to provide capital arising from their lack of familiarity with EPC (ICF and NAESCO 2007; Bhattacharjee et al. 2010). This evolved through time to the current condition, whereby ESCOs no longer directly provide financing, due

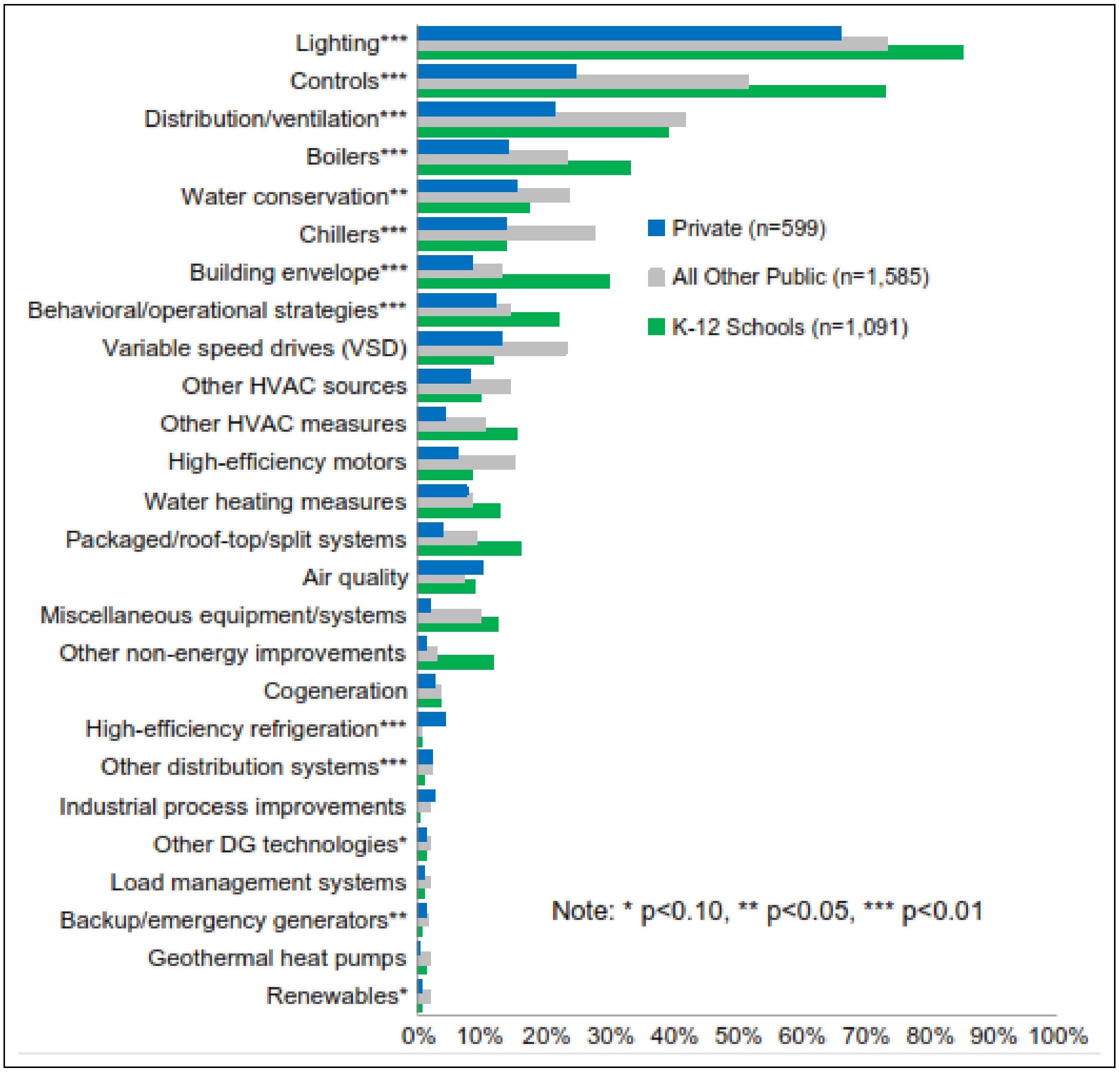


Figure 2-3. Percentage of Projects Installing Various Retrofit Measures
(Source: Larsen et al. 2012a)

to a mature financial market that is willing to work with such projects, although ESCOs may still provide assistance to the owner in recommending the appropriate financing vehicle (ICF and NAESCO 2007). Public projects are typically funded through debt financing (e.g., loans) or lease-based financing (Hansen 2006; ICF and NAESCO 2007), although bonds are also frequently used to fund MUSH market EPC projects (Hansen 2006; CCI 2009b). Power purchase agreements may also be used when EPC projects involve the deployment of distributed generation or combined heat and power technologies (ICF and NAESCO 2007). Financing costs increased during the economic downturn in the mid-2000s, although this did not appear to materially deter the ESCO industry from providing EPC services during this time (Satchwell et al. 2010).

Some form of a performance guarantee is included in many EPC projects (ICF and NAESCO 2007). When examining the NAESCO database for EPC projects between 1990 and 2008, Larsen et al. (2012a) found that 73% of public and institutional projects utilized a performance guarantee, whereas only 40-45% of private sector projects included such a guarantee. Among projects with guaranteed performance, the guaranteed savings model was vastly preferred across sectors – 92% of public and institutional projects and 71-80% of private sector projects used this contractual form. A more complete discussion of EPC savings models is included in section 2.2.3.

2.2.2.2 Energy Performance Contract Life Cycle

The life cycle of an EPC retrofit project can be divided into five phases: (1) Project Development, (2) Energy Audit, (3) Retrofit Design, (4) Project Execution, and (5) Energy Savings, which are described below.

Project Development, Energy Audit, and Retrofit Design: The first three phases of the EPC process encompass the work conducted by ESCOs with regard to the decision to bid, the response to a request for proposals which often includes a preliminary technical audit, completion of the investment grade audit (IGA), an analysis of potential energy savings and cash flows, and the final development of the retrofit design (AEPCA 2000; Waste Reduction Partners

2008; Petersen 2009; Tetreault and Regenthal 2011). A critical element of this phase is the completion of the IGA as it includes several pre-requisites that define the remainder of the EPC scope of work to include development of the baseline, against which performance guarantees are developed and expected levels of performance from the specified energy conservation measures (ECMs) (Sankey 2007). Critical areas addressed by the IGA include (AEPCA 2000; Ganji and Gilleland 2002; ASHRAE 2011; Baechler et al. 2011):

- Identify opportunities for energy savings through detailed energy calculations, derived from a site assessment, analysis of utility bill data, and review of current energy-consuming equipment performance data;
- Fully define the scope of work to be undertaken during the project execution and project performance phases to include M&V procedures; and
- A comprehensive financial analysis that identifies retrofit implementation costs, guaranteed levels of performance, and cash flows during the performance period of the project.

The scope of work to be delivered and M&V plans may be impacted by system upgrades required under the current version of the building code that is in force during the term of the retrofit (Hansen 2006). This may require added work scope items merely to make systems code-compliant, whether or not those systems were an integral component of one or more ECMs. As information is gathered relative to the development of the IGA, ESCOs must also analyze the potential impacts of humans on the retrofit, to include behavioral impacts known as the “rebound effect” (Hertwich 2005; Herring and Roy 2007; Strand 2011), the ability for maintenance personnel to operate newly-installed systems based on the ESCO’s assumptions (Hansen and

Brown 2004), and potential changes in the operational profile of the building (e.g., hours of operation, temperature and humidity set points, building use) (Baechler et al. 2011). Indoor environmental quality issues may also be addressed during the IGA (Hansen and Brown 2004) and a complete assessment of risks related to each ECM should also be completed (Hansen 2006).

Project Execution: Once the retrofit design is complete and ECMs have been specified, work commences on the actual retrofit activities. While this phase of the work is similar to other construction projects, there are unique considerations for work conducted through an EPC. The overarching concern is that delays, procurement issues, productivity losses, equipment substitutions, substandard performance of ECMs, and delayed commissioning can all impact the project's objectives and the attainment of energy performance goals (Sankey 2007; Silberman 2010). Delays on projects with statutorily-mandated contract terms will shorten the period of time during which energy savings may be accrued; such delays almost always lead to monetary claims against the ESCO (Silberman 2010).

System commissioning in EPC projects may need to address issues differently than in traditional construction, to include interaction between commissioning, M&V, and required documentation to support any included non-energy benefits (NEBs) (Stum 2000). Jennings and Skumatz (2006) found that negative impacts to the project schedule were cited by survey participants as the primary negative outcome of undertaking commissioning. Silberman (2010) suggested that ECMs should be commissioned as they are installed in order to avoid potential delays in project execution that could lead to claims against the ESCO. Stum (2000) also found that the intensity of commissioning and the rigor of the M&V plan may be inversely related; however, there is a question as to the optimal level of intensity in each component that would yield an acceptable result.

Jennings and Skumatz (2006) found that commissioning can assist in the valuation of non-energy benefits (NEBs) accrued through the retrofit process. The application of such benefits in EPC projects is inconsistent due to legislative variation among jurisdictions undertaking the work (Larsen et al. 2012b) and the lack of a standardized protocol for quantifying these benefits (Birr and Singer 2008). Including these benefits is potentially important to project economics, as Tso et al. (2003) found the payback period for commissioning costs could be reduced by approximately 19% when including NEBs.

Energy Savings: Once ECMs are installed and commissioned, the project moves into the energy savings phase. As stated above, many jurisdictions statutorily limit the overall contract length for EPCs, so the owner benefits if the project can quickly move to the energy savings phase, where efficiency-related operational savings are accrued. Two interrelated elements of the energy savings phase established during the IGA are the energy consumption baseline and the M&V plan (AEPCA 2000; Mozzo 2001; Waste Reduction Partners 2008; Petersen 2009; Tetreault and Regenthal 2011). The establishment of the baseline is critical, as it is the basis upon which all energy savings are based and it may be adjusted during the energy performance phase if changes are detected in system operational parameters (FEMP 2007). The baseline may be established through measurement and analysis of existing conditions or by stipulation; the latter option potentially reduces risk exposure for all parties to an EPC (Mozzo 2001). Adjustments to the baseline are considered to be either routine or non-routine (EVO 2012). Routine adjustments include "energy-governing factors" that are likely to change during the energy performance period, such as weather. Non-routine adjustments are also "energy-governing factors," but those considered less likely to change, such as facility size, occupant type, volume of conditioned space, or facility operating profile (EVO 2012).

Measurement and Verification Options: The International Performance Measurement and Verification Protocol (IPMVP) is an internationally-recognized, consensus-based M&V standard that was first developed in the mid-1990s through consultation with hundreds of professionals representing 12 countries (IPMVP Committee 2002). The IPMVP recognizes four options for M&V, referred to as options A through D (EVO 2012), which are described in Table 2-1. Options A and B establish the M&V boundary as the system components directly related to the equipment impacted by the EPC retrofit. Option C utilizes the entire facility as the measurement boundary in order to manage total facility energy performance. Option D is used when baseline or reporting period data are not available and requires calibrated whole-building simulation, using a measurement boundary at either the whole building or installed system scale.

Stipulation in Option A: Stipulation is an option that is available when the ESCO and owner agree to hold a performance term constant, regardless of actual performance during the energy performance period (FEMP 2002). Stipulation may be allowed in Option A if three conditions are met: (1) measures can be reasonably estimated, (2) they are documented, and (3) they contribute a relatively small amount of uncertainty toward the overall savings guarantee (FEMP 2002). Data used to estimate and stipulated savings may include manufacturers' or national

Table 2-1. IPMVP Option Descriptions

IPMVP Option	Savings Calculation Methods	Typical Applications
A. Retrofit Isolation: Key Parameter Measurement Savings are determined by field measurement of the key performance parameter(s) which define the energy use of the ECM's affected system(s) and/or the success of the project. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the measured parameter, and the length of the reporting period. Parameters not selected for field measurement are estimated. Estimates can based on historical data, manufacturer's specifications, or engineering judgment. Documentation of the source or justification of the estimated parameter is required. The plausible savings error arising from estimation rather than measurement is evaluated.	Engineering calculation of baseline and reporting period energy from: • Short-term or continuous measurements of key operating parameter(s); and • Estimated values. Routine and non-routine adjustments as required.	A lighting retrofit where power draw is the key performance parameter that is measured periodically. Estimate operating hours of the lights based on facility schedules and occupant behavior.
B. Retrofit Isolation: All Parameter Measurement Savings are determined by field measurement of the energy use of the ECM-affected system. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the savings and the length of the reporting period.	Short-term or continuous measurements of baseline and reporting period energy, and/or engineering computations using measurements of proxies of energy use. Routine and non-routine adjustments as required.	Application of a variable speed drive and controls to a motor to adjust pump flow. Measure electric power with a kW meter installed on the electrical supply to the motor, which reads the power every minute. In the baseline period this meter is in place for a week to verify constant loading. The meter is in place throughout the reporting period to track variations in power use.

Table 2-1 (cont'd)		
IPMVP Option	**Savings Calculation Methods**	**Typical Applications**
C. Whole Facility Savings are determined by measuring energy use at the whole facility or sub-facility level. Continuous measurements of the entire facility's energy use are taken throughout the reporting period.	Analysis of whole facility baseline and reporting period (utility) meter data. Routine adjustments as required, using techniques such as simple comparison or regression analysis. Non-routine adjustments as required.	Multifaceted energy management program affecting many systems in a facility. Measure energy use with the gas and electric utility meters for a twelve month baseline period and throughout the reporting period.
D. Calibrated Simulation Savings are determined through simulation of the energy use of the whole facility, or of a sub-facility. Simulation routines are demonstrated to adequately model actual energy performance measured in the facility. This Option usually requires considerable skill in calibrated simulation.	Energy use simulation, calibrated with hourly or monthly utility billing data. (Energy end use metering may be used to help refine input data.)	Multifaceted energy management program affecting many systems in a facility but where no meter existed in the baseline period. Energy use measurements, after installation of gas and electric meters, are used to calibrate a simulation. Baseline energy use, determined using the calibrated simulation, is compared to a simulation of reporting period energy use.
(Source: EVO 2012)		

association-developed performance curves, manufacturer's specifications, standard lighting tables, and government weather data. The use of stipulation has grown in EPCs as there is a significant benefit to all parties (ICF and NAESCO 2007). Owners can direct more of the project value toward capital improvements by reducing the complexity, and therefore cost, of M&V and the ESCO can reduce their long-term performance risk (ICF and NAESCO 2007). Due to the nature of stipulation, excess savings are not possible and therefore cannot be accrued.

2.2.3 Savings Models

As discussed in section 2.2.1, the use of shared savings has waned in favor of guaranteed savings. Customers prefer guaranteed savings due to its lower financing costs (most MUSH market entities are tax-exempt), greater certainty in savings (the ESCO is contractually-obligated to achieve guaranteed performance), and lower transaction costs, since the ESCO is focused solely on performance, to the exclusion of financial risks (Hopper et al. 2005). Despite the current focus on the guaranteed savings model, this section will briefly discuss and compare both shared savings and guaranteed savings. A summary of the key aspects of each contract type is presented in Table 2-2.

Table 2-2. Comparison of EPC Contract Types

Contract Type	**Finance Risk**	**Performance Risk**	**Balance Sheet**	**Project-Specific Financing**
Shared Savings	ESCO	ESCO	ESCO	Yes
Guaranteed Savings	Customer[a]	ESCO	Customer	Yes

Notes:
a\ ESCO bears finance risk if guaranteed savings is ESCO-financed
(Sources: Hopper et al. 2005; IFC 2011)

2.2.3.1 Shared Savings

The shared savings model of EPC requires that the ESCO carry the credit risk of the customer in addition to the technical performance risk of the project (Hansen 2006; ICF and NAESCO 2007; IFC 2011; Larsen et al. 2012a). The ESCO also bears the risk of energy rate increases that exceed the agreed-upon escalation factor in the contract (ICF and NAESCO 2007). If there are no energy savings, the facility owner pays the utility bill as usual; while the ESCO does not receive any payments, they also do not owe anything to the owner (ICF and NAESCO 2007). In the event that the project does not result in energy savings, the ESCO is required to pay for the up-front project costs (equipment is owned by the ESCO until the project is turned over at the end of the performance period); however, if the project does achieve net savings, they are divided with the owner based on agreed-upon terms. While this contractual form has declined in use in the U.S., Da-li (2009) reports that it is still preferred in the building sector in China, and Okay and Akman (2010) report its preference in the developing world, since owners limit their financial risk and can keep these projects off their balance sheets. This latter situation is particularly important as it enables an owner to minimize exposure of their credit capacity, which can be a benefit in developing economies which typically have less-robust financial institutions (IFC 2011).

2.2.3.2 Guaranteed Savings

As stated earlier in this section, the U.S. ESCO industry has moved nearly exclusively to guaranteed savings for EPC retrofits. This contractual form has a decidedly different risk profile compared to shared savings, and releases the ESCO from financial risk (Table 2-2); however, the performance guarantee must ensure that a wider range of costs are recoverable, to include debt service, M&V fees to the ESCO, and any maintenance obligations or other incremental costs stipulated by the contract (IFC 2011). The main advantages of this method, compared to shared savings for owners, are that public or non-profit customers can secure financing at lower rates by carrying the debt on their own balance sheet, more comprehensive projects are possible because the ESCO is less highly-leveraged through not financing the work, and the amount of energy saving is guaranteed. If there is a shortfall in the guaranteed amount of energy savings, the ESCO will pay the shortfall amount to the owner using previously-agreed upon utility rates and escalation factors; in this way, the ESCO does not guarantee cost savings, rather a quantity of saved energy (CCI 2009a).

The ESCO benefits by reducing their risk profile through elimination of carrying owner credit risk and by being able to assemble larger, more complex projects which potentially carry more value (European Commission 2014). Additionally, the ESCO is generally paid up-front for the construction costs of the project via the owner's financing, and ongoing payments are directed toward ongoing costs (e.g., O&M and M&V costs, if included in the contract) (Hopper et al. 2005).

Establishing the appropriate level of guarantee is a subject of much debate, but little research has been conducted on this subject. Goldman et al. (2002) examined the difference between ESCO-guaranteed savings to customers and the ESCO's own predicted savings estimates for 15 companies. Seven companies reported that they guarantee 100% of predicted savings, while six reported guarantees between 50% and 100% of predicted savings. Two companies guaranteed less than 50% of predicted savings. Establishing the appropriate guarantee can be a risky proposition, especially since Goldman et al. (2002) found that 30% of the 369 projects examined had actual savings that were less than predicted savings. Hopper et al. (2005) reviewed 534 EPC projects and found that 34% had shortfalls between predicted savings and actual savings; 57% of these projects had shortfalls in excess of 10%. Only 12% of projects used stipulation in the Hopper et al. (2005) study; 14% of projects used stipulation in the Goldman et al. (2002) study.

2.2.4 Information Categories for EPC Retrofits

The EPC process relies on both quantitative and qualitative sources of data when developing the project technical requirements. The IGA is the manifestation of the information needed for a successful EPC project, and can be divided into two primary categories – energy accounting information and O&M related information (Hansen 2002). The quality of information gathered and reported throughout the life cycle of an EPC project is a major determinant of that project's success (Allen et al. 2006). The specific types of information categorized thusly include:

- Monthly utility bill data:
    - Electricity – usage (kWh), demand (kW and kVA), power factor penalties (if assessed), and the total bill (dollars);
    - Other fuels – billing period, consumption units (e.g., CCF, gallons), cost per unit, and the total bill (dollars); and
    - Energy use normed to BTUs or therms to permit cross-fuel source comparisons;
- Energy consumption per unit of product (for industrial facilities);
- Facility information:
    - Conditioned gross square footage of building(s);
    - Operational profile, end-use(s), occupant types, building ages, age(s) of previous retrofits; and
    - Known locations of hazardous materials (e.g., asbestos) and code non-compliant infrastructure;
- Current and estimated future energy prices;
- Technical requirements of and eligibility for utility rebate, incentive, and grant programs;
- Emissions reductions resulting from energy efficiency;
- Benchmark data based on EPC retrofit goals;
- Calculated costs based on existing data collection:
    - Cost of delay (CoD), where

CoD= -(energy cost savings for period + O&M savings for period) + initial investment prorated; and

    - Cost avoidance (Ca), normalized to changed conditions (e.g., increased conditioned gross floor area), where

      Ca = (baseline cost X current energy cost) – current costs;

- O&M costs (e.g., training, staff time on O&M-related activities);
- O&M service log (e.g., frequency and severity of required O&M activities);
- Inventory of all energy-consuming equipment (location, use, operational profile, descriptive information, nameplate information);
- Equipment replacement and upgrade costs; and
- New equipment costs (purchase, O&M, and replacement), energy consumption, and operating parameters.

The IGA also requires information related to the owner's project requirements (OPR), relevant statutory requirements or limitations, special operating parameters for the facility (e.g., the presence of medically-fragile patients), specific site access and security requirements, climate, and building conditions.

The various types of information needed for the retrofit process (as listed above) can be described as being quantitative or qualitative (Samuel 2010; Duah 2014). Quantitative information generally includes published standards and literature that is agreed upon by domain experts (Duah 2014). This may include published information about retrofit technologies, cost information from published databases (Duah 2014), equipment operating cost databases (such as the ASHRAE Service Life and Maintenance Cost Database) (Abramson et al. 2005), energy simulation analyses from simulation software (e.g., DOE2, eQuest, TRNSYS), system design tools (e.g., Trane TRACE, Carrier HAP), building information modeling results, design guides (e.g., ASHRAE 2012), information available from corporate databases on previous projects, and company-wide planning and risk mitigation checklists (such as implemented by Honeywell, Johnson Controls, and McKinstry, among others).

Qualitative information is generally considered to be expert knowledge, and consists of experience-based judgment possessed by domain professionals (Duah 2014). In the case of EPC retrofits, qualitative information may include heuristics employed when making project-level decisions (e.g., the decision to bid, risk-based decision making with regard to retrofit measures) and the incorporation of domain-level expertise in the development and execution of EPC retrofits. The first information communicated to the ESCO is typically qualitative and is directed by the OPR and the experience of the ESCO. This is used to provide an initial response to those requirements, often without the ability to compile large amounts of information or perform a preliminary audit.

2.2.4.1 Sources of Quantitative Information

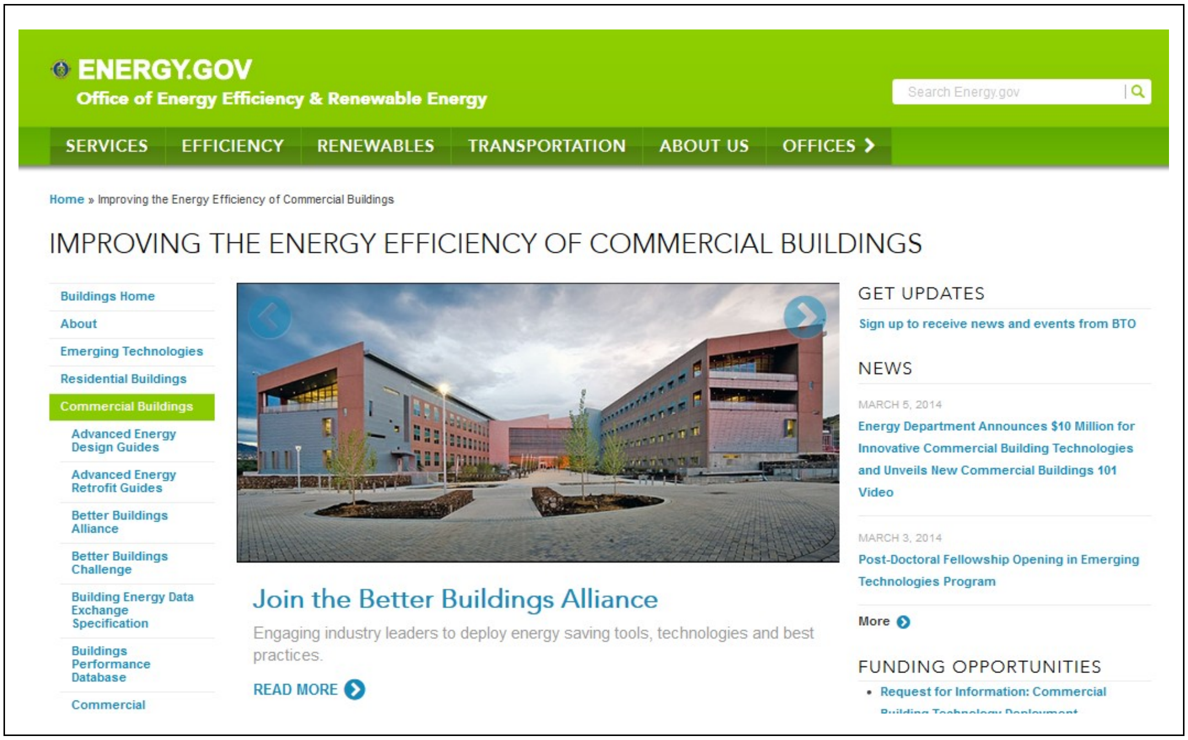
The following section appraises various sources of quantitative information for non-residential energy efficiency retrofits. A variety of quantitative information sources and models developed by the U.S. DOE and third-party organizations are available for the non-residential market.

State energy efficiency databases provide technical and financial information about installed technologies. Examples of state energy efficiency databases include the California Database for Energy Efficient Resources (DEER) (California Public Utilities Commission 2014) and the Michigan Energy Measures Database (MEMD) (Michigan Public Service Commission 2014), which includes data for residential and non-residential applications. Both databases include information on various energy savings technologies and measures to include energy savings potential estimates, typical measures installed in the marketplace, and cost and benefit data of more energy-efficient measures.

The **U.S. DOE Commercial Buildings Portal** (Figure 2-4) provides access to a large number of U.S. DOE research products and databases (some of which are described below), including:

- Advanced Energy Design Guides and Advanced Energy Retrofit Guides
- Buildings Performance Database
- Commercial Buildings Resource Database
- Energy Modeling Software

Both ASHRAE and the U.S. DOE have created **energy efficient design guides** for a number of building types, to include office buildings, schools, and hospitals (ASHRAE 2012; U.S. Department of Energy 2013b). The ASHRAE guides provide information and tools to support 50% energy savings over ASHRAE Standard 90.1-2004, and 30% savings over ASHRAE Standard 90.1-1999 through their Energy Efficient Design Guides (AEDG). The U.S. DOE Advanced Energy Retrofit Guides (AERG) do not use a benchmarked standard; instead, the guide offers flexibility to meet individual building retrofit needs and uses a pre-1980 reference



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MARCH 3, 2014

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FUNDING OPPORTUNITIES

- Request for Information: Commercial

Figure 2-4. U.S. Department of Energy Commercial Buildings Portal Screenshot
(Source: U.S. Department of Energy 2014a)

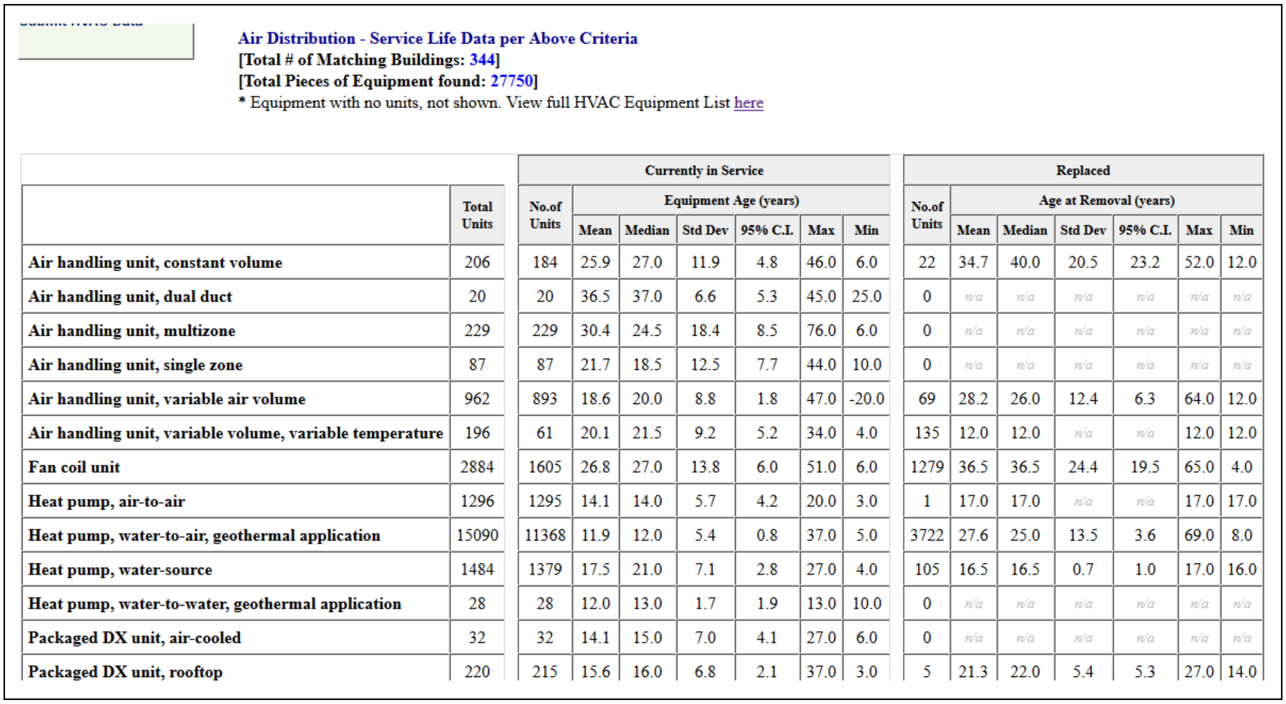
building that was previously developed by the U.S. DOE. Both guides provide information related to retrofit measures, ECMs, and building strategies to achieve stated energy performance goals; however, the U.S. DOE guides are formatted in line with the phases of an EPC retrofit, and offer technical guidance regarding commissioning, ECMs, M&V, and O&M, in addition to cost considerations for recommended retrofit packages (U.S. Department of Energy 2013b).

The U.S. DOE publishes two **buildings databases** of interest for this research – the Buildings Performance Database (BPD) and the High Performance Buildings Database. The purpose of both products is to disseminate information about high performance buildings, and in the case of the BPD, to permit users to perform statistical analyses on an anonymous dataset comprising tens of thousands of actual buildings in the U.S. (U.S. Department of Energy 2014b).

The U.S. DOE provides a portal containing information about commonly-used and widely available **energy models**, including EnergyPlus, OpenStudio, RADIANCE, and DOE-2, in addition to a comprehensive database of over 300 other models for whole building analysis; codes and standards; materials, components, equipment, and systems; energy economics; and indoor environmental quality, among other subjects (U.S. Department of Energy 2014c).

The purpose of the **ASHRAE Service Life and Maintenance Cost Database** is to help building managers make better-informed decisions about life cycle costs related to equipment O&M and replacement, and to provide engineers and facility managers with the ability to "distinguish between low price and best value in the selection of HVAC [heating, ventilation, and air conditioning] systems" (Abramson et al. 2005). The database currently features an internet-based interface (ASHRAE 2014), depicted in Figure 2-5, which provides information related to evaluating equipment service life. Mechanical equipment service life data is currently available for 40,000 pieces of equipment. There are 155 different types of HVAC equipment and systems included in the database, including:

- Air Distribution
- Cooling
- Heat Rejection
- Cooling Pump
- Heating
- Heating Pump
- Control
- Miscellaneous



Air Distribution - Service Life Data per Above Criteria
[Total # of Matching Buildings: 344]
[Total Pieces of Equipment found: 27750]
* Equipment with no units, not shown. View full HVAC Equipment List here

		Currently in Service							Replaced						
	Total Units	No.of Units	Equipment Age (years)						No.of Units	Age at Removal (years)					
			Mean	Median	Std Dev	95% C.I.	Max	Min		Mean	Median	Std Dev	95% C.I.	Max	Min
Air handling unit, constant volume	206	184	25.9	27.0	11.9	4.8	46.0	6.0	22	34.7	40.0	20.5	23.2	52.0	12.0
Air handling unit, dual duct	20	20	36.5	37.0	6.6	5.3	45.0	25.0	0	n/a	n/a	n/a	n/a	n/a	n/a
Air handling unit, multizone	229	229	30.4	24.5	18.4	8.5	76.0	6.0	0	n/a	n/a	n/a	n/a	n/a	n/a
Air handling unit, single zone	87	87	21.7	18.5	12.5	7.7	44.0	10.0	0	n/a	n/a	n/a	n/a	n/a	n/a
Air handling unit, variable air volume	962	893	18.6	20.0	8.8	1.8	47.0	-20.0	69	28.2	26.0	12.4	6.3	64.0	12.0
Air handling unit, variable volume, variable temperature	196	61	20.1	21.5	9.2	5.2	34.0	4.0	135	12.0	12.0	n/a	n/a	12.0	12.0
Fan coil unit	2884	1605	26.8	27.0	13.8	6.0	51.0	6.0	1279	36.5	36.5	24.4	19.5	65.0	4.0
Heat pump, air-to-air	1296	1295	14.1	14.0	5.7	4.2	20.0	3.0	1	17.0	17.0	n/a	n/a	17.0	17.0
Heat pump, water-to-air, geothermal application	15090	11368	11.9	12.0	5.4	0.8	37.0	5.0	3722	27.6	25.0	13.5	3.6	69.0	8.0
Heat pump, water-source	1484	1379	17.5	21.0	7.1	2.8	27.0	4.0	105	16.5	16.5	0.7	1.0	17.0	16.0
Heat pump, water-to-water, geothermal application	28	28	12.0	13.0	1.7	1.9	13.0	10.0	0	n/a	n/a	n/a	n/a	n/a	n/a
Packaged DX unit, air-cooled	32	32	14.1	15.0	7.0	4.1	27.0	6.0	0	n/a	n/a	n/a	n/a	n/a	n/a
Packaged DX unit, rooftop	220	215	15.6	16.0	6.8	2.1	37.0	3.0	5	21.3	22.0	5.4	5.3	27.0	14.0

Figure 2-5. ASHRAE Service Life and Maintenance Cost Database Web Interface Screenshot
(Source: ASHRAE 2014)

2.2.4.2 Sources of Expert Knowledge

Expert knowledge used in this domain is largely derived from expertise accumulated over a period of time performing related work. Duah (2014) provided a complete treatise on the theoretical framework for expertise development, and he noted that the U.S. DOE and Building Performance Institute collaborated on developing guidelines and certification standards for professionals involved in various aspects of residential energy efficiency. Such standards do not currently exist in the non-residential market; however, the U.S. DOE is currently developing a series of workforce development guidelines for jobs in the commercial and industrial buildings sector (U.S. Department of Energy 2013c). Without such industry-accepted guidelines, there is little consistency in education for EPC retrofit professionals nor is there an accepted body of knowledge that would result in a framework for describing domain-level expertise. A review of project documents revealed a heavy degree of reliance on licensed Professional Engineers and

Certified Energy Managers; however, those bodies of knowledge are relatively broad and these are not industry-required credentials for EPC experts. Further challenging this issue is the critical role of risk management in EPC projects. Retrofit professionals must rely on their expertise when making risk-based decisions, even when completing corporate risk guidelines, but the lack of a codified body of knowledge may hamper this decision making.

2.3 RISK IN CONSTRUCTION

All human enterprises contain elements of risk including the construction industry (Dey and Ogunlana 2004). Construction projects are often beset with risks which in turn lead to poor performance throughout the project life cycle (Tah and Carr 2000; Zavadskas et al. 2010; Banaitiene and Banaitis 2012). Despite this, the literature has only placed the concept of construction risk management within the context of decision-making and management science theories since the 1960s (Edwards and Bowen 1998).

This section of the literature review provides an overview of how risk in construction is addressed. The section begins with a presentation of key definitions of uncertainty, risk, and risk management, then addresses foundational theories of decision-making under risk and the elicitation of judgment from experts. Sources of risk in construction projects and energy performance contracting are discussed, which leads to a discussion of risk management process applied to construction projects.

2.3.1 Key Concepts

Three key concepts must be defined before undertaking a review of the literature focused on risk in the built environment and construction projects:

- Uncertainty may be defined as a lack of knowledge about current conditions or some future state. In examining uncertainty, one must distinguish between random uncertainty and knowledge-based uncertainty (Ang and De Leon 2005). Aleatory uncertainty (that due to randomness) cannot be systematically addressed and reduced; however, epistemic uncertainty (that arising from gaps in knowledge) can be reduced through increased knowledge and/or models that can address this gap. Tserng et al. (2009) demonstrated the importance of extracting process knowledge in the effective management of project risks in order to address this knowledge gap.
- Risk is defined in a number of ways, depending on its context. Webster's dictionary defines risk as ''possibility of loss or injury.'' Construction researchers have re-stated that definition as a quantifiable standard, "a measure of the probability, severity, and exposure of all the hazards of an activity" (Jannadi and Almishari 2003). This definition is adopted for this work. The probability of a hazard occurring alludes to uncertainty, as defined above. Hertz and Thomas (1983) defined the relationship between risk and uncertainty such that highly uncertain outcomes cannot be determined to be risky unless they also carry a potential for damage or loss. Kmenta and Ishii (2004) restated damage as the potential consequence of uncertainty. This can therefore be represented conceptually as:

$$Risk = Uncertainty \times Consequence$$

- Risk management (RM) is the systematic process of applying management science to address risks in projects (Edwards and Bowen 1998; Arashpour and Arashpour 2012). The RM process consists of risk identification (and classification), risk analysis and evaluation, risk mitigation/allocation, and decision influencing, and risk monitoring (Edwards and Bowen

1998; Ahmed et al. 2007; Liu et al. 2010; Arashpour and Arashpour 2012; Banaitiene and Banaitis 2012) framed within an appropriate project context to achieve management goals throughout the project lifecycle (Ward and Chapman 1995).

2.3.2 Decision Making Under Risk and Uncertainty

2.3.2.1 Bounded Rationality

Economic and psychological models of decision-making traditionally held that individuals behaved rationally, until the late 1950s when it is believed that Herbert Simon introduced the concept of "bounded rationality" (Russell and Thaler 1985), which holds that individuals' ability to act rationally is limited by information availability, cognitive abilities, and limited time to make decisions. Research between the 1970s and 2000s further explored this concept (Russell and Thaler 1985; Kachelmeier and Shehata 1992; Fehr and Tyran 2001; Tse and Love 2001) and studied the conditions under which such behavior takes place. Tversky and Kahneman's (1981) seminal empirical study demonstrated that people make different decisions about the same decision problem when it is presented differently, thereby lending support to the notion of bounded rationality. This "framing problem" arises when the problem's form has a greater influence on the decision maker than does the substance of the problem under analysis. This has been shown to be a systematic problem, in that specific decisions can be predicted by knowing how the problem has been framed, which has been termed as quasi-rational behavior (Russell and Thaler 1985).

Tversky and Kahneman (1986) demonstrated that this framing problem can lead to violations of the two widely-supported axioms of expected utility theory that define rational behavior –

dominance and invariance. The dominance axiom states that a decision option that is preferred in one context and at least as good in other contexts is the preferred option. The invariance axiom represents the inverse of the framing problem and states that the preferred decision option should be the same regardless of the way the problem is represented. They noted that McNeil et al. (1982) observed an increased preference for significant medical procedures when immediate risks were reduced despite greater long-term risks of mortality. Furthermore, they noted that this framing effect risk preference was the same for experienced physicians, business students with significant statistical knowledge, or clinic patients.

These examples are illustrative of Kahneman and Tversky’s (1979) Prospect Theory (PT), which holds that people make decisions based on potential losses and gains as compared to a reference point, rather than based on an end-state condition. The theory is based on individual decision-maker behaviors that are loss averse – in other words, losses hurt more than gains feel good. In PT, the individual employs heuristics as their primary decision-making tool. While PT relies on choosing among outcomes with known probabilities, Cumulative Prospect Theory (CPT) offers the ability to provide decision weights, which can vary for gains and losses (Tversky and Kahneman 1992). CPT demonstrates a “fourfold pattern of risk attitudes: risk aversion for gains and risk seeking for losses of high probability; risk seeking for gains and risk aversion for losses of low probability” (Tversky and Kahneman 1992).

As a result of previous work on rationality, quasi-rationality, PT/CPT and psychological considerations (e.g., framing) of decision-making under risk, it is important to understand the context of a decision problem in order to examine individual behavior under risk. Berny and

Townsend (1993) recognized that effective risk analysis in technical projects relies on expert knowledge of the systems under risk. These experts tend to be risk-averse (Berny and Townsend 1993; Raftery et al. 2001), which may lead to unintentionally ignoring specific risks in a comprehensive analysis since they tend to rely on previous experience rather than to analyze risks with unknown likelihoods of occurrence (Wirba et al. 1996). Furthermore, construction professionals have been shown to maintain identical risk attitudes before and after a “turning point” event on a project and displayed more loss aversion when smaller amounts of money are at risk (Raftery et al. 2001) than what would be predicted by PT/CPT(Tversky and Kahneman 1992).

When analyzing risks, McKim (1992) found that contractors tended to assign discrete percentages to the likelihood of a project risk occurring as opposed to developing probability functions, they tended to believe that risks could not happen to them, and that they largely ignored contractual risks. As a result, McKim (1992) recommended that risk analysis for construction projects should favor qualitative methods over statistical techniques. Despite these individual aspects of decision-making under risk by construction professionals, Birnie (1993) found that estimators subject to his study held the same judgmental biases and used the same heuristics in their decision-making process as the population at large. Raftery (1994) suggested that construction professionals could benefit from techniques that make them more aware of their decision-making process since they do not possess significantly better decision-making abilities or different risk attitudes than the general public.

2.3.2.2 Cognitive Biases and Energy Efficiency

Klotz (2011) investigated the role of cognitive biases during the early stages of energy efficiency project delivery, when decisions made can have the greatest impact on project performance at the least cost. His assertion is that understanding potential cognitive biases is important to understanding the full scope of why buildings use more energy per square foot today than ever before, despite technical advancements and proven cost-effective technologies. The literature review conducted as part of the research identified six potential cognitive biases and placed them in the context of the project phase where they may occur with an example of how they could impact energy efficiency performance (Table 2-3).

Table 2-3. Potential Cognitive Biases During Energy Efficient Project Lifecycle

Project Phase	**Cognitive Bias**	**Energy Efficiency Example**	**Impact**
Planning	Anchoring	Set an energy performance goal.	Anchoring on minimum standards (e.g., building codes, LEED points) may inhibit higher performance.
	Status Quo	Adopt an integrated design approach.	Obstacle to implementation of new approaches.
Design	Groupthink	Conduct a charrette.	Stifle novel ideas.
	Professional Bias	Use natural features to reduce cooling load.	Engineers may ignore natural/ passive options.
	Framing	Use day lighting to reduce electrical requirements.	Framing costs in appealing terms is critical.
Construction	Professional Bias	Specify design team participation during construction.	Need to overcome professional bias for parties to work together.
	Mental Accounting	Seek incentives for meeting the energy performance goal.	Consider mental accounting when seeking incentives.

(Adapted from Klotz 2011)

This, in part, points back to the earlier discussion of PT and CPT as these theories have been applied to the understanding of three biases examined by Klotz (2011) - framing, status quo, and mental accounting. The framing problem was discussed in some detail earlier in this section. It may be relevant to energy efficient retrofit problems when discussing the costs of various retrofit measures; rather than discuss savings, Klotz recommends discussing them in terms of cost avoidance, or costs if not adopted. While the EPC process is built around determination of a savings guarantee (e.g., energy saved per unit time), avoided costs are allowed by many jurisdictions' EPC legislation and may be valuable in describing the full impact of not undertaking a specific portfolio of ECMs.

The status quo bias, first described by Samuelson and Zeckhauser (1988) has been described as continuing to choose the current situation (e.g., follow company policy, employ ECMs that worked on previous projects) even when given new alternatives (Kahneman et al. 1991; Kwak et al. 2010). Klotz (2011) reported that this might lead to refusal to adopt new technologies. Toole (1998) found that architecture and engineering professionals may exhibit this bias when considering new technologies with high levels of uncertainty related to market acceptance. That bias was not noted when considering innovations with a high degree of technical uncertainty. While Toole (1998) observed the status quo bias in residential energy efficiency projects, it has also been shown to impact decision making in public-private partnership (PPP) projects (van Buiten and Hartmann 2013).

According to mental accounting (Thaler 1985), decisions are impacted by the way possible outcomes are coded and categorized, and explains violations of basic economic principles (Klotz 2011). Wilson and Dowlatabadi (2007) noted that this cognitive bias may lead decision makers to partition benefits from energy efficiency retrofits such as monetary/non-monetary or energy/

non-energy into different mental accounts and assess the overall project benefit across multiple accounts. Klotz (2011) suggests that this bias may manifest itself if energy costs are treated separately from building costs in an organizational budget.

While the aim of this research does not include accounting for effects of these cognitive biases on risk-based decisions made during the EPC retrofit process, the preceding discussion assists in framing the nature of expertise sought from study participants in chapters 4 and 5. It also provides context for the discussion of risk in construction and engineering in the following section.

2.3.3 Risk in Construction and Energy Performance Contracting

2.3.3.1 Construction Risk

Construction projects are inherently risky, owing to the unique nature of each project, the interactions among a large number of diverse stakeholders, the size and complexity of most projects, and the political/economic/social landscape in which the project takes place (Zavadskas et al. 2010; Banaitiene and Banaitis 2012). The cost of bearing certain risks has been proposed as a technique to understand construction risk management; however, literature reviews have concluded that this approach does not seem to be widely used (Yang and Lowe 2011) and up-front pricing of risks may not be incorporated in final bids, in order to improve bid competitiveness (Laryea and Hughes 2011).

There is a clear distinction in the literature among research focused on overall project risk (Tah and Carr 2000; Tah and Carr 2001; Zavadskas et al. 2010; Banaitiene and Banaitis 2012; Goh and Abdul-Rahman 2012) versus research focused on individual project phases, elements, and critical success factors such as the project planning phase (Diab 2012), time and cost (Doloi 2012), safety, and delay (Assaf and Al-Hejji 2006). The technical aspects of construction risk management have been explored related to design and retrofit of structures to withstand seismic events (Pampanin 2009) and selection of energy conservation measures (Willis 2008). A second and significant body of the literature addresses business and decision-related aspects of risk (Ward and Chapman 1995; Assaf and Al-Hejji 2006; Subramanyan et al. 2012; Xiang et al. 2012).

This highlights the need to find methods that adequately address the aspects of risk under review in a given problem, to include the need to develop a comprehensive framework for addressing all of the elements of risk that impact a specific project objective (Yang and Lowe 2011). Such a framework must include the ability to capture expert knowledge and judgments related to the treatment of risks in decision-making and provide a basis for incorporating that information into a complete risk management scheme.

Broad categories of risk in construction projects have been given as arising from financial, operational, technological, and legal aspects of the project environment (Kindinger and Darby 2000; Dey and Ogunlana 2004). These categories may include risks such as poor communication among project team members, cost overrun, poor indoor environmental quality, design discrepancies, delays in appointing subcontractors, low productivity, unacceptable performance of installed technologies, and legal issues among project stakeholders (Dey and Ogunlana 2004; Assaf and Al-Hejji 2006; Goh and Abdul-Rahman 2012; Jefferies and Chen 2012).

The literature has also identified risks by project phase, as presented in Table 2-4. Given the lack of a rich literature focused on EPC risks, build-operate-transfer (BOT) and PPP projects were examined when completing this table, as they share some characteristics with EPC, including turnkey service, the integrated partnership approach, and the use of performance guarantees.

Table 2-4. Sources of Risk by Phase in BOT and PPP Construction Projects

	Project Phase		
Risk	**Planning/Design**	**Construction**	**Operation**
Technical risk (frequent design change, design discrepancies, unknown site conditions)	X		
Credit risk	X		
Bid risk	X		
Completion risk		X	
Cost overrun risk		X	X
Performance risk		X	X
Political risk		X	
Liability risk			X

(Sources: Dey and Ogunlana 2004; Kokkaew and Chiara 2010; Goh and Abdul-Rahman 2012; Jefferies and Chen 2012)

2.3.3.2 Energy Performance Contracting Risk

As discussed earlier, EPC projects finance the work performed by the ESCO through savings accrued from reduced operational costs. These projects are typically financed over a lengthy performance period (12-15 years is not uncommon in the MUSH market) and benefits begin to accrue during the energy savings phase, although some savings may occur during execution. For ESCOs conducting EPC retrofits, the overarching issue is risk, because performance-related risks are transferred from the owner to the ESCO (Deng et al. 2014). The level to which ESCOs can manage and mitigate their performance risk defines a successful ESCO. In essence this means that the concepts of risk analysis, risk management, decision-making under uncertainty, and EPCs are interrelated and must be treated as such. The development of the retrofit design is an iterative processes based on the data analysis conducted as part of the IGA and the expert judgment of domain experts engaged in the work. Despite the large quantity of information collected and analyzed as well as the use of expert knowledge, EPC retrofits still run the risk of not meeting their savings guarantee. A 2005 study conducted by the Berkeley National Laboratory analyzed 517 performance contract projects and found that 72% had excess savings beyond the guarantee, while another 9% were fully stipulated (Hopper et al. 2005), as depicted in Figure 2-6. While these results point to only 19% of projects failing to meet the savings guarantee, approximately 5% of the included projects failed to meet their guarantee by 25% or more, indicating significant potential economic risk to the ESCO in these cases.

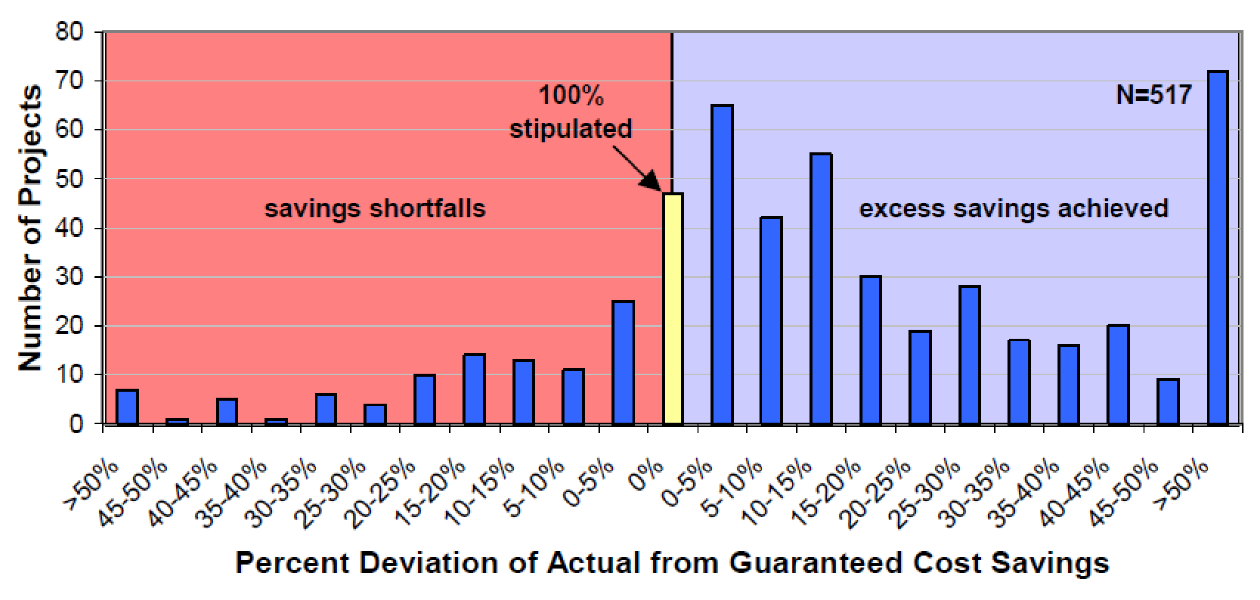


Figure 2-6. Performance of ESCO Savings Guarantees
(Source: Hopper et al. 2005)

2.3.3.3 Preliminary Risk Framework

The research literature lacks a comprehensive risk framework for EPC retrofits. Hansen (2006) provided an outline of key risks that ESCOs should be aware of when undertaking EPC retrofits. Many of these risks were confirmed in an interview with the author (Hansen 2013). The existing work by Hansen (2006) was built from over three decades of experience; however, it was not verified through a literature review. Using this experience as a base, a literature review was conducted to further examine risks faced by ESCOs when undertaking EPC retrofits. The net result of that review was a preliminary risk framework that includes ten risk categories for ESCOs to consider when undertaking EPCs (eight from Hansen 2006; two additional risks were identified in the literature that were not included in Hansen 2006). Since the primary technical risk retained by ESCOs is failure to achieve guaranteed performance, this framework can be considered a first step toward identifying critical risk factors for ESCOs undertaking EPC retrofits. These categories and the preliminary risk framework are depicted in Table 2-5.

Customer Pre-Qualification: The pre-qualification of customers is important to ensure that ESCOs minimize financial performance and project management-related risks. Hansen (2006) identified three categories of qualification factors, including: (1) financial/economic factors, (2) facility/technical factors, and (3) people factors (e.g., commitment of management, manpower, capacity, etc.). These issues may manifest themselves through customer-preferred short performance periods that limit the technical approach (Bertoldi and Rezessy 2005), changes in future occupancy and building use (Walker and Dominick 2000; Shonder and Hughes 2005), interference with customer operations (AEPCA 2000), unknown latent conditions that can cause delay (AEPCA 2000), improper operations and maintenance undertaken by the customer (AEPCA 2000; Mills et al. 2006), human activity that is inconsistent with the M&V plan (Mills et al. 2006), and the risk that the customer may go out of business prior to full payment of the contract (Bertoldi and Rezessy 2005).

Table 2-5. Preliminary Risk Framework for ESCOs Undertaking MUSH Market EPC Retrofit Projects

Risk Category	**Risks**	**References**
Client Pre-Qualification	Financial factors • Client may go out of business before full contract payment.	Bertoldi and Rezessy 2005; Hansen 2006
	Facility/technical factors • Client-preferred short performance periods limit technical approach. • Changes in future occupancy and use. • Unknown latent conditions.	AEPCA 2000; Walker and Dominick 2000; Shonder and Hughes 2005; Hansen 2006; Bertoldi and Rezessy 2005
	People factors • Human activity inconsistent with M&V plans . • Improper O&M undertaken by client. • Interference with client operations.	AEPCA 2000; Hansen 2006;Mills et al. 2006
Project Development	Costs incurred from project start-up; long development phases can lead to difficult to recover costs.	Hansen 2006
Energy Audit Quality	The investment grade audit must include a risk assessment for each proposed ECM.	Hansen 2006
	Improperly-established or disputed baseline can impact calculations of energy savings and also give rise to disputes.	Mozzo 2001; Mills et al. 2006; Sankey 2007
Equipment Selection and Installation	Selected ECMs not aligned with findings of the IGA.	Hansen 2006
	ECM package feasibility, failure to perform as designed, uncertainty in factors used to predict performance.	Shonder and Hughes 2005; Mills et al. 2006; Shang et al. 2008; Wang and Chen 2008; Jinrong and Enyi 2011
	Reduced involvement of ESCO in ECM selection/installation, procurement through bidding, risk of improper installation if the ESCO is not involved during the construction phase.	Hansen 2006

Table 2-5 (cont'd)		
Risk Category	**Risks**	**References**
Commissioning	Failure to commission may lead to missed opportunities to verify ECM performance and better overall project performance; Failure to commission may miss opportunities to verify installed equipment performance, to ensure that calibration, operation, and maintenance procedures are well-understood, and that all system documentation is turned over.	Stum 2000; Sankey 2007
Operations and Maintenance Practices	Poorly understood responsibilities by each party if the O&M plan is unclear.	AEPCA 2000
	The customer may not perform O&M work to specification.	Mills et al. 2006
	Customer self-performance or contracted O&M may reduce revenue for ESCO.	Hansen 2006
Measurement and Verification of Savings	Poorly-developed M&V plans can create additional risk for the ESCO.	Hansen 2006
	Poorly-designed M&V sampling protocols may not accurately reflect the overall performance of the ECM package.	Mills et al. 2006; Mozzo 2001; Shang et al. 2008
	M&V protocols that do not capture non-energy benefits of EPCs may understate overall system performance.	Larsen et al. 2012a
	Failure to include O&M in the M&V plan may lead to missed savings.	Schweitzer et al. 2000
Project Management Over the Project Life-Cycle	Failure to adopt life-cycle based management approaches may result in failure to meet project objectives.	Hansen 2006
Construction-Specific Concerns	Schedule growth may cause unrecoverable costs for the ESCO.	Silberman 2010
	Cost growth may impact the financial analysis that the savings guarantee is premised on - cost overruns may result from schedule delays, latent site conditions, and field changes.	Smith and Ferber 1996; AEPCA 2000; Sankey 2007; Silberman 2010
Volatility of Energy Prices	Changing prices can reduce project value.	Bertoldi and Rezessy 2005; Shonder and Hughes 2005; Mills et al. 2006; Shang et al. 2008; Wang and Chen 2008

Project Development: Energy service companies incur costs from the start of their work on the development of an EPC project (Hansen 2006). The longer the development phase takes to complete, the greater the risk to the ESCO that incurred costs will not be recovered, especially if no agreement can be reached during this phase, effectively halting the project.

Energy Audit Quality: Energy audits must include ESCO verification of facility operating parameters in establishing the baseline for energy consumption. That information, along with equipment nameplate data, utility bill analysis, and a physical observation of building conditions comprise an energy audit. The next stage of sophistication, known as an investment-grade audit (IGA) incorporates a risk assessment for each proposed ECM (Hansen 2006). An improperly-established or disputed baseline can impact calculations of energy savings and also give rise to disputes (Mozzo 2001; Mills et al. 2006; Sankey 2007).

Equipment Selection and Installation: The development of a portfolio of ECMs should be aligned with the findings of the IGA (Hansen 2006). However, there is still the question of the feasibility of the specified ECM package, and concerns about whether they will perform as designed and what factors were included in considering predicted performance (Shonder and Hughes 2005; Mills et al. 2006; Shang et al.2008; Wang and Chen 2008; Jinrong and Enyi 2011). Energy service companies may encounter risks during selection if the customer assumes a greater role in this process or if bidding is required to procure ECM-related equipment and technology. There is also a risk of improper installation if the ESCO does not have a role during the construction phase, functioning as either a general contractor or a construction manager (Hansen 2006).

Commissioning: Commissioning is an important element of all energy efficient retrofit and high performance building projects; however, it is particularly important in an EPC, where system performance (or lack thereof) is a critical component to achieving the performance guarantee and release of the ESCO from financial liability. The lack of commissioning can result in missed opportunities to verify ECM performance that would otherwise lead to better overall project performance (Stum 2000; Sankey 2007). Commissioning can verify that installed equipment performs as specified, that calibration and maintenance procedures are well-understood, that proper operation procedures are understood, and that all required documentation is conveyed to the party responsible for operation and maintenance (O&M) (Hansen 2006). Completing this process with representatives of the owner's staff and ESCO project management staff is important in order to obtain agreement among all parties about future operating requirements and savings potential (Hansen 2006).

Operations and Maintenance Practices: Operations and maintenance may be undertaken by the ESCO, by the owner, or by a contractor to either party (Hansen 2006). Each arrangement carries different risks to each party – to alleviate this; the O&M plan must clearly define each party's responsibilities (AEPCA 2000). The most obvious risk to an ESCO related to O&M is that the customer may not perform this work to specification (Mills et al. 2006). Additional risks may be present if self-performing O&M activities is a part of an ESCO's financial consideration when evaluating whether to bid on work – if the customer decides to self-perform this work, or hire their own contractor, the ESCO misses this revenue opportunity (Hansen 2006). While this can be compensated for in other areas of the project, this may make the project less- or non-viable for the ESCO.

Measurement and Verification of Savings: Measurement and verification is important to ensure that systems perform as designed and yield savings in accordance with the performance guarantee (Hansen 2006). It is important that the ESCO and owner agree upon the M&V plan, as this project phase is typically the longest of all phases and the information collected during this stage establishes whether or not guaranteed performance levels are attained. A proper M&V plan that adequately measures system performance is necessary; however, a plan that collects unnecessary or unreliable data, that collects information that is not consistent with the ECM being evaluated, or is too costly to implement, can create opportunities for additional risk to the ESCO (Hansen 2006). A poorly-designed M&V sampling protocol may not accurately reflect the overall performance of the ECM package (Mills et al. 2006; Mozzo 2006; Shang et al. 2008).

Missing information from M&V plans can also create risks for ESCOs. Measurement and verification protocols that do not capture non-energy benefits of EPCs (e.g., deferred maintenance improvements) may understate overall system performance (Larsen et al. 2012a). Similarly, O&M savings have been shown to constitute a large portion of projected savings; however, O&M is often excluded from the M&V plan (Schweitzer et al. 2000).

Project Management over the Project Life-Cycle: The long-term nature of EPCs requires a life-cycle management approach to ensure that project objectives are met (Hansen 2006). While ESCOs should ensure that they take at least a portion of their fee from the guarantee to cover initial costs, taking some of their fee from a share of the excess savings may signal to a customer the ESCOs commitment to work with them throughout the entire performance period to ensure that systems continue to perform well and accrue excess savings (Hansen 2006).

Construction-Specific Concerns: Several construction issues have been identified in the literature that potentially add risk to an ESCO. While many of these concerns exist across a variety of construction projects, the structure of EPCs makes ESCOs particularly vulnerable to some of them. Schedule delays may shorten the project's performance period, particularly in the case of public projects with legislated maximum project durations. As a result, any delay in the project schedule may create the potential for unrecoverable costs by the ESCO (Silberman 2010). Cost overruns are a problem for all construction managers, but in an EPC, any additional cost borne by the ESCO will impact the financial analysis that their savings guarantee is predicated on (Smith and Ferber 1996; AEPCA 2000; Silberman 2010). Cost overruns may result from a number of factors – those identified in the literature regarding EPCs include schedule delays related to potential interference with customer operations (AEPCA 2000), unknown latent site conditions leading to delay (AEPCA 2000), and field changes that result in delays or poor system performance (Sankey 2007).

Volatility of Energy Prices: Volatility of energy prices is typically more of a customer risk issue because changing prices can potentially reduce the value of the project (Bertoldi and Rezessy 2005; Shonder and Hughes 2005; Mills et al. 2006; Shang et al. 2008; Wang and Chen 2008). Energy service companies should be aware of this issue, though, as customer sensitivity to this concern may lead to an objective to diversify fuel mixes used in a project to hedge against such long-term fluctuations (Berghorn 2012).

2.3.4 Risk Management Framework and Methods

The construction risk literature is replete with discussions of the risk management process. While individual terms and concepts vary slightly, particularly in terms of the number of steps involved with the process, there is broad agreement that risk management consists of three steps: (1) risk identification and classification, (2) risk analysis and evaluation, and (3) risk control and allocation/mitigation.

2.3.4.1 Risk Identification and Classification

In this step, all possible risk conditions are recognized and organized in such a way to permit further analysis during later steps. Risks may be identified using a variety of methods, including checklists, influence diagrams, interviews, use of expertise, cause and effect diagrams, failure mode and effect analysis (FMEA), hazard and operability study, fault trees, and event trees.

An important step of risk identification is termed risk classification. In the classification step, risks are structured in a logical way such that their individual and cumulative impacts on a project may be understood and represented. Several classification methods have been suggested in the literature including Perry and Hayes (1985), Cooper and Chapman (1987), Tah et al. (1993), Dey et al. (1994), Wirba et al. (1996), Tah and Carr (2000).

Perry and Hayes (1985) developed lengthy lists of project risk categories which were then attributed to contractors, consultants, and clients. Tah et al. (1993) developed a risk breakdown structure (RBS) to identify the sources of risk based on their project location and their origin in the larger project environment. Tah and Carr (2000) refined the RBS concept to that of “hierarchical risk breakdown structure” (HRBS). This method uses a multi-tiered approach to classify risks based on their overall type (internal or external), scope (global – affect entire project; local – affect individual work packages), risk center (open-ended list of project areas), risks (specific risks each belonging only to one risk center), and risk factors (specific factors affecting the likelihood and severity of a risk). Dey et al. (1994) classified risk by first creating a project work breakdown structure (WBS) and then analyzing risk separately for each “work package” identified in the WBS. Cooper and Chapman (1987) identified risks based on their source and magnitude, and then classified them as primary or secondary risks. This approach then allowed the examination of dependencies among risks, which may lead to better understanding of the potential sources of project failure (Wirba et al. 1996).

Wirba et al. (1996) developed a hybrid approach of Tah et al. (1993) and Cooper and Chapman (1987). The RBS approach of Tah et al. (1993) was used to provide a comprehensive classification of all project risks and the risks are then classified as primary and secondary based on Cooper and Chapman (1987). This classification then permits the identification of dependencies between risks and an estimate of their level of dependence.

2.3.4.2 Risk Analysis and Evaluation

Once risks have been identified, they must be analyzed based on their potential to influence the entire system under review, which may be the project as a whole, a particular project phase, or a specific project element (Ahmed et al. 2007; Arashpour and Arashpour 2012). Pai et al. (2003) suggested a framework for analyzing risk factors based on a three step process of vulnerability assessment, consequence analysis, and implementation. Risk evaluation then seeks to prioritize risk events in order to develop mitigation and allocation plans. These plans may be based on past experiences, accepted best practices, institutional knowledge, or standard practices (Ahmed et al. 2007).

Risk analysis techniques can include the construction of probability and impact grids, estimation of system reliability, fault tree analysis, event tree analysis, collaborative processes, FMEA, and sensitivity analysis. Risk evaluation techniques can include decision tree analysis, portfolio management of projects, FMEA, or multiple-criteria decision-making (Ahmed et al. 2007; Arashpour and Arashpour 2012).

2.3.4.3 Mitigation/Allocation

During risk mitigation and allocation, strategies are developed to address project risks, by either retaining the risk (mitigation) or transferring to another party (allocation) (Perera et al. 2009). Attempts to respond to risk events once they occur generally relies on utilizing contingency plans (Ahmed et al. 2007). Proactive risk mitigation seeks to implement actions based on the probability that a risk will occur, before it is actually realized. Risk mitigation and allocation have often been considered to be the weakest stage of the RM process (Banaitiene and Banaitis 2012). Risk mitigation/allocation has been classified into four categories: (1) risk retention, (2) risk reduction, (3) risk transfer, and (4) risk avoidance (Perera et al. 2009), and projects have been shown to utilize a combination of techniques based on project-specific factors.

2.3.5 Risk Identification, Analysis, and Evaluation Methods

Qualitative and quantitative analysis are distinguished in the risk management literature. During the identification stage, risk factors may be identified through quantitative methods or through qualitative processes. Qualitative methods typically assess the impact and likelihood of identified risks and can prioritize them for examination during the risk analysis and mitigation/allocation stage of risk management (Banaitiene and Banaitis 2012). Tah and Carr's (2001) HRBS and fuzzy set analysis are examples of qualitative risk assessment. Quantitative analysis is concerned with techniques to estimate the frequency and magnitude of risks, and makes use of tools such as decision tree analysis and Monte Carlo simulation. Studies such as Kindinger and Darby (2000) focused on development of a qualitative risk assessment method (risk factor analysis), but also demonstrated its integration with a quantitative analytical method.

A thorough inventory of analytical methods supporting risk management is provided by Grimaldi et al. (2012). These methods are presented in terms of their applicability to phases of a project life cycle as well as a corporate maturity toward risk, as follows:

- A novice level of maturity is focused solely on risk identification;
- A normalized maturity level adds qualitative risk analysis, sometimes risk response and monitoring and control; and
- A natural level of maturity undertakes the complete risk management process, to include quantitative analysis, and integrates the risk management into the project management process.

Forbes et al. (2008) also developed and tested a matrix of risk management techniques to be applied to various risk management phases and to evaluate specific risk categories (e.g., technical, social, legal) as well as the characteristics of the data about that risk category (fuzziness, incompleteness, randomness). They then applied the case-based reasoning approach to identify where specific techniques were used in similar risk management problems in an effort to help guide the selection of appropriate techniques. Forbes et al. (2008) also outlined a method to determine the applicability between two risk management methods in a specific problem context – that of a sustainability assessment of housing. Grimaldi et al. (2012) and Forbes et al. (2008) agree that it is important to select the appropriate methods based on the nature of the decision problem under analysis and that understanding of the individual methods is critical to the overall success of the analysis.

Grimaldi et al. (2012) classified 31 risk management techniques based on the following criteria:

- Risk management phase;
- Project life cycle phase (conceptualization [development], planning [design], and execution); and
- Level of corporate maturity with regard to risk management (novice, normalized, and natural).

The goal of the review in this section is to identify potential risk management techniques considering the characteristics of the problem that is the subject of this research – the risk of failing to meet the performance guarantee in EPC retrofits. Key criteria for selection of a risk management strategy for this research include:

- Qualitative techniques, based on the recommendation of McKim (1992);
- Applicability across the development and design phases (treated as two phases by Grimaldi et al. 2012), as this is where the majority of risk-based decisions are made in EPC projects, and when changes can have the greatest impact at the lowest incremental cost (Kmenta and Ishii 2001; Horsley et al. 2003; Kishk et al. 2003);
- Applicability to organizations in the first two stages of organizational maturity (novice and normalized) per Grimaldi et al. 2012;
- Techniques favoring the use of expert knowledge;
- Techniques enabling the incorporation of life cycle costs as part of risk evaluation (Research Premise #4 in Chapter 1); and
- Iterative, consensus-based techniques to address Raftery's (1994) observation that construction professionals could benefit from being made aware of their decision-making process.

Based on a review of Grimaldi et al. (2012), four risk management techniques that met one or more of the selection criteria presented above were subjected to further review (Figure 2-7). It is worth noting that the risk monitoring and control phase is absent from Figure 2-7; since the research focuses on activities that take place in early phases of EPC retrofits, this phase has less weight in the selection of appropriate risk management techniques.

As a result of Figure 2-7, expertise elicitation using the Delphi technique will be discussed relative to risk identification during project development and design, as well as to contribute to risk analysis/evaluation and risk response. Failure mode and effects analysis (FMEA)/failure

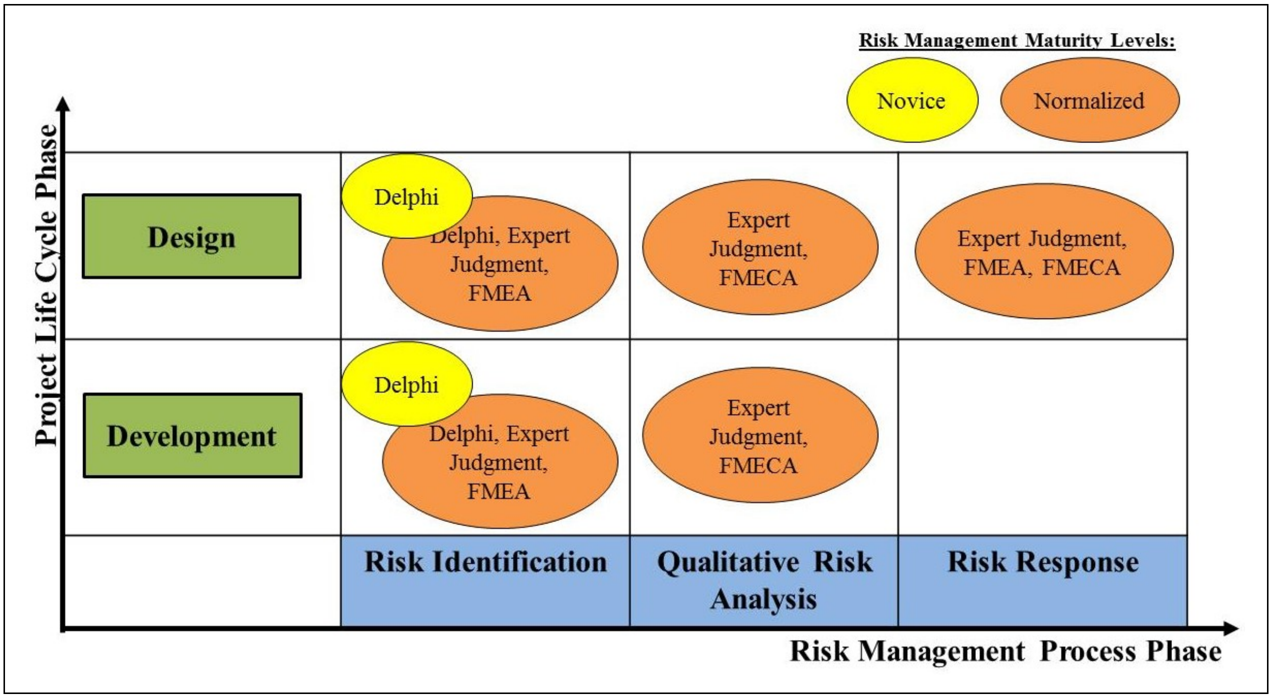


Figure 2-7. Evaluation of Selected Risk Management Strategies by Project Life Cycle Phase, Risk Management Phase, and Organizational Maturity Toward Risk
(Adapted from Grimaldi et al. 2012)

mode and effects criticality analysis (FMECA) will be reviewed as the primary tools for risk analysis and risk response because they are well-suited to all phases of the project life cycle (Onodera 1997). There is also a body of literature supporting the incorporation of life cycle costs into FMEA/ FMECA analysis as a measure of risk severity during the evaluation phase (Kmenta and Ishii 2000; Rhee and Ishii 2002; Marenjak et al. 2003; Rhee and Ishii 2003; Rhee and Spencer 2009; Chen and Zhang 2012; Liu et al. 2013). The next section includes a discussion of FMEA/FMECA; expertise elicitation and the Delphi technique are discussed in section 2.3.6.

2.3.5.1 Failure Mode and Effects Analysis

The goal of FMEA is to help engineers focus on high-risk components, typically during design; however, systems and processes can also be analyzed with this technique (Teng and Ho 1996;

Stamatis 2003; AIAG 2008; McDermott et al. 2009; Curkovic et al. 2013). The method employs an inductive logic process, whereby a team of analysts examine potential failures in a design or process in a bottom-up fashion, beginning with known or assumed failure modes at one level (e.g., individual component), and then investigate its effects on higher levels (e.g., system or operational subsystems). These methods assess the risk of failure of a system, process, design, or service proactively – that is before they occur (Stamatis 2003). This has the net effect of allowing these tools to inform the design process and permit improvement by identifying and correcting potential failure modes.

FMEA was developed in the 1960s for the aerospace industry and has since been used by the defense, nuclear, space exploration, automotive, software systems, healthcare, and construction industries (Bednarz and Marriott 1988; Dhillon 1992; Latino 2004; Liu et al. 2013; Rahimi et al. 2013). Built environment applications of FMEA/FMECA have included an assessment of barriers to innovation in construction (Murphy et al. 2011), broadly understanding the risks of moisture problems in buildings (Nielsen 2002), an analysis of the effects of interior insulation on moisture-related damage to masonry walls with wooden floor beam ends (Morelli and Svendsen 2012), risk of failure in building envelope systems (Layzell and Ledbetter 1998), and risk of life cycle environmental impacts of a given design (Lindahl 1999). Despite the goal of risk reduction, in its current form FMEA is unable to evaluate the cost of risks and the cost-benefit relationship of proposed mitigation measures.

Methodological Concerns – RPN: Despite the wide application of this method, FMEA has its own limitations, to include its complexity (Grimaldi et al. 2012), as well as criticism leveled at the primary measure of failure mode criticality, the risk priority number (RPN) (Bowles 2004; Gargama and Chaturvedi 2011; Liu et al. 2013). The RPN is constructed by assessing severity (S), occurrence (O), and detection (D) ranks for each failure mode, utilizing a scale of 1-10; the three measures are then multiplied to obtain the RPN, a score between 0 and 1,000 (Gargama and Chaturvedi 2011; Liu et al. 2013).

Primary criticisms of the RPN include the use of ordinal rankings (Imbeah and Guikema 2009), duplicate values of the RPN having very different characteristics (Kmenta and Ishii 2004), and a lack of linguistic terms regarding priority for managing critical failures identified through RPN values (Bowles 2004; Abdelgawad and Fayek 2010). Specific challenges also arise due to the somewhat arbitrary nature of S, O, and D scales and the way in which they are applied in the analysis.

Severity scores are only assigned to the end effects of a failure mode; the cause of the failure (the failure mode) is not scored, thereby making the end effects independent of the cause and any intermediate effects. Also at issue when conducting FMEA to asses built environment risks, each cause or groups of causes may need to be evaluated contextually, related to severity. Mecca and Masera (1999) illustrated that notion by creating different severity measures based on the risk factor to which they were connected.

Multiple definitions for detection have been proposed within the context of manufacturing, typically falling into one of three categories: (1) the ability to detect a potential cause before a component or system is released for production (AIAG 2008); (2) the likelihood that process controls will detect a root cause before the part leaves the manufacturing area (Stamatis 2003); and (3) the chance that the customer (end-user) will detect the problem before a catastrophic failure (Palady 1995). Kmenta and Ishii (2004) noted that this is problematic, as it is difficult to discern which of these definitions measures the contribution towards realized risk. Several authors have suggested eliminating the detection score from FMEA (Bowles 1998; Society of Automotive Engineers 2001; Bowles2004) because the ranking itself is very subjective, leading to a high degree of variation among detection scores. The traditional use of detection indicates the likelihood that a failure mode will be detected through subsequent testing, not at the point of occurrence; and detections occurring late in the product or process life cycle typically are typically not cost effective, yet the detection score may not change based on when detection happens. A method is needed that can accurately analyze and evaluate risks based on the project or process life cycle phase where they are realized.

Several methods have been proposed to address these shortcomings (Liu et al. 2013), to include tree analysis (Abdelgawad and Fayek 2012), risk probability and impact assessment, advanced programmatic risk analysis and management model (Imbeah and Guikema 2009), multi-criteria decision models (Franceschini and Galetto 2001), artificial intelligence/fuzzy analysis (Abdelgawad and Fayek 2010; Abdelgawad and Fayek 2012), Pareto analysis (Carbone and Tippett 2004), and cost-based models (Kmenta and Ishii 2000; Rhee and Ishii 2002; Rhee and Ishii 2003; von Ahsen 2008).

2.3.5.2 Scenario-Based FMEA (SFMEA)

Gilchrist (1993) was among the first to suggest an alternate means for calculating risk criticality, replacing the traditional RPN with expected cost, which was measured as cost multiplied by probability. Kmenta and Ishii (2004) identified an additional shortcoming of FMEA methods, including many of those that attempted to correct shortcomings of the RPN. A goal of FMEA is to include a large set of empirically-derived failures, to encourage deeper review of risks that might be ignored; however, many applications rely on mathematical functions or one-to-one relationships between a failure mode and its end effect (e.g., cause and effect). In order to represent multi-level cause-effect relationships, FMEA requires the use of multiple levels of analysis (e.g., effects at the system level may become causes at the design level). Rhee and Ishii (2002 and 2003) improved upon previous methods by incorporating life cycle cost into FMEA, but there was limited discussion of the link between failure representation and risk evaluation (Kmenta and Ishii 2004). Kmenta and Ishii (2000) introduced failure scenarios with expected cost and compared the results of FMEA and follow-on activities based on expected costs and RPN. Traditional FMEA and SFMEA are compared in Table 2-6.

Table 2-6. Comparison Between Traditional FMEA and Scenario FMEA

Method	**Strategy**	**Failure Probability**	**Cost of Failure**	**Product Cost**	**Total Cost**
Traditional FMEA	Increase reliability	Reduce	No change	Same or increase	Uncertain
Scenario-Based FMEA	Reduce total cost (failure cost and product cost)	Cost-based decision	Cost-base decision	Cost-base decision	Same or lower

(Source: Kmenta and Ishii 2004)

Since life cycle costs are an integral element of EPC retrofits, a FMEA method that can adequately address both issues is preferred for this research. Scenario FMEA (Kmenta and Ishii

2000; Kmenta and Ishii 2004) is therefore used as the primary risk analysis and evaluation tool for this research.

Failure Scenarios: Conventional FMEA is constructed around failure modes, which describe the cause of a failure and have associated effects. Failure modes may occur across various system levels, and the standard practice is to represent that through the use of "nested" FMEAs, where the effects at a lower level become causes at the next higher level, and so on. These separate analyses lack consistency in managing information across these various levels, thereby making a life cycle-based analysis very difficult (Kmenta and Ishii 2004). There is typically a one-to-one relationship between the causes and effects in a given failure mode, so a cause and effect chain is only represented by the cause and the end effect – intermediate effects are not evaluated explicitly.

Scenario-based FMEA allows the creation of many possible "failure scenarios," which are cause and effect chains that can be lengthened, as needed, if new effects and new causes are identified during analysis (Kmenta and Ishii 2000; Kmenta and Ishii 2004). Failure scenarios are found in the risk literature (Kaplan and Garrick 1981) and have recently been applied in construction and engineering research (Esmaeili and Hallowell 2013; Pallin 2013; Hamilton et al. 2014). This also permits description of the entire failure chain, to include intermediate effects (Figure 2-8).

Risk Evaluation Using Expected Cost: Risk was defined earlier in this section as the product of uncertainty (probability) and consequences (damages). Gilchrist (1983) and Kaplan and Garrick (1981) identified cost as an acceptable measure of consequences, so for each failure scenario,

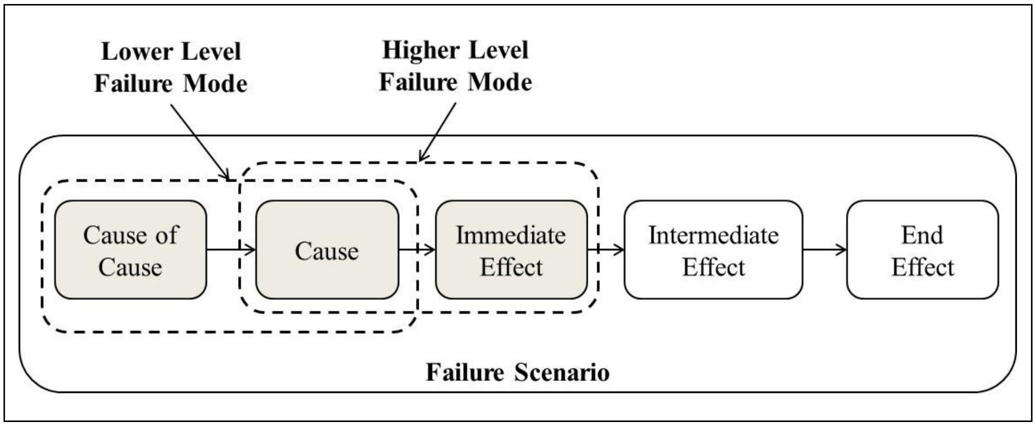


Figure 2-8. Comparison of Failure Modes and Failure Scenarios
(Source: Kmenta and Ishii 2004)

Kmenta and Ishii (2004) posited that risk can be calculated as expected cost (Rasmussen 1981; Kmenta and Ishii 2000).

The expected cost can be shown mathematically as:

Expected Cost (EC) = p_i x c_i where p_i is the probability of risk *i* and c_i is the cost of risk *i*.

A hypothetical example of failure scenarios throughout a product's life cycle is shown in Figure 2-9. There are eight possible cause-effect scenarios represented by combinations of causes being introduced into the system and downstream discoveries of those causes through an observed effect. As depicted in Figure 5-5, a failure cause may be discovered at various life cycle phases. The conditional probability of this failure scenario can be calculated using Bayes' theorem (Bolstad 2013) which states the probability of a given scenario can be found by multiplying the probability of the cause by the conditional probability of the end effect (i.e., the probability of discovering the failure at point d, point b, etc.). Figure 2-10 shows the expected cost equation for scenario a-d from Figure 2-9.

This also demonstrates the robustness of scenario FMEA throughout the project life cycle; traditional FMEA separates process, design, and system cause-effect relationships into separate FMEA sessions, and might miss lower level failure modes when aggregating up to the next level

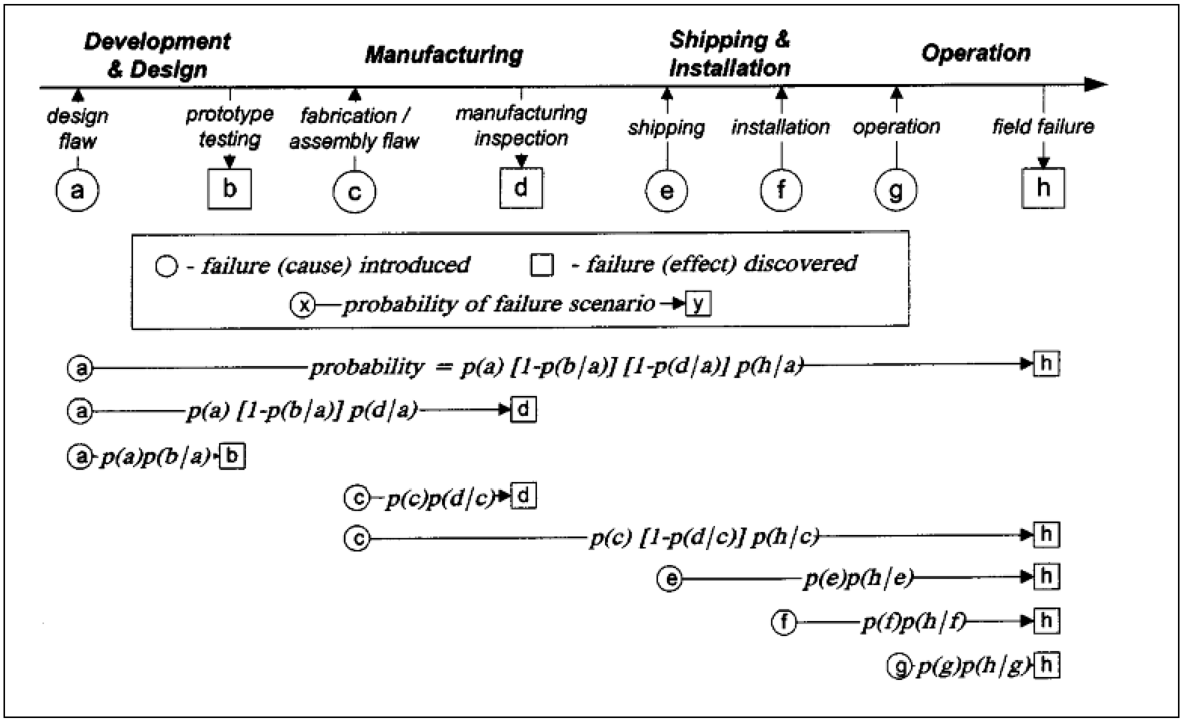


Figure 2-9. Example Failure Scenarios Over a Product Life Cycle
(Source: Kmenta and Ishii 2004)

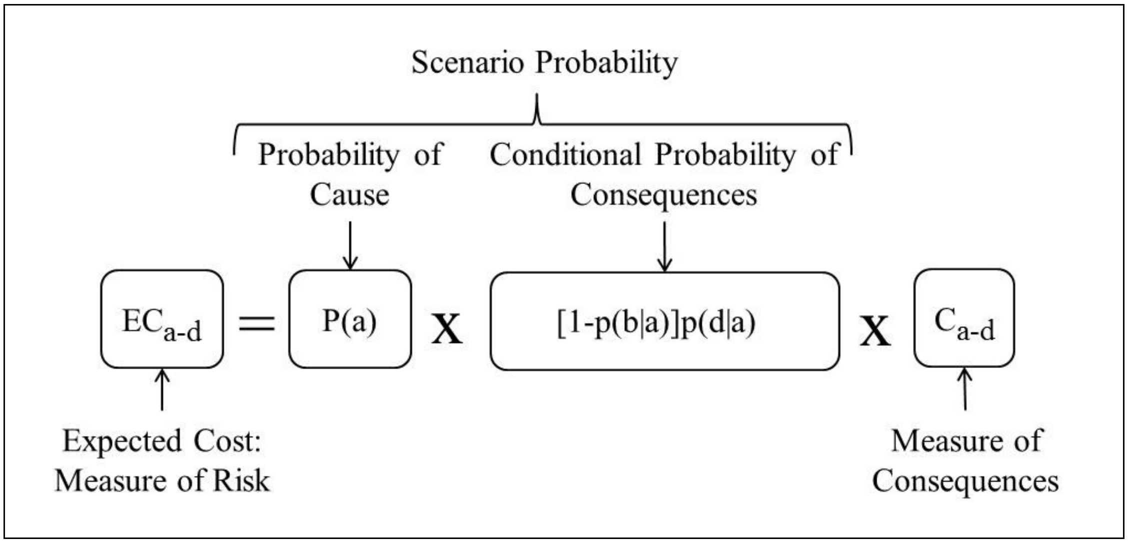


Figure 2-10. Expected Cost Components in Failure Scenarios
(Source: Kmenta and Ishii 2004)

FMEA. Scenario-based FMEA allows the same panel to examine multiple levels of causes and effects, using the same evaluative criteria and language to describe risks.

2.3.6 Expertise Elicitation and Delphi Technique

The following section provides a brief discussion about the need for expertise elicitation in qualitative risk assessment and describes several elicitation techniques found in the literature. The Delphi technique is explored in greater detail, in connection with the screening of risk management techniques in the previous section.

2.3.6.1 Elicitation in Qualitative Risk Assessment

Risk assessment consists of qualitative and quantitative methods that may be used separately or collectively as part of the analysis (Liu et al. 2010). Quantitative methods may not be able to effectively reduce uncertainty in all decision parameters due to limitations in knowledge. As a result, expert knowledge, experience, and judgment may be sought to represent a problem qualitatively, which ultimately requires the elicitation of this information from experts to be used in the analysis. The current literature on expert elicitation has focused on three broad topics: (1) methods of elicitation, (2) the role of heuristics and human cognitive processes on elicitation, and (3) methods of aggregating elicited information from multiple experts (Mosleh et al. 1988; Moon and Kang 1999; Engel and Dalton 2012).

Qualitative elicitation methods include focus groups that yield risk rankings and identification of decision alternatives, whereas quantitative methods can lead to the development of probability distributions of risk occurrence based on expert information. Numerous elicitation techniques have been researched for the impact of the framing of the elicitation technique on the type of expert behavior elicited, particularly as related to decisions made under risk (Ranasinghe and Russell 1993; Crosetto and Filippin 2013). A hybrid qualitative-quantitative method has been proposed by Engel and Dalton (2012).

Bonano et al. (1990) suggest that there are four fundamental cognitive processes that experts engage in when making judgments: (1) identification of decision alternatives, (2) screening of alternatives, (3) decomposition of the judgment task into smaller elements, and (4) quantification of comparative judgments about decision alternatives. These processes must be represented in an elicitation strategy in order to effectively capture the information desired from the experts. These cognitive processes intersect with psychological research related to heuristics and biases. Tversky and Kahneman (1974) operationalized a definition of heuristics as principles that help a decision-maker reduce complex decision variables into simpler judgments. They identified three widely-used heuristics: (1) representativeness, (2) availability, and (3) adjustment and anchoring, as well as judgmental biases corresponding with each.

Methods of expert judgment aggregation can be divided into mathematical and behavioral approaches (Engel and Dalton 2012). Mathematical approaches are typically undertaken when interaction between experts is not possible or not desired, and utilizes methods such as averaging(Keeney and von Winterfeldt 1991), Bayesian aggregation (Adams 2008), aggregation based on the analytic hierarchy process (AHP), and applications of fuzzy set theory (Moon and Kang 1999), which can incorporate variable weights assigned to each expert based on prior performance in training and calibration sessions (Engel and Dalton 2012). Behavioral approaches seek to build consensus among experts and can utilize the Delphi technique (Ranasinghe and Russell 1993; Schieg 2007).

The use of expert judgment has been shown to be effective in risk-based decisions related to engineered component failure analysis and seismic risk analysis (Mosleh et al. 1988). However, concerns have arisen over reliance on "rules of thumb" and common sense of experts, the lack of standardized frameworks for expert information aggregation, and a limited use of normative expertise in structuring elicitation exercises (Mosleh et al. 1988). Knowledge-based (De Zoysa and Russell 2003a; De Zoysa and Russell 2003b; Tserng et al. 2009), linguistic (Liu et al. 2010), and Delphi technique (Ranasinghe and Russell 1993; Schieg 2007) approaches have been suggested to combat these concerns.

2.3.6.2 Delphi Technique

Construction research is driven by the need to account for the actions of people engaged in the process of design, building, and operations, and as such, requires the careful application of social science research methods (Toole 2006). A suitable research design is needed to ensure that research questions can be answered appropriately (Keeney et al. 2011). Research designs used in construction engineering and management research may be categorized as being experimental or qualitative, theoretical or empirical (Toole 2006). Experimental-based research has been called the "gold standard," mainly due to its strength in assuring internal validity of results (Vogt 2005; Trochim 2006); however, it is likely not practical nor is it appropriate for the study of human-related factors in construction management research (Toole 2006). Two methods that have shown success for application to human-related factors in construction industry have been case study analysis and the use of surveys (Duah 2014).

Case study is a qualitative research technique whereby a researcher intensely studies an individual or a setting over time. This approach lacks a single methodological framework and instead frequently relies on multiple sources of data, such as semi-structured interviews, direct observation, or participant observation (Trochim 2006). Analysis includes a description of the cases and emergent themes derived through observation and data collection (Miles et al. 2014, Yin 2014). Survey research systematically elicits information from participants about the attribute(s) of interest to the researcher and may consist of a questionnaire or interview. Interviews offer the researcher greater flexibility than a traditional survey questionnaire and permit open-ended responses that enable the researcher to be more probative when needed (Trochim 2006).

The Delphi technique is a method of survey research that was developed by the RAND Corporation during the early days of the Cold War to study technological applications related to defense (Vogt 2005; Keeney et al. 2011). Delphi has received a great deal of recognition and use in a number of disciplines that focus on research involving human interactions and behaviors (Keeney et al. 2011) and has more recently been shown to offer a robust method for construction researchers (Rajendran and Gambatese 2009; Hallowell and Gambatese 2010). Delphi utilizes the judgments of qualified experts in a well-structured technique that permits the researcher to maintain control over participant biases (Hallowell and Gambatese 2010). Keeney et al. (2011) stated that the underlying principle of Delphi is the assumption that the group opinion is more valuable than individual opinions. Chapter 3 includes a discussion of notions of group opinion and its representativeness of consensus or merely “majority rule;” however, for the sake of this discussion, this premise has been accepted at its face value. Delphi utilizes an iterative, multi-round survey process to combine individual expert opinion into group consensus, and is particularly useful where there may be wide divergence among expert opinion and where it is not possible to convene such experts in a single meeting (Yousuf 2007).

Several **variations of Delphi** have been presented in the literature (Turoff 1970; Linstone and Turoff 1975; Mitroff and Turoff 1975; Rauch 1979; Keeney et al. 2011), to include the classical, modified, policy, and decision Delphi. Classical Delphi utilizes a relatively unstructured first round to facilitate idea generation and often uses three or more survey rounds. Modified Delphi usually replaces the first round with face-to-face interviews or focus groups (Keeney et al. 2011). In both cases, achieving consensus among the participants is the overarching goal.

While achieving consensus among participants is associated with traditional or modified Delphi, this reflects the so-called “Lockean Perspective,” whereas variations exist that do not seek such agreement and instead seek to address reality through alternate means (Mitroff and Turoff 1975). The policy Delphi (Turoff 1970) and the decision Delphi (Rauch 1979) are two such variations where the interpretation of reality and the creation of reality are the goal, respectively; however, the decision Delphi enables panelists to give structure to potentially broad lines of inquiry and aid the decision-making process through this newly constructed reality (Rauch 1979). The decision Delphi may be well-suited to fully understanding and evaluating risks, particularly in the context of decisions made over the life of complex processes.

Regardless of the method used, key elements of Delphi include contributions of expert knowledge by panel members; assessment of the group consensus and outlying opinions; an opportunity for individuals to revise their responses, as needed; and some degree of anonymity among individual responses (Linstone and Turoff 1975; Hsu and Sandford 2007). The iterative and anonymous inclusion of a large number of panelists is important in order to avoid dominance and Von Restorff biases (Hsu and Sandford 2007; Hallowell and Gambatese 2010; Keeney et al. 2011). Dominance bias is whereby one member of the group exercises control of group direction and feedback. Bias attributed to the Von Restorff effect is described as the condition whereby respondents recognize and remember more extreme events more accurately and more often than less extreme events (Hallowell and Gambatese 2010).

Delphi rounds could theoretically be iterated infinitely until consensus is reached; however, the research is clear that the return on investment in terms of robustness of findings versus the effort expended diminishes after the third round, therefore the decision of the appropriate number of rounds to use is a practical one, particularly in light of diminishing response rates when more rounds are used (Hsu and Sandford 2007; Hallowell and Gambatese 2010; Keeney et al. 2011; Duah 2014). Skulmoski et al. (2007) reported that fewer than three rounds may be adequate to attain research goals when there is a high degree of homogeneity among panelists. The goal of the first round is typically to provide scope to the research topic (Powell 2003), which then leads to construction of a survey instrument through qualitative analysis of the results for use in subsequent rounds (Powell 2003; Hsu and Sandford 2007). Alternative approaches to the first round include the use of a semi-structured questionnaire coupled with an extensive literature review, and pilot testing of questionnaires to help diagnose and treat problems with the questionnaire construction and its feasibility of administration (Powell 2003; Hsu and Sandford 2007).

The second and subsequent rounds seek to quantify earlier findings, often through rating or ranking techniques (Powell 2003) or seek to re-frame questions that have not achieved consensus (Hallowell and Gambatese 2010). In the latter case, it is suggested that panelists are provided with median response values along with the range of round one responses and their first round response, and then be given the chance to modify their response or respond to the re-framed question. The median is often used to de-emphasize biased responses and minimize contrast bias (Hallowell and Gambatese 2010). Hallowell and Gambatese (2010) suggested a method whereby medians are reported along with reasons for outlying responses in the third round, in a final attempt to achieve consensus] (Hallowell and Gambatese 2010).

Two typical ways to **measure the attainment of consensus** are the statistical approach and through the use of percentages. Statistics used are typically measures of central tendency (mean, median, and mode) and level of dispersion (standard deviation and inter-quartile range) (Hasson et al. 2000). Median and mode are favored through the use of a Likert-type scale, and as described above, can also help minimize contrast bias and further diminish previously-biased responses (Keeney et al. 2011). Response frequency criteria are assessed as having achieved consensus when a certain percentage of expert responses fall inside a prescribed range adopted prior to the commencement of data collection (Keeney et al. 2011). The lack of clearly-defined measures of consensus and adequate explanation of the threshold values used to attain consensus is a methodological weakness observed in a large number of Delphi studies (Evans 1997).

Keeney et al. (2011) found disagreement on a standard threshold value for percentage consensus, and cited varying thresholds identified in the research of 51%, 66%, 70%, 75%, and 80%. Thus, the researcher must exercise appropriate judgment to develop an appropriate threshold that is applicable to the domain and topic being studied.

A critical success factor of any Delphi study is the combined expertise of the panelists, which is defined by the size of the panel and the qualifications of each expert panelist (Powell 2003). There is a lack of guidance on the appropriate panel size to be used in Delphi (Keeney et al. 2006). While the reliability of the consensus achieved by the panel will increase with a larger number of participants, Murphy et al. (1998) reported there is little empirical data to support a connection between panel size and overall reliability and validity of the research, although a diverse panel may ensure better performance through the consideration of different perspectives. Skulmoski et al. (2007) stated that a panel of 10-15 experts may be sufficient when the group is homogenous. Hallowell and Gambatese (2010) found that panels of 8-12 highly qualified experts are adequate for effective results in construction and engineering management research.

The success of a Delphi study depends on the expertise of the participants comprising the panel (Powell 2003); however, the characteristics to determine expertise are ambiguous and defined on a project-specific basis (Hallowell and Gambatese 2010). Thus, there is a correlation between the quality of the research findings and the quality of the expert panel. Delphi panels are not statistical samples of a larger population (Hasson et al. 2000; Keeney et al. 2006; Duah 2014), and instead are constructed using purposive sampling techniques (Hasson et al. 2000; Oliver

2006; Tongco 2007) such as expert sampling, snowball sampling, and critical case sampling (Teddlie and Yu 2007).

The following panelist characteristics have been suggested to promote the successful use of Delphi (Duah 2014):

- Willing and able to make a valid contribution (Powell 2003);
- Reflect current domain knowledge, perceptions, and relatively impartial to findings (Jairath and Weinstein 1994);
- Highly trained and competent within their domain related to the issue being studied (Hsu and Sandford 2007);
- Panelists are nominated from among the targeted groups of experts (Ludwig 1994);
- Panelists are identified through literature searches and/or recommendations from other recognized domain experts (Gordon 1992); and
- Primary stakeholders with various interests related to the issue being studied (Hsu and Sandford 2007).

Reliability and Validity of Delphi: Reliability refers to the quality of the measurement employed in the research, and addresses the consistency and stability of research findings – in essence, whether the work is repeatable and yields similar results (Vogt 2005; Trochim 2006). Delphi enhances reliability through the avoidance of group biases and groupthink (Keeney et al. 2011). Unlike other research methods where bias can be introduced through the research, particularly by the interactions of subjects, Delphi depends on the unbiased judgment of experts (Hallowell and Gambatese 2010). Such biases are reduced, and reliability is enhanced, due to the anonymity of participants, which limits the ability for one or more respondents to dominate the process, and through iteration which enables respondents to reformulate answers from previous rounds.

Validity is built on a foundation of reliability, and refers to a method that accurately measures what it is supposed to measure and research designs that help collect data appropriate for the construct being studied (Vogt 2005). External validity is concerned with the generalizability of findings, and internal validity speaks to whether the research yielded a confident cause and effect relationship (e.g., is there another cause that can explain the observed effects?).

Validity can be measured as being content- or criterion-related (Keeney et al. 2011). Content validity is concerned with the ability of the research tool to sample the complete range of the attribute under study (DeVon et al. 2007). Evidence of content validity in Delphi is based on the following methodological characteristics (Keeney et al. 2011):

- Results are based on group opinion, which provides greater validity than individual opinions. The entire process is based on confirmative judgments from expert panelists.
- A less-structured, qualitative round allows experts to scale items and iteration allows for an opportunity to review and judge the suitability of that scale.

Criterion-related validity is established when a test can accurately predict criterion or indicators of a construct (Keeney et al. 2011). A number of studies have shown that Delphi helps achieve such validity through its iterative survey rounds, achieving consensus, and observed accuracy in long-range forecasting (Keeney et al. 2011). The authors also reported on a number of threats to external and internal validity.

Threats to external validity may arise due to the inability to generalize findings, since Delphi panels are ephemeral, and consist of experts who may not be representative of the larger population from which they are drawn (Keeney et al. 2011). Such threats may include:

- Selection -The makeup of the Delphi panel may lead to results that are not repeatable with other panels, and the inclusion of non-experts on the panel may yield different results from the experts;
- History - Outside events may influence expert's responses between Delphi rounds;
- Situation – The characteristics of the Delphi design, to include timing, number of rounds, feedback, and lack of agreement on thresholds for consensus can limit generalizability;
- Reactivity – There is little accountability for views expressed by panelists and since true anonymity cannot be guaranteed, some experts may be influenced by others;
- Natural loss - Participants may drop out or lose interest between successive Delphi rounds; and
- Researcher bias – The open qualitative round is designed to capture a broad range of ideas from experts, which is then reduced by the researcher based on content analysis.

2.4 LIFE CYCLE COST ANALYSIS

This category presents an overview of life cycle cost analysis (LCCA) and its applicability to the current research. Also discussed here are LCCA publications that incorporate risk and uncertainty into the analysis.

2.4.1 LCCA Overview

Life cycle cost analysis is a method for assessing alternatives by considering significant costs over the economic life of each alternative (Dell'Isola and Kirk 2003), and is particularly well-suited for fixed assets and other products (Woodward 1997; Asiedu and Gu 1998). Since its inception, it has enjoyed significant use in the construction industry. Korpi and Ala-Risku (2008) found that 62% of the 55 examined LCCA case studies were in the construction industry; another 18% came from the energy industry. Life cycle cost analysis enables an investor to make decisions based on the total costs and benefits accrued over the entire economic life of an investment. In the building industry this economic life includes:

- Initial costs for design and construction of buildings;
- Costs incurred during the operational life of the building; and
- End of life or demolition costs.

Harvey (1976 – cited in Woodward 1997) proposed a four step general life cycle cost model:

- The cost elements of interest are the cash flows that occur during the asset's life, which includes all costs from purchase through end of life disposal.
- Defining the cost structure involves grouping costs in order to identify potential tradeoffs. Identification of tradeoffs is an important concept toward developing an optimal life cycle cost. The groupings are defined in a manner that is appropriate to the system under review in order to facilitate this tradeoff analysis (Harvey 1976 - cited in Woodward 1997). Figure 2-11 depicts a three category cost grouping that might be relevant to the design of building retrofit measures.

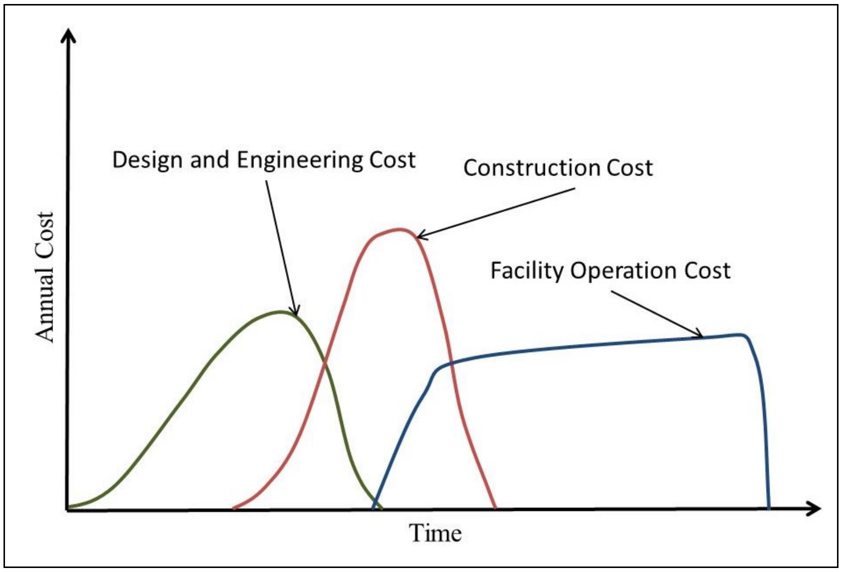


Figure 2-11. Example Life Cycle Cost Categorization
(Based on Woodward 1997)

- A cost estimating relationship mathematically describes the cost of the asset under review (e.g., product or activity) as a function of one or more independent variables, such as energy costs, running hours, and labor costs (Emblemsvag 2001). This information may come from historical costs databases or expertise (Korpi and Ala-Risku 2008), and utilizes defined relationships (e.g., linear, parabolic, hyperbolic) between the dependent and different independent variables.
- Establishing the method of life cycle cost formulation entails selecting an appropriate methodology to evaluate the life cycle cost of the asset under review. Examples of LCCA methods include those developed by Kaufman (1970 – cited by Woodward 1997), the cost-benefit analysis developed by Hanley and Spash (1994), and the requirements of the Federal Energy Management Program (FEMP) (NIST 1995).

The frameworks presented by Kaufman (1970 – cited in Woodward 1997), Hanley and Spash (1993), and the FEMP guidance (NIST 1995), while slightly different, require discounting of costs to the base period and calculation of the life cycle cost (Woodward 1997; Kishk et al. 2003). Present worth and annualized LCCA are most often used in design economic analysis, which seeks to find the most cost-effective design solution which meets project requirements (Dell'Isola and Kirk 2003). Investment economic analyses typically use payback period, return on investment, or savings to investment ratio to decide whether an investment is justified, and if so, to determine the most cost-effective course of action (Dell'Isola and Kirk 2003).

Cost-effectiveness analysis, also termed benefit-cost analysis (BCA), can be used whenever dollar value calculations of the benefits provided by the alternatives under review are either unnecessary or impractical (Dell'Isola and Kirk 2003). Similarly, BCA can be used to examine alternatives with identical costs but different benefits. This is possible because the BCA calculation allows separate calculation of life cycle costs and benefits while incorporating the discount rate, and inflation rate. This method also includes discounting future costs to their present value, and may be considered one of the methods for calculating net present value.

2.4.2 Applications of LCCA to the Built Environment

Recent literature focused on built environment sustainability and energy costs/savings is rich with cost-benefit evaluations; however, EPC-specific literature is again lacking. Larsen et al. (2012a) addressed this concept in the aggregate sense by reporting simple payback times for 15 years-worth of EPC retrofit projects. The simple payback time was defined as project installation costs (financing costs were excluded) divided by the dollar value of annual energy and O&M

savings. This method was selected for ease of reporting to a diverse audience and for consistency with previous research conducted by the same group at the Berkeley National Laboratory (e.g., Goldman et al. 2005). Additionally, other metrics of investment performance are only valid when there is no interim cash flow generated (e.g., internal rate of return), which is often not the case in EPC projects. When evaluating data from a sample of 2,484 projects, it was observed that K-12 schools had the longest median payback times for all retrofit strategies studied (7–15 years), while median payback times for public/institutional sector projects (excludes K-12 schools) was 7–10 years for onsite generation, non-energy, and major HVAC retrofits. The median payback time for lighting only retrofits was 3 years in ESCO projects targeting public sector customers. Additionally, public-sector projects had median BCA values of 1.1 (K-12 schools) up to 2.6 (health and hospitals). The authors posited that lower observed BCA ratios are likely the result of larger amounts of deferred maintenance work being financed through the EPC vehicle, thereby limiting the potential for energy savings to a smaller subset of work scope items. Within this context that EPC retrofits have demonstrated positive BCA values, several example LCCA papers in the built environment are described briefly below.

2.4.2.1 Indirect Benefits of Sustainable Building Retrofits

A variety of research has also been conducted in an attempt to quantify indirect benefits of sustainability-based retrofits and new green construction. Singh (2009) found BCA values of 3-8 for LEED-certified office buildings in Michigan, where the benefits were derived from increased worker health and productivity as a result of improved health and well-being. A 2003 study conducted for the Seattle Office of Sustainability and Environment (SBW 2003) quantified BCA ratio values for incorporating LEED in two state office buildings. Results showed BCA ratios of

0.78-1.1, 1.49-2.16, and 1.19-1.72 when considering only direct financial benefits, including indirect benefits, and considering community-wide benefits, respectively. The Rocky Mountain Institute was able to quantify worker productivity gains from eight different work-environment case studies with lighting upgrades (Romm and Browning 1994).

Larsen et al. (2012b) reported that approximately 40% of public sector projects reported the inclusion of non-energy benefits (NEBs) in their EPC projects, mostly generated by O&M savings. Birr and Singer (2008) analyzed the barriers to the use of NEBs in EPC retrofit projects. They suggested that blending the value of quantifiable NEBs into the project mix of longer and shorter payback measures would add value and be attractive to public customers. Survey participants identified data availability and management; however, O&M savings and avoided utility system costs were cited as regularly-included NEBs. Other areas for monetizing and including NEBs included the use of emissions reduction markets, avoided environmental compliance savings, and health and productivity benefits. While Birr and Singer (2008) reported that the latter category of NEBs might be the most difficult to quantify, Singh (2009) empirically demonstrated the relationship between green construction principles and these indirect benefits, and Berghorn and Vallad (2013) reported anecdotal evidence to support such claims after an EPC retrofit was performed in a correctional facility. Jennings and Skumatz (2006) found positive BCA ratio values as high as 3.1when considering NEBs from commissioning projects.

2.4.2.2 Example LCCA Applications

Chew et al. (2004) utilized a combination of quality parameters and LCCA to develop a framework for making building maintainability decisions. This framework was applied to decisions made during the design phase in an attempt to develop buildings that are more maintainable and cost effective. Frangopol and Liu (2007) demonstrated an approach whereby maintenance and management decisions for deteriorating infrastructure were made using an optimization method that considered structure condition, safety, and life cycle cost. Furuta et al. (2004) took a similar approach, examining service life as one of the decision factors for optimization.

Lee et al. (2013) took a different approach, using LCCA as an integral part of a simulation to set target building performance levels and allowable financing for construction costs. The simulation was suggested for use by borrowers and lenders during early phase decision making, and it reduced uncertainties related to project cost-related risk (level of investment needed for retrofit) and project performance risks (the level of performance achieved after retrofit to attain positive cash flow).

Consideration of Indirect Benefits: Lucuik and Meil (2004) examined the complete life cycle costs of various designs of commercial wall systems. They found that the total life cycle costs changed significantly when incorporating indirect costs, defined in this case as broader societal environmental impacts typically found in a life cycle analysis. Carter and Keeler (2008) were able to monetize and include tradable emissions values for nitrogen oxides (NOx) as part of an LCCA of green roof systems. Gu et al. (2007) developed an integrated environmental-economic LCCA method called the life cycle green costs assessment method that monetized environmental loads through the assumption of an emissions tax that could be incorporated into the initial and operating costs of the building.

2.4.3 Addressing Risk and Uncertainty in LCCA

Nearly half of the papers reviewed by Korpi and Ala-Risku (2008) were deterministic, meaning that they arrived at a life cycle cost value without considering uncertainty in the analysis. Kapp and Girmscheid (2005) articulated important sources of uncertainty in building projects owing to their relatively long life cycles (30-100 years), to include challenges in predicting exact future values of inflation and price increases and the useful lifetime of individual assets/investments.

Emblemsvag (2001) proposed an activity-based LCCA framework. This method emphasized the modeling of uncertainty using Monte Carlo simulation, which facilitated the identification of critical success factors, and in this case contributed to long term profitability. Kirkham et al. (2002) developed probability density functions from a data set of over 450 hospitals across the United Kingdom in order to accurately model the relationship between physical characteristics of these buildings and their facility management costs.

Zhu et al. (2012) used a probabilistic LCCA method to compare building mechanical system options. They examined the feasibility of installing a ground source heat pump versus a single zone split system that used heat pumps. The probabilistic LCCA was facilitated through the use of Monte Carlo simulation, and utilized directly collected data as well as data from the literature and published performance data. By comparing deterministic and probabilistic methods of conducting the LCCA, the authors found that the latter method yielded more reliable conclusions and provided more critical information to the decision maker. Garber et al. (2013) also employed Monte Carlo simulation to provide a risk-based assessment of a ground source heat pump compared to four other potential HVAC systems. They employed an energy simulation platform called TRNSYS to parameterize key input values for components of the system under review. Brink (2012) analyzed upgrade options for a municipal water system and divided input data into three types: (1) cost inputs (dollars), (2) schedule inputs (years), and (3) cost drivers (value). Minimum, most likely, and maximum values for each of the 20 inputs were used to construct Monte Carlo distributions. The analysis revealed different results using a deterministic LCCA model, thereby supporting the need to more broadly implement probabilistic models to obtain more accurate results.

2.5 CHAPTER SUMMARY

This chapter identified and reviewed literature related to three broad categories of energy performance contracting, risk in construction engineering and management, and life cycle cost analysis. The first category gave an overview of the EPC method, its history and current use, and information categories used when developing EPC retrofit projects. The second category examined the nature of risk and concepts of decision making under conditions of uncertainty and risk. That was followed by an overview of risk in construction and EPC, a discussion of the risk management process and various risk evaluation methods, and finally an overview of expertise elicitation and use of the Delphi technique. The third section reviewed basic concepts of LCCA and examined its application in the built environment and how concepts of risk and uncertainty are addressed methodologically.

CHAPTER 3

RESEARCH METHODS AND DATA COLLECTION

3.1 CHAPTER OVERVIEW

This chapter presents a discussion of the research methods used in this study. This research includes four objectives, as described in section 1.3. The conduct of the research and connection to project objectives is presented in this chapter and was previously depicted in Figure 1-5.

Objective 1 steps include a preliminary ESCO expert interview as well as a literature and document review which summarizes the EPC process; the use of EPC in the MUSH market, specifically correctional facility retrofit projects; risk identification, classification, analysis, and mitigation in EPC retrofits; LCCA methods and sources of uncertainty and risk in LCCA; and analytical methods for LCCA and risk management. Collectively, this information was used to construct a preliminary ESCO risk framework and identify a proposed risk management method to be used in this research; this literature review and preliminary risk framework are presented in Chapter 2.

Work steps in Objective 2 add to what is learned from the preliminary interview and the literature and document review by eliciting expertise from ESCO professionals about sources of project-level risk to contractors related to non-attainment of the performance guarantee in EPC retrofit projects, including an assessment of the most critical risk categories. This data was used to construct an EPC retrofit process model and refine the preliminary risk framework from Objective 1.

Objective 3 work steps are primarily concerned with thoroughly evaluating and analyzing the most important risk categories, as identified in Objective 2. A cost-based risk analysis and evaluation approach will be used to assess risk criticality based on its economic impact throughout the project life cycle. This in turn leads to the development of a framework for a life cycle cost-based risk model, which is parameterized in the final work step of Objective 3.

Pilot application of the life cycle cost-based risk model and its refinement is the focus of Objective 4. Primary activities directed toward this final research objective include the evaluation of a correctional facility EPC case study using the risk model.

3.2 OBJECTIVE 1 – ENERGY PERFORMANCE CONTRACT RETROFIT PROCESS

The purpose of the work conducted in Objective 1 was to construct greater understanding of the EPC retrofit process and to gain insight into the types of risks faced by ESCOs when performing such projects. The work in this objective was initiated through a comprehensive review of the literature which provided the necessary theoretical and current state-of-knowledge underpinnings for the dissertation. Three categories of literature were reviewed to provide appropriate context for the research: (1) energy performance contracting, (2) construction and EPC risk, and (3) life cycle cost analysis. The work related to Objective 1 and its relation to other objectives is depicted in Figure 3-1.

The EPC literature was reviewed primarily within the context of MUSH market projects, to understand its various contractual forms, its history and current use in the MUSH market, and the types of information needed during planning and design phases. The risk literature was reviewed

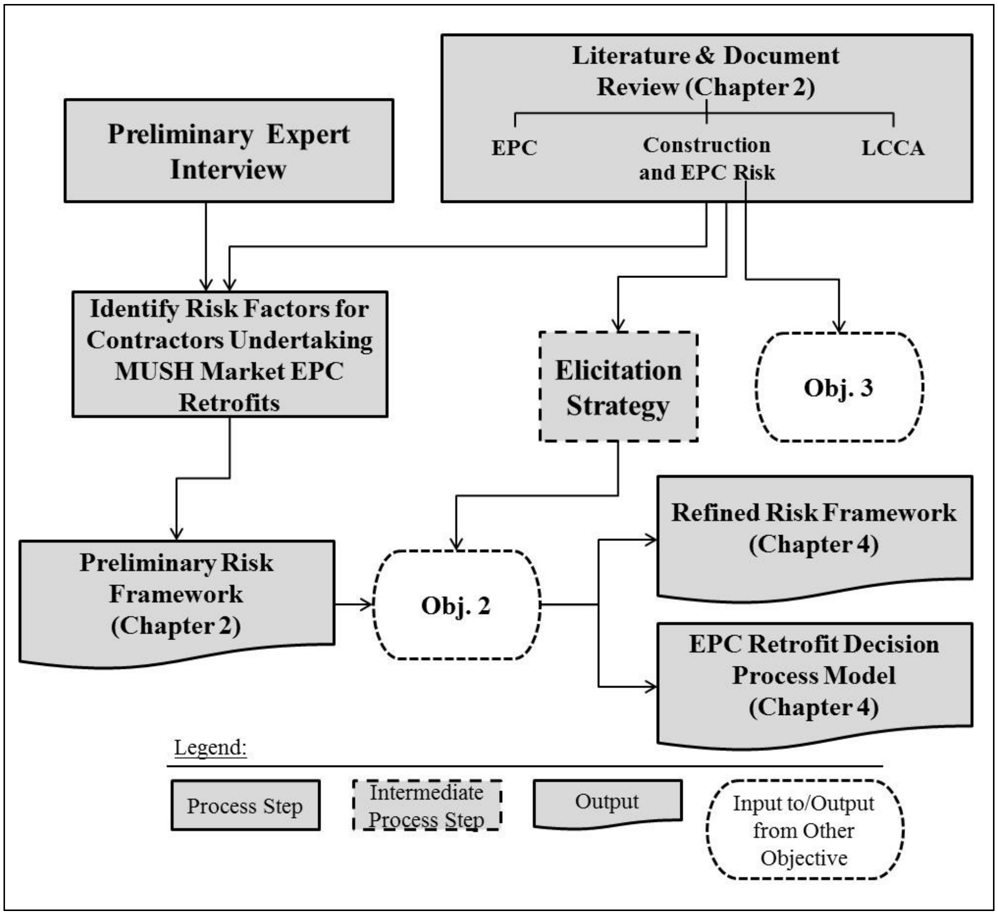


Figure 3-1. Objective 1 Methods and Outputs

to understand general concepts of decision making under uncertainty and risk, frameworks for the assessment and management of project- and technical-based risks, applications of these frameworks to construction and building projects methods of risk evaluation tailored to the research undertaken in this thesis, and a discussion of methods used for the elicitation of expertise in a risk management process. The LCCA literature was reviewed to understand how concepts related to life cycle costing are applied in the built environment and how uncertainty and risk are addressed in this analysis. The first two focus areas from the literature review were used to develop the expertise elicitation strategy in Objective 2 and the risk analysis and evaluation strategy in Objective 3. The latter area was used to inform the parameterization of the risk framework in Objective 3 and model application in Objective 4.

The primary deliverable of the work conducted in Objective 1 was the development of a preliminary ESCO risk framework for MUSH building EPC retrofits, presented in Chapter 2. This framework was developed through the review of the two literature categories identified above, along with an interview with an EPC professional with over 30 years of experience. The preliminary framework was focused on identifying broad categories of relevant risks, termed risk categories, with example risks and causes belonging to each category. This deliverable served as an input to the work undertaken in Objective 2, which refined the framework through elicited expertise from a panel of ESCO professionals with regard to comprehensive risk identification, risk importance, risk causes, and mitigation activities.

3.3 OBJECTIVE 2 – RISK FRAMEWORK FOR MUSH MARKET EPC PROJECTS

Objective 2 consists of two sub-objectives: (1) Objective 2a is focused on development of an expertise elicitation strategy and (2) Objective 2b addresses data collection and analysis of elicited expertise, as it relates to refinement of the risk framework first developed in Objective 1 and development of an EPC retrofit process model. In the context of the risk management process described in Chapter 2, data collected in Objective 2 is used to complete the risk identification step.

3.3.1 Objective 2a – Energy Performance Contract Expertise Elicitation

The central data collection activity of this research is the elicitation of expertise from ESCO practitioners who have had significant roles in developing, designing, and executing EPC retrofits in the MUSH market. This section discusses the development of a research approach that maximizes the ability to collect and analyze qualitative data in the form of expert knowledge and judgments, which are framed by individual attitudes and approaches to risk. A strategy for eliciting this expertise is presented in this section, along with a discussion of considerations made when constructing the sample population for this study.

3.3.1.1 Application of the Delphi Technique to Construction Engineering and Management

This research is premised largely on qualitative information. As discussed in chapters 1 and 2, EPC retrofit projects rely significantly on expert judgment and implicit knowledge to make decisions under conditions of uncertainty and risk. Furthermore, as discussed in section 2.3.2, such expertise-based decision making is subject to cognitive biases. As a result, a research method is needed that can capture the judgment of experts and resolve any apparent differences among expert opinions. The Delphi technique has been proposed as a useful research method for construction engineering and management research that addresses limitations inherent in existing experimental techniques due to the complexity of the domain and the presence of biases among research subjects (Hallowell and Gambatese 2010). This method has been found to be particularly applicable when source agreement is desired through a refereed process to collect, aggregate, and organize expertise from potentially unique or divergent information sources (Pill 1971; Powell 2003; Yousuf 2007). Furthermore, Yousuf (2007) stated that an advantage of the method is its ability to collect such data when time, distance, and other logistical factors make it difficult for such an expert panel to be convened in a single in-person event.

As described in Chapter 2, The Delphi technique is a group process that is facilitated by the researcher in order to elicit knowledge from a qualified panel of experts to reliably structure the group’s communication (Linstone and Turoff 1975). Experts participate in multiple rounds of questionnaires until a pre-determined measure of consensus is reached. While achieving consensus among participants has typically been associated as an overarching goal of Delphi, methodological variations exist that instead seek to create alternatives or address “wickedly unstructured problems” through the presence of conflict among panelists (Mitroff and Turoff 1975). The policy Delphi seeks to generate strongly opposing views regarding potential resolutions to a policy issue (Turoff 1970; Turoff 1975). The decision Delphi seeks to create the future reality, rather than predict that future condition, which is typically the focus of the reliance on building consensus in traditional Delphi (Rauch 1979). The decision Delphi then aids the decision-making process through analysis of the newly constructed reality that was created by panelists, comprised of decision-makers from the domain being studied (Rauch 1979).

Since the goal of this study is to fully explore and construct an understanding of risks present in the EPC retrofit process and to evaluate those risks as they relate to retrofit decisions made throughout the project development and execution process, a hybrid Delphi technique is used for this study, combining the traditional and decision Delphi methods. As a result, panelists must be recruited from among domain experts who occupy positions of decision-making authority within their organizations. Regardless of the method used, the use of Delphi contributes to a robust qualitative approach through the following methodological aspects:

- Accuracy – obtained through knowledge elicited from a properly constructed panel of experts (Hallowell and Gambatese 2010);
- Precision – obtained through consensus (traditional Delphi), iterative rounds of feedback (traditional Delphi and decision Delphi), and knowledge construction (decision Delphi) (Rauch 1979; Hallowell and Gambatese 2007);

- Minimize bias – assured through anonymity (Hallowell and Gambatese 2010), although quasi-anonymity (participants were known but individual responses were anonymous) was shown to improve response rates due to panelists wishing to provide input to minimize the chance that their competitors would have undue influence (Rauch 1979). This study only identified participants by company name (when such a release was consented to) or by description (e.g., N nationwide independent ESCOs have participated, N nationwide equipment manufacturer ESCOs have participated); and
- Account for judgment – Delphi enables researchers to study questions which do not lend themselves to traditional statistical analysis due to the nature of the question, lack of objective data, or lack of agreement among professionals (Hallowell and Gambatese 2010).

Participant selection is critical, as the success of a Delphi study depends largely on the expertise of the participants comprising the panel (Powell 2003). Hasson et al. (2000) suggested that selection of participants requires a balance between finding those with interest in the subject (so that they remain engaged throughout the Delphi study), which may lead to bias, and those with current domain knowledge who are impartial to the outcome so as to provide unbiased information. Diversity among the panel members may bring different perspectives to the study and enable a wider range of alternatives (Murphy et al. 1998); however, this effect may be minimized in large panels that are overly heterogeneous. Keeney et al. (2006) reported a lack of guidance on the appropriate panel size, with reviewed studies ranging from hundreds to thousands of participants. Murphy et al. (1998) advocated for larger panels despite their own assertion that there is little empirical data to support a connection between panel size and reliability or validity of the research. Hasson et al. (2000) identified panel sizes in the literature of between 15 and 60 participants, and cautioned that larger panels lead to the generation of additional data, which can cause problems during analysis. Hallowell and Gambatese (2010) provided guidance on the selection of panel members relative to Delphi studies in the construction engineering and management domain. Their research recommended panels consisting of 8-12 participants so long as the panel is diverse and members are highly-qualified within their domain.

Regardless of panel size, the literature is clear that Delphi panels are not statistical samples of a larger population and thus should not be treated as such (Hasson et al. 2000; Keeney et al. 2006; Duah 2014). The Delphi panel may be constructed using criteria sampling or purposive sampling techniques (Hasson et al. 2000). Purposive sampling is defined as a non-probability sampling technique where the researcher exerts influence on the selection of the sample based on participants' expert knowledge of the domain being researched or their willingness to participate (Oliver 2006; Tongco 2007); this definition is particularly applicable to Delphi research.

The identification and selection of panelists for inclusion in this research utilized three purposive sampling methods identified by Teddlie and Yu (2007): (1) expert sampling, (2) snowball sampling, and (3) critical case sampling. Identification and selection of panelists was based on the guidelines presented by Hallowell and Gambatese (2010) for construction engineering and management and Duah (2014) for energy efficient retrofit. In considering these existing guidelines, several selection criteria were difficult to align with the overall scheme of EPC retrofits, due to the lack of literature focused on this domain as compared to construction engineering and management in general. Additionally, Duah's (2014) expertise framework focused specifically on residential energy retrofits, a related but separate domain from EPC retrofits in commercial buildings. Given these variations, this research defines analogous relationships among selection criteria and EPC retrofits, as needed. For example, Duah (2014) requires 10 residential retrofits per year to define expertise; one MUSH market retrofit project can have a longer project life cycle than 10 residential retrofits. Based on the foregoing, expert selection guidelines used in this research are provided in Table 3-1.

Table 3-1. Guidelines for Expert Selection

Identification and Recruitment (based on Hallowell and Gambatese 2010)

- Member of the National Association of Energy Service Companies (NAESCO)
- Employed by a NAESCO-accredited company
- Member of American Correctional Association (ACA) Clean and Green Committee
- Member of the Construction and Maintenance Institute for Criminal Justice Agencies (CMI)
- Past presenter at ACA or CMI conferences or the Green Prisons Annual National Symposium on Sustainability in Corrections – topics focused on EPC retrofits
- Previous participant in similar expert-based studies

Expert Qualifications (at least five out of nine qualifications must be met)

- 8 years EPC experience with no break in industry work during that time (Duah 2014)
- Work on at least 8 previous EPC projects in a professional (design, engineering, or construction) capacity (based on Duah 2014)
- Average project impacted at least three building systems (e.g., lighting, central plant decoupling, envelope) (based on Duah 2014)
- Active role in seeking financing and financial incentives (based on Duah 2014)
- Professional registration - CEM, CxA, PE, or AIA (based on Hallowell and Gambatese 2010)
- Advanced degree in engineering or a related field to building construction, operations, design, or energy (at least BS) (based on Hallowell and Gambatese 2010)
- Faculty member in an energy engineering or management program at an accredited college or university (based on Hallowell and Gambatese 2010)
- Two peer-reviewed publications or one book/book chapter related to EPC (based on Hallowell and Gambatese 2010)
- Invited conference presenter (based on Hallowell and Gambatese 2010)

Based on Duah's (2014) attribute weighting and Hallowell and Gambatese's (2010) flexible scoring system, the expertise scoring rubric in Table 3-2 was developed in order to provide a relative measure of expertise among the panelists. The rubric is connected to the expert selection

Table 3-2. Scoring Rubric for Expert Determination	
Experience	**Points**
At least 8 years professional EPC experience	1
At least 8 previous EPC projects	1
At least 75% of EPC project experience is in the MUSH market	1.5
At least three building systems impacted per project, on average	0.5
Role in financing and financial incentives per project	0.5
Professional registration	2
Advanced degree in a related field (BS or higher)	2
Faculty member	1
Peer-reviewed publications	1
Invited conference presenter	0.5

guidelines in Table 3-1, and emphasizes professional experience in the EPC process, particularly in MUSH market projects, involvement in building systems and financing/incentive aspects of projects, professional registration, and advanced education in a related field. While a threshold value of points was not used, as was the case with expert qualification categories, a goal was established that panelists would have a score of at least 4.5 points out of the 8.5 points available for professional experience, registration, and education.

Reaching consensus among panelists is an important part of traditional Delphi, and is important for several of the questions posed to participants in this study. The literature includes several measures of consensus and many threshold values to establish the point at which consensus has been reached. This study utilized a two-round Delphi questionnaire to investigate consensus- and non-consensus- (e.g., knowledge construction) driven aspects of ESCO risks in the EPC retrofit process. The first Delphi round was preceded by the development of the preliminary risk framework, which was the result of a literature review, an open-ended interview with a domain expert, and a semi-structured interview with a test panelist possessing over 30 years of experience in correctional facility energy retrofits. The test panelist interview was used to finalize development of the questionnaire for the Delphi panel; the final version of the instrument was re-administered to the test panelist concurrently with administration with the rest of the panelists. A second round of the Delphi questionnaire was employed for questions where consensus was not reached in round one.

A variety of statistical parameters are commonly used in Delphi studies to indicate when consensus has been reached, and include percent agreement, mean, median, standard deviation, and/or mode (Hasson et al. 2000; Hsu and Sanford 2007; Hallowell and Gambatese 2010). This study uses percentage of agreement among panelists which is a commonly reported parameter. A predetermined percentage agreement of 70% or more was used as an indicator of consensus (Duah 2014).

The questionnaire also included the ability to detect the difference between participants achieving consensus and achieving agreement. Evans (1997) questioned the working definition of consensus based on the review of 30 consensus-based expert panels in pharmacoeconomics research. The research revealed three uses of the term: (1) views that are “acceptable” to all panelists, (2) the same view that is held by all panelists, and (3) the majority view. Keeney et al. (2006) explained that most studies opt to measure the extent to which participants reach agreement with one another, fundamentally ignoring whether the “correct” answer has been found or whether true consensus has been reached. To address this concern, several items in the questionnaire elicited expertise with regard to elements of the preliminary risk framework. This enabled the researcher to capture panelists’ reactions to information obtained through the literature review and the preliminary expert interview and provided them the ability to add other risk-related information, as necessary. This approach deemphasized the need for panelists to merely agree with one another, and instead sought triangulation among multiple data sources represented in the preliminary risk framework and provided participants with the opportunity to contribute their expertise to the construction of reality represented by the decision Delphi questions.

3.3.1.2 Elicitation Strategy

Duah (2014) provided a complete review of knowledge elicitation techniques to address problems related to: (1) eliciting tacit or intuitive knowledge from experts, (2) eliciting knowledge from experts that may be unavailable due to their difficulty in articulating this knowledge, and (3) having a knowledge elicitor with limited domain knowledge. This research generally follows the framework for elicitation described by Duah (2014). The elicitation strategy for this research consisted of two elements: (1) knowledge elicitor training and (2) the selection and use of appropriate elicitation techniques.

Knowledge elicitor training was used to help achieve a principal goal in the elicitation process, to help experts articulate their knowledge which is often unstructured and tacit, in order to document expert knowledge in a usable format (Duah 2014). The training of the knowledge elicitor included a review of existing research and industry-specific literature as well as interactions with members of the ESCO industry beyond just the administration of the Delphi questionnaire. The first part of this training, the literature review, was presented in Chapter 2 and included information about the energy performance contracting industry, sources of contractor's risk in construction engineering and management, and cost-based approaches to assessing risk. Industry interactions included appointment of the researcher to a national sustainability in corrections research committee, work with the Clean and Green Committee of the American Correctional Association, presentation of an EPC industry workshop at the 2nd National Symposium on Sustainability in Corrections, and participation in an EPC industry panel presentation during the American Correctional Association 2014 Winter meeting. All interactions have focused on the use of EPC retrofits and have involved work with facility management professionals and ESCO staff in business development, engineering, construction, and project management functions.

Since the **selection of knowledge elicitation techniques** depends on characteristics of the domain and the experts under study, this research followed the framework for selection of elicitation techniques provided by Duah (2014) given the similarity between domains – energy efficiency retrofits – while making appropriate changes to reflect the differences between residential retrofits and MUSH market EPC retrofits. Based on Duah's (2014) framework for selection of elicitation techniques, semi-structured interviews, job shadowing, and the Delphi technique have been selected for this research.

Semi-structured interviews were used to collect data from the Delphi panel, which was preceded by the preliminary EPC expert interview and the test panelist interview. These were conducted as open-ended interviews in order to better explore key concepts related to the research objectives. The test panelist interview was also used to clarify information gaps remaining after the literature review and to test the structure of the questionnaire which would be administered to the complete Delphi panel. The final semi-structured questionnaire was developed based on refinements to the previous open-ended documents, and focused less on capturing basic domain knowledge (e.g., questions such as, “please describe the phases of an EPC retrofit project” were rejected) and instead focused on tacit knowledge, non-linear information, and probative questioning, such as questioning about controls used to manage risks identified as most important under various project conditions. The preliminary and finalized questionnaires are provided in Appendix A.1 and Appendix A.2, respectively.

Job shadowing of experienced ESCO and correctional industry facility energy management professionals was undertaken in order to gain fundamental knowledge about the early phases of the EPC retrofit process in MUSH market buildings,. The objective was to observe their early interactions when the investment grade audit (IGA) was being conceptualized, developed, and finalized, in order to gain insights about how the retrofit decision process occurs and the types of information used, as well as to gain experience with the risk-based decisions made by ESCOs during the earliest phases of EPC projects. This participation also enabled the researcher to become familiar with the language used by ESCOs in order to facilitate better communication with panelists during the Delphi rounds. This was also critical during data compilation and analysis in order to establish the basis for identifying emerging themes. The researcher was invited to observe these otherwise closed meetings. So as not to interrupt the meeting and ESCO-client interactions with questions, requests for further information or clarification were made after the conclusion of each meeting and through follow-up emails and meetings with the ESCO team members.

The **Delphi technique** is especially useful for unstructured and semi-structured problems which rely less on inferential statistics and more on the knowledge of domain experts (Pill 1971; Powell 2003). The ability to build consensus among experts using a refereed communication process for areas of disagreement or to construct knowledge in complex decision scenarios are hallmarks of the Delphi technique that make it particularly useful for this research, as is the knowledge construction aspect of the decision Delphi (Linstone and Turoff 1975; Rauch 1979). Since this research is focused largely on development, audit, and design phase activities (e.g., procurement, IGA completion, and retrofit design) based on input gathered from experts with moderate and high levels of experience, the technique is well-suited to this project.

As shown in this section, a combination of elicitation techniques was employed for this research, which placed an emphasis on knowledge elicitor training and used a hybrid of the traditional and decision Delphi techniques as the dominant elicitation method (Figure 3-2). This figure also depicts the activities conducted in Objective 2.

3.3.2 Objective 2b – Data Collection and Analysis - Refined Risk Framework

Data was collected following the EPC risk expertise elicitation model depicted in Figure 3-2. Based on Hallowell and Gambatese's (2010) review of Delphi studies in construction engineering and management, this project sought to impanel between 12 and 20 domain experts over two rounds. A third round was considered, if needed, to deeply explore the reasons for outlying responses if any exist after round 2; however, the research points to diminishing returns in achieving consensus after the third round (Hallowell and Gambatese 2010).

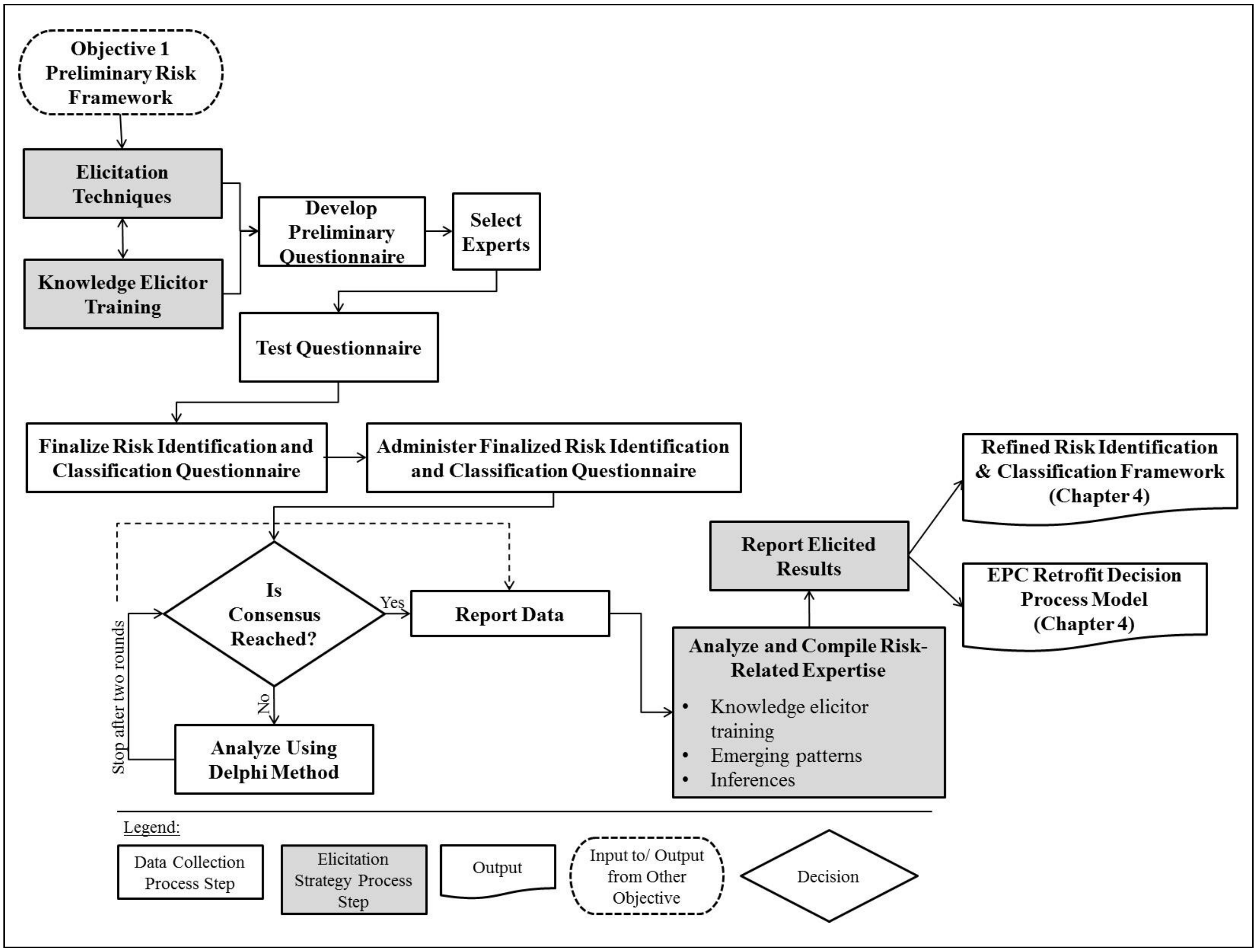


Figure 3-2. EPC Risk Expertise Elicitation Process Model and Objective 2 Methods and Outputs

3.3.2.1 Data Collection

Participants whose expertise about EPC retrofit project risks was to be elicited were selected based on the qualification rubric described in section 3.3.1. The characteristics of the panel and determinants of expertise for each participant are provided in Appendix B. In total, 19 participants were included in the Delphi panel – ten represented independent ESCOs, seven represented equipment manufacturer-based ESCOs, and two represented utilities. This distribution approximates the nationwide share of ESCO ownership, and was an important part of the purposive sampling strategy employed by this study.

The expert questionnaire was divided into four parts: Part I - Risk Tolerance; Part II – Professional Experience and Determination of Expertise; Part III – Risk Management Process, and Part IV – Life Cycle Cost Analysis. Part I questions used the TIAA-CREF Asset Allocation Evaluator (AAE) to assess each panelist's attitudes toward risk by using the analog of allocating assets in a financial portfolio (TIAA-CREF 2013). Out of 31 total questions, six were for Part I, 11 were for Part II, ten were for Part III, and four were for Part IV. Data collected in Part IV of the questionnaire was not included in this research; rather, the intent of these questions was to explore possible future research related to concepts of life cycle costing in considering non-energy benefits (NEBs) and potentially non-recoverable project costs. As a result, data collected from Part IV questions are not discussed further in this dissertation.

Consensus was not sought for questions in parts I and II, as those parts were focused on identifying and classifying participants' levels of expertise and their risk tolerance. Consensus was sought for four of the ten Part III questions. Consensus was not sought for questions that sought to elicit information about specific decision processes used in the identification and evaluation of risks, as well as the causes of the most significant risks and the methods used to control them on projects. Those questions were intended for "knowledge construction" as previously described in the discussion of the decision Delphi (Rauch 1979). This information is summarized in Table 3-3.

3.3.2.2 Data Analysis

Data was analyzed following the elicitation process model in Figure 3-2. Key aspects of this process included elements of knowledge elicitor training, observance of emerging patterns in the

Table 3-3. Summary of Question Focus Areas and Need for Consensus

Question No.	Question Focus	Consensus Sought
Part I – Risk Tolerance		
TIAA-CREF 1-6	Risk Tolerance	Not Needed
Part II - Professional Experience and Determination of Expertise		
1a-1k.	Expert Criteria	Not Needed
Part III - Risk Management Process		
2a.	Risk Identification	Yes - Knowledge Elicitation
2b.		Yes - Knowledge Elicitation
2c.	MUSH Market-Specific Risks	Yes - Knowledge Elicitation
3a.	Risk Identification Methods	No - Knowledge Construction
3b.	Risk Identification Timing	No - Knowledge Construction
3c.	Risk Identification Responsibility	No - Knowledge Construction
3d.	Risk Evaluation Methods	No - Knowledge Construction
3e.	Identification of Most Important Risk Categories	Yes - Knowledge Elicitation
4a.		No - Knowledge Construction
4b.		No - Knowledge Construction

data, and inferences that were drawn from both. The application of knowledge elicitor training to data analysis centered on the use of the preliminary risk framework to evaluate responses. Additionally, EPC professionals encountered through industry interactions provided guidance and feedback throughout data analysis and construction of intermediate outputs.

Findings and inferences from elicited expertise are provided in Chapter 4, Appendix C.1, and Appendix C.2. The data analysis resulted in inputs to the refined risk framework and to the EPC retrofit process model. These outputs are briefly described below and are fully discussed in Chapter 4. These are the primary deliverables from Objective 2.

3.3.2.3 Refined Risk Framework Construction

The elicited expertise from the Delphi panel was analyzed in the context of the preliminary risk framework developed in Chapter 2. Refinements were made to the 12 original risk categories and the risks assigned to each. Further information about specific ways in which these risks are realized on EPC retrofit projects and mitigation strategies used for their control were included, and a risk importance scoring was used to identify those risks that panelists identified as being the most important toward meeting the performance guarantee. The refined risk framework is the primary output of this objective and is described in Chapter 4.

3.3.2.4 Energy Performance Contract Retrofit Process Model

During development of the refined risk framework, it became apparent that the quality of the IGA has significant influence on the overall level of project risk. Many of the causes and mitigation strategies elicited from panelists were focused on issues related to information quality and availability, which could be expected given that a significant activity during the IGA is the collection and analysis of large quantities of information about the facility under review. Much of the elicited expertise addressed the types of information used during each phase of the EPC retrofit process to assist in the decision making process. As a result, the development of an EPC retrofit process model provides the ability to analyze key decisions made throughout the project life cycle. This model was also used to establish the system boundary for the risk analysis and evaluation process in Objective 3.

3.4 OBJECTIVE 3 – RISK ANALYSIS AND EVALUATION

The focus of work in Objective 3 is to develop an appropriate risk analysis and evaluation strategy for EPC retrofits that has the ability to incorporate life cycle costing as a measure of risk. Since these projects have lengthy performance periods (i.e., 12-15 years is common), unmitigated risks that become apparent after the contract is signed can lead to significant financial implications for ESCOs. Delphi panelists provided a risk importance score for each risk category in the preliminary framework. Importance scores were analyzed and resulted in the inclusion of energy audit quality- and ECM selection and installation-related risks in Objective 3 risk evaluation and analysis activities.

As discussed in Chapter 2, a single method for conducting risk evaluation and analysis was sought that incorporated qualitative techniques (McKim 1992), was applicable to early design phases (Grimaldi et al. 2012), that favored the use of expert knowledge, that enabled the incorporation of life cycle costing as part of the risk evaluation, and was consensus-based (Raftery 1994). Based on a review of Grimaldi et al. (2012), failure mode and effects analysis (FMEA) was selected as the risk evaluation tool because it is widely understood, it provides a comprehensive framework for data collection and understanding of complex system dynamics (Grimaldi et al. 2012), and places of a focus on understanding the primary modes of system or product failure resulting from technical factors (Stamatis 2003). Since the focus of this research is a system failure (i.e., failing to meet the performance guarantee as a result of project-level risks), FMEA is particularly well-suited. Additionally, FMEA addresses some of the shortcomings of other methods identified by Grimaldi et al. (2012), including single event focus (event trees), overlooking dependencies among systems elements (event trees), missing the nature of risks (interviews), and a lack of appropriate ranking tools (risk index).

Two types of FMEA are widely used – the design FMEA and the process FMEA. Both are conducted at system, subsystem, and component levels (Stamatis 2003; McDermott et al. 2009), indicating the ability to analyze risks at various life cycle phases. Conducting the FMEA in this way requires multiple analyses, which must be conducted sequentially, in order to examine the complete life cycle of a design or process (Kmenta and Ishii 2005). This has been identified as a methodological shortcoming due to the additional analysis time, the need to impanel a larger number of experts, and the linear nature of the “nested FMEAs” over a design or process life cycle, which prevents an iterative analysis of complex risk relationships (Kmenta and Ishii 2004).

Another FMEA method variant (FMECA) includes a measure of risk criticality; it is worth noting that this has increasingly become incorporated in standard FMEA methods (AIAG 2008). Risk criticality is typically determined through the calculation of the risk priority number (RPN); however, there are shortcomings of this method, as described in Chapter 2. Liu et al. (2013) conducted a comprehensive review of literature related to the risk evaluation methods used in FMEA, directed at addressing the shortcomings of the RPN method. Cost-based methods were identified as one of the 33 distinct evaluation methods identified by the authors, and six papers were reported as using this approach.

A life cycle cost-based approach to risk evaluation is desirable for this research since EPC retrofits are premised on financial guarantees made by the ESCO, which must remain robust over lengthy project performance periods. Much of the analysis in the IGA is presented in terms of ESCO costs, cash flow, guaranteed savings, and project value, highlighting the importance of developing a measure of risk that utilizes similar terms.

Figure 3-3 depicts the relationships among the works steps in Objective 3, as described in the sections below. Data collection and analysis relative to this objective is fully described in Chapter 5.

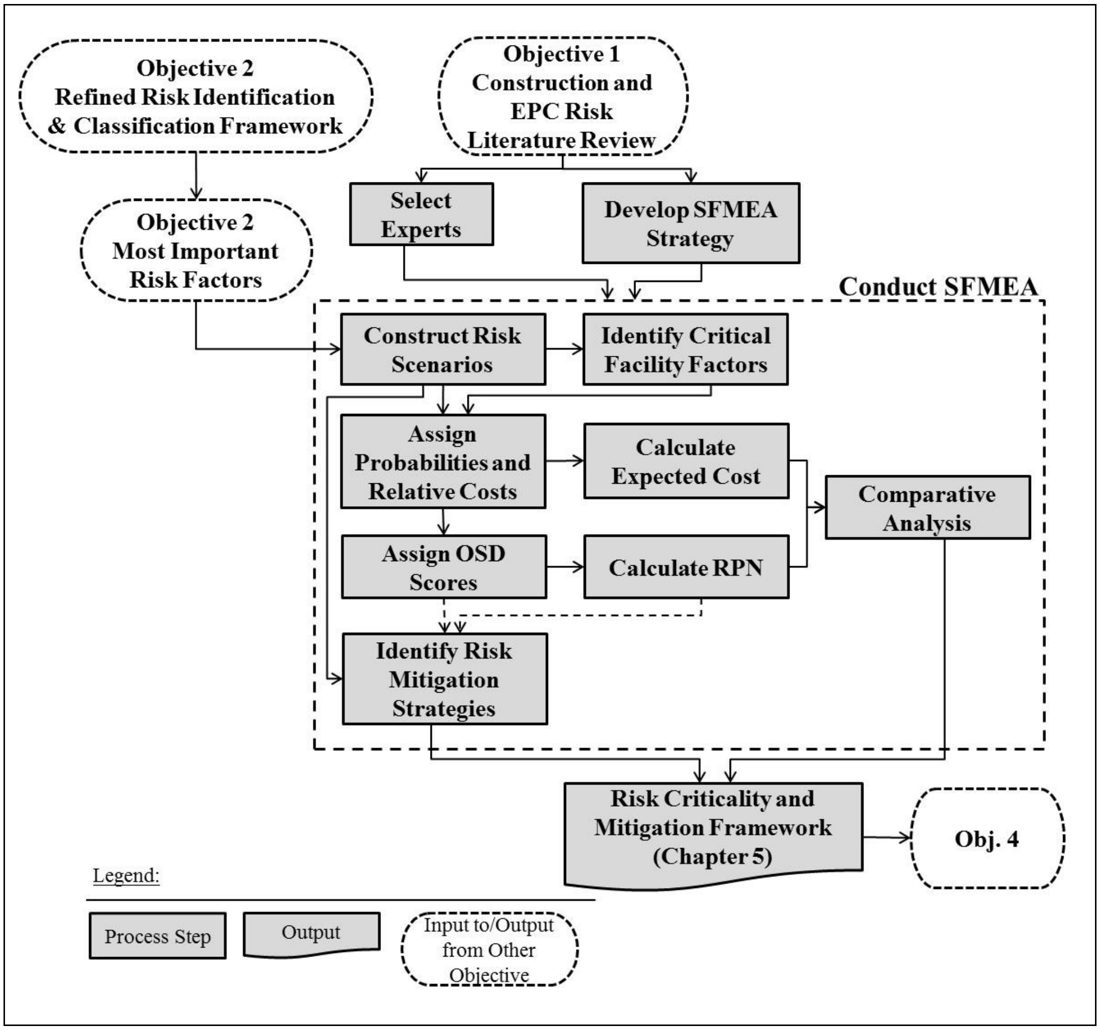


Figure 3-3. Objective 3 Methods and Outputs

3.4.1 Risk Analysis Strategy Development

Based on the desire to analyze risks in an iterative fashion throughout the project life cycle and to utilize cost-based terms to express the measure of risk criticality, scenario-based FMEA (SFMEA) was selected for further review. SFMEA and its methodological enhancements over traditional FMEA methods were detailed in Chapter 2; a summary of relevant characteristics for the development of the Objective 3 research methods are described below.

SFMEA was first proposed by Kmenta and Ishii (2000) and refined by Kmenta and Ishii (2004). The goal of this method is to overcome barriers in conventional FMEA related to the handling of interrelated risks and more accurately define and evaluate risk events. This method also uses cost as a measure of risk, replacing the RPN which has been challenged by numerous authors. Cost-based models were first proposed over 20 years ago; an early adopter of this method was Gilchrist (1993). Additional cost-based models have been used by Rhee and Ishii (2002), Rhee and Ishii (2003a), Rhee and Ishii (2003b), Spencer and Rhee (2003), von Ahsen (2008), Carmignani (2009), Rhee and Spencer (2009), and Chen and Zhang (2012). These models achieved the goal of evaluating risks by their cost impacts by beginning with a conventional FMEA framework, and modifying elements necessary to incorporate cost information when substituting for the traditional RPN method.

A key characteristic of SFMEA is the construction of failure scenarios, which replace the analysis of single point failure modes found in traditional FMEA. Conventional FMEA is built around failure modes, which describe the cause of a failure and have associated effects. Failure modes may occur across various system levels, and the standard practice is to represent that through the use of “nested” FMEAs, where the effects at a lower level become causes at the next higher level, and so on. As described earlier in this section, these separate analyses lack consistency in managing information across levels, thereby making a life cycle-based analysis very difficult (Kmenta and Ishii 2004). There is typically a one-to-one relationship between the causes and effects in a given failure mode, so a cause and effect chain is only represented by the cause and the end effect – intermediate effects are not evaluated explicitly.

Scenario-based FMEA allows the creation of many possible “failure scenarios,” which are cause and effect chains that can be lengthened, as needed, if new effects and new causes are identified during analysis (Kmenta and Ishii 2000; Kmenta and Ishii 2004). Failure scenarios are found in the risk literature (Kaplan and Garrick 1981) and have recently been applied in construction and engineering research (Esmaeili and Hallowell 2013; Pallin 2013; Hamilton et al. 2014). Failure scenarios were meant to be constructed by panelists participating in the FMEA. As a result, the scenario development process and the scenarios themselves are akin to the construction of Bayesian Belief Networks (BBNs), which were more thoroughly described in Chapter 2.

The construction of a BBN is a participatory decision-making strategy whereby expertise is elicited from participants in a structured manner so that complex systems with a great deal of uncertainty can be reduced through graphical representation (Hart and Pollino 2008). A key strength of this approach is that complex causal relationships that are not easily expressed in mathematical terms can be analyzed to gain insight into the relationships among variables under study. This is especially relevant in this case, where data collected in Objective 2 was through elicited expertise and was qualitative in nature. The construction of BBNs in the risk analysis process permits FMEA participants to structure and understand the system under review.

BBNs use three probabilities to represent participants’ beliefs: (1) prior probability, (2) conditional probability, and (3) posterior probability. These are incorporated in the SFMEA method as the probability of the cause and the conditional probability of the end effect given the intermediate effects present in the scenario. These probabilities are then analyzed using Baye's Theorem, which enables the belief network to be updated if new evidence causes a change to the state of the network (Grinstead and Snell 1997). The use of point estimates of probabilities was preferred by construction professionals studied by McKim (1992), who noted that these individuals tend to assign discrete percentages to a likelihood of a risk as opposed to developing probability functions. Thaheem and DeMarco (2013) also found that probability functions were used by less than 30% of construction professionals responding to a risk management methods survey. The use of SFMEA requires modifications to the traditional FMEA method. These are identified and discussed briefly in the following sections.

3.4.1.1 Modified FMEA Matrix

A matrix was developed specifically for this research based on standard documents as provided by AIAG (2008) with modifications per Kmenta and Ishii (20004). The matrices used for this research are provided in Appendix D. Modifications to the matrix included the collection causes and effects for each risk scenario, any specific facility factors that give rise to individual causes, percent likelihoods (i.e., probabilities) for the risk cause and end effect given any intermediate effects, and relative cost data for each risk scenario.

3.4.1.2 Modified Risk Criticality Measure

The purpose of the criticality analysis is to identify the risk scenarios having the greatest impact on the ESCO's financial performance in EPC retrofit projects. This research utilizes expected cost as included in SFMEA as the primary measure of risk criticality (Kmenta and Ishii 2000;

Rhee and Ishii 2002; Kmenta and Ishii 2004). The authors modeled the relationships between occurrence, severity, and detection and probability and cost. This effort gave rise to the notion that a 1:1 relationship does not exist between the values of the RPN and expected cost. Criticality measures were evaluated based on their relational differences, and three scenarios were detected: (1) identical RPN values can have large expected cost variances, (2) identical expected cost values can have different RPN values, and (3) the RPN and expected cost values can yield mixed priorities for risk control (Kmenta and Ishii 2004). Additionally, the authors found that in 10,000 simulated FMEAs, the RPN priority and expected cost priority never matched. As a result, the risk analysis strategy developed in this objective will also collect measures of occurrence, severity, and detection from panelists to construct RPNs for each risk scenario. This data will be used to empirically test the modeled relationships between RPN and expected cost observed by Kmenta and Ishii (2004).

3.4.2 Analyze Risk Criticality

The risk analysis strategy utilizing SFMEA described above was conducted through a FMEA panel of domain experts representing various facets of EPC retrofits. The recommended panel for conducting a FMEA includes individuals who have professional responsibility and authority for the system or process being evaluated (Stamatis 2003). Panels must reflect the multiple disciplines represented in the process and system under review and multiple technical disciplines should be represented, to the extent possible (Teng and Ho 1996; Stamatis 2003; McDermott et al. 2009). Recommended panel sizes range from four to nine and should include participation by end-users or clients (Stamatis 2003; McDermott et al. 2009). McDermott et al. (2009) also recommend balancing the panel composition among participants with more experience and those with less. The rationale for this is that less experienced panelists may perceive issues differently than those panelists for whom these projects have become familiar, thereby potentially revealing additional issues that could be missed by those who routinely perform this work.

A panel comprised of four professionals was assembled for this task. Panelist expertise and risk tolerance measures are described in Chapter 5. All members were convened for a half-day SFMEA meeting. An expert facilitator was retained to co-lead the process with the researcher. This was critical to ensure that the SFMEA achieved its stated goals and analyzed risk scenarios in a comprehensive manner. The researcher thoroughly explained the goals of the SFMEA and shared the modified matrix with the facilitator prior to convening the panel. The EPC retrofit process model was also explained, as was the refined risk framework, so panelists could begin to understand the connections among the process model, the SFMEA goals, the development of failure scenarios, and the cost-related information required of participants. A fellow researcher was included as a secondary recorder and analyst to ensure that SFMEA details were transcribed accurately and to assist with performing life cost-based calculations during the SFMEA panel. Panelists engaged in an iterative process consisting of the following steps:

1. Construct risk scenarios – Panelists were provided with an example scenario, previously constructed by the researcher, in order to visualize the related concepts of risk scenarios, cause and effect probabilities, cost, and expected cost. Participants were also given a list of the 27 risks belonging to the IGA quality and ECM selection and installation risk categories. Members determined the priority order for these risks before beginning to construct scenarios, aided by the facilitator and the researcher.

2. Identify critical facility factors – As risk scenarios were being constructed, panelists were asked to provide a measure of specific facility-related factors that could give rise to specific risk causes. For example, the age of the facility and the age of the last major retrofit is related to the probability of the facility containing asbestos-containing materials, lead-based paint, thus requiring necessary code upgrades.
3. Assign probabilities and relative costs – Panelists individually provided probabilities and relative costs for each risk scenario. Relative costs were used to represent the consequence of an individual risk scenario based on the percentage of the ESCO's margin, defined as the difference between calculated savings and guaranteed savings. This was advantageous for two reasons: (1) panelists were readily able to assign a percentage value of the margin that could be at risk in each scenario and (2) these values captured the essence of the financial risk in each scenario without requiring significant participant time to derive construction cost estimates for each individual scenario. Once probabilities and costs were recorded for each panelist, consensus measures were gathered using the median of the panelist values. The median was selected for its ability to minimize the impact of outliers on this small data set, and provide a more robust measure of central tendency among the four responses. Probability and cost data is provided for each panelist and the median values in Appendix D.
4. Assign occurrence, severity, and detection scores – Panelists were then prompted to score each scenario using traditional measures of criticality using custom tables developed for this research (tables 3-4, 3-5, and 3-6). RPN values were calculated for each scenario and also for the median case, and are presented in Appendix D.

Table 3-4. Occurrence Measure Ranking Scale

Likelihood of Failure	**Criteria: Occurrence of Causes**	**Rank**
Very High	90+ in 100 projects	10
High	80 in 100 projects	9
	70 in 100 projects	8
	60 in 100 projects	7
Moderate	50 in100 projects	6
	40 in 100 projects	5
	30 in 100 projects	4
Low	20 in 100 projects	3
	10 in 100 projects	2
Very Low	<1 in 100 projects	1

Table 3-5. Severity Measure Ranking Scale

Effect	**Criteria: Severity of Effect on Project**	**Rank**
Failure to Meet Safety or Regulatory Requirements	May endanger lives of personnel.	10
Major Project Impact	May singularly lead to failure to achieve performance guarantee or endanger safety of personnel.	9
	Requires changes to the scope of work based on client requirements and project goals; may endanger future working relationship.	8
	Requires recalculation of energy guarantee.	7
Moderate Project Impact	Requires recalculation of key IGA elements/findings or similar.	6
	Inconvenience to ESCO staff and client staff time or after execution phase.	5
	Inconvenience to ESCO staff time in or after execution phase.	4
Minor Project Impact	Slight inconvenience to ESCO staff and client staff time in earliest project phases.	3
	Slight inconvenience to ESCO staff time in earliest project phases.	2
No effect	No effect.	1

5. Conduct comparative analysis of expected cost and RPN – The calculated values of expected cost and RPN were compared to detect the presence of a relationship among the measures and to fully describe any discrepancies observed between them. A detailed discussion of this analysis is provided in Chapter 5.

Table 3-6. Detection Measure Ranking Scale

Detection Likelihood and Early Project Phase Timing	**Criteria: Likelihood and Timing of Detection**	**Rank**
Almost impossible to detect until execution phase commences	Cannot detect until after energy guarantee and price guarantee have been fixed by ESCO.	10
Very remote chance of detection before execution phase	Slight chance of detection before energy guarantee and price guarantee have been fixed by ESCO, but only through significant additional scope completed by ESCO.	9
Remote/May be after execution	Failure mode *may be* detected before entering execution through past project experience.	8
Very low/May be after execution	Failure mode *may be* detected before entering execution through modeled results.	7
Low/May be after execution	Failure mode *may be* detected before entering execution through a combination of visual inspection, laboratory testing, or direct measurement/observation.	6
Moderate/Before execution	Failure mode *is* detected before entering execution through past project experience.	5
Moderately high/Before execution	Failure mode *is* detected before entering execution through modeled results.	4
High/Before execution	Failure mode *is* detected before entering execution through a combination of visual inspection, laboratory testing, or direct measurement/observation.	3
Very high/Before execution	Design solutions have been highly correlated with early detection ability in previous projects of a similar type.	2
Almost certain/Before execution	Failure mode cannot occur because it is addressed fully through design solutions.	1

6. Identify risk mitigation strategies – Risk mitigation strategies were developed from three sources: (1) review of the literature, (2) elicited expertise from Objective 2, and (3) interview with an ESCO expert. The refined risk framework contains a number of risk mitigation strategies identified by the Delphi panelists; however, that list was not complete for all identified risks. The literature review and interview with the ESCO expert were used to provide missing information and confirm data obtained from the panel. This final step of the SFMEA is discussed below and in Chapter 5.

3.4.3 Evaluate Critical Risks

Mitigation strategies were evaluated for each scenario, first using a Boolean operator; risks could either be retained or allocated. In each case, data was collected regarding the efficacy of the strategy in eliminating risk and the cost to undertake the activity was identified. This led to the creation of multiple mitigation scenarios for each selected risk scenario, based on combinations of the selected approach (i.e., retain or allocate), the effectiveness of the measure, and its cost. These were used to construct cost-benefit relationships for each risk scenario and its attendant mitigations strategies, thereby enabling decisions to be made about effective strategies to reduce the risk of the most critical scenarios that are present in a given EPC retrofit.

3.4.4 Parameterize Risk Framework and Construct Risk Model

The principal output from Objective 3 is the life cycle cost-based risk criticality and mitigation framework. By parameterizing that framework, a risk model is constructed to encapsulate the qualitative and quantitative data collected from experts in objectives 2 and 3. Parameterization consists of assigning functions and values for the following elements of the framework:

- Connect identified facility factors with probabilities of cause;
- Define relationships among the following four parameters and individual risk scenarios: (1) equipment service life and replacement cost; (2) equipment maintenance cost; (3) fuel cost escalation; and (4) weather-related variation;
- Develop probability density functions for the four parameters listed above using external data; and
- Determine criteria weights for the four parameters listed above.

Criteria weights for each of the four parameters obtained from each SFMEA panelist will be applied to the values of expected cost for each relevant scenario. Additionally, the SFMEA data in Appendix D will be analyzed to detect whether a relationship exists between assigned probabilities and costs and the risk tolerance and experience level of panelists. If such a relationship is detected, this will be included as part of the framework parameterization to allow end-users the ability to model risk scenarios based on either the panel-developed probabilities and costs or user-specified probability and cost values. This is discussed in greater detail in Chapter 5. Model construction is also described in Chapter 5 and consists of representing the parameterized framework in a data collection and analysis tool that utilizes end-user inputs about facility and EPC project characteristics to determine cost-benefit relationships for risks and mitigation strategies, using automatic or end-user inputs for values of probability and cost.

3.5 OBJECTIVE 4 – PILOT LIFE CYCLE COST-BASED RISK MODEL

The life cycle cost-based risk model developed in Objective 3 will be pilot tested through application to one case study site, selected in accordance with parameters described below, and described in Chapter 6. Facility and EPC project characteristics from this case study will be used to provide the inputs to run the life cycle cost-based risk model. Model implementation is conducted primarily to test model usability and usefulness of outcomes. The model will be tested for its applicability, that is, that it can be applied by users with available data in typical retrofit projects during the energy audit phase. This is important given the potentially large number of input parameters to the risk model.

Sensitivity analysis will be conducted to determine the response of model outputs to changes in model parameter values. Since the framework was parameterized using responses from a panel of four experts, the resultant data set is somewhat limited. Monte Carlo simulation can be used to examine model performance when varying individual parameter values in an effort to address model uncertainties resulting from the small data set. This process affords the ability to determine the relative importance of individual parameters in influencing the modeled result and provides insight for model refinement.

Implementation will also consider whether the model yields results that are feasible, and balance risk mitigation, life cycle costs, and technical approach in assisting decision makers to better evaluate project level risks. As a result of this final step and the sensitivity analysis described above, the model will be refined, as needed, to address the issues of model applicability, feasibility, and parameter development.

To pursue this objective, a correctional facility case study has been identified where an EPC retrofit has completed within the past two years, and the facility is currently in the measurement and verification phase. Key selection criteria included the presence of identified project risk categories and life cycle cost implications as described by the Delphi panel. Additionally, a site was sought that was located in either climate zone 5 or 6, in order to minimize variation in the technical approach in response to climatic conditions. A facility was also sought that included a representative sample of ECM strategies, to include short (e.g., <5 years) and longer (e.g., >5 years) payback periods and strategies that utilized stipulated performance as well as performance monitoring and verification. A summary of case study characteristics is provided in Table 3-7.

Table 3-7. Selected Correctional Facility Case Study Characteristics

Facility Name [Years Built] Total Building Area (SF) [EPC Project SF]	Construction Types and Security Levels	Project Components	Project Cost (Total Savings) [Total Annual Savings]	Payback Period
Parnall Correctional Facility [1925-2002] 905,220 [~250,000]	• Primary structures are brick, pre-cast concrete block, steel, and glass • Additional housing units are weatherized pole barns with sealed concrete floors and plaster-board walls • Security level I	• Lighting Retrofit • Water Efficiency • Retrofit HVAC	$12,891,626 ($15,646,197) [$1,881,274]	10 yrs

Despite being public facilities, information about correctional facilities and physical access to these structures can be difficult to obtain because of significant security concerns. The researcher was able to obtain access to EPC project teams and decision makers, gain site access in order to visually inspect the scope of installed ECMs, and access all EPC-related work products (solicitations and contracts, investment grade audit results, and construction documents).

3.6 CHAPTER SUMMARY

This chapter described the research approach for the identification, analysis, and evaluation of project-level risks faced by ESCOs in the development and execution of EPC retrofits in correctional facilities and other MUSH market buildings. The four objectives include: (1) attainment of knowledge about the EPC retrofit process; (2) elicitation of expertise from ESCO professionals through the Delphi technique to construct a risk framework and a retrofit process model; (3) analysis and evaluation of identified risks using SFMEA and expected cost, and parameterization of this framework as a life cycle cost-based risk model; and (4) pilot application of the developed risk model using a correctional facility case study.

CHAPTER 4

ENERGY PERFORMANCE CONTRACT RISK FRAMEWORK AND RETROFIT PROCESS MODEL

4.1 INTRODUCTION

The need for increased energy efficient retrofit in the municipalities, universities, school, and hospitals (MUSH) market and the role of energy performance contracting (EPC) in promoting the wider adoption of energy efficient retrofit practices was established in Chapter 1. A number of risk sources for energy service companies (ESCOs) undertaking MUSH market EPC retrofits were discussed in the first two chapters, three of which have particular relevance to this research: (1) ESCOs bear the primary project performance risk, which must be properly understood and mitigated during early project phases; (2) EPC project decision making can be shaped by cognitive biases, based on available information, during the development and design of EPC projects; and (3) the availability and quality of information has a significant impact on activities and decisions made during the energy audit phase and during retrofit design. These issues informed the development of the research design presented in Chapter 3.

This and the following two chapters are grounded by the premise that ESCOs must fully understand and control the risks that they bear throughout an EPC retrofit project at the earliest project life cycle phases. This chapter is the first of three that focus on the risk management process (Figure 4-1). This process involves understanding the context within which EPC retrofit decisions are made, the types of information resources available for decision making, and the identification of risks inherent in EPC retrofit projects. The result of this understanding was the

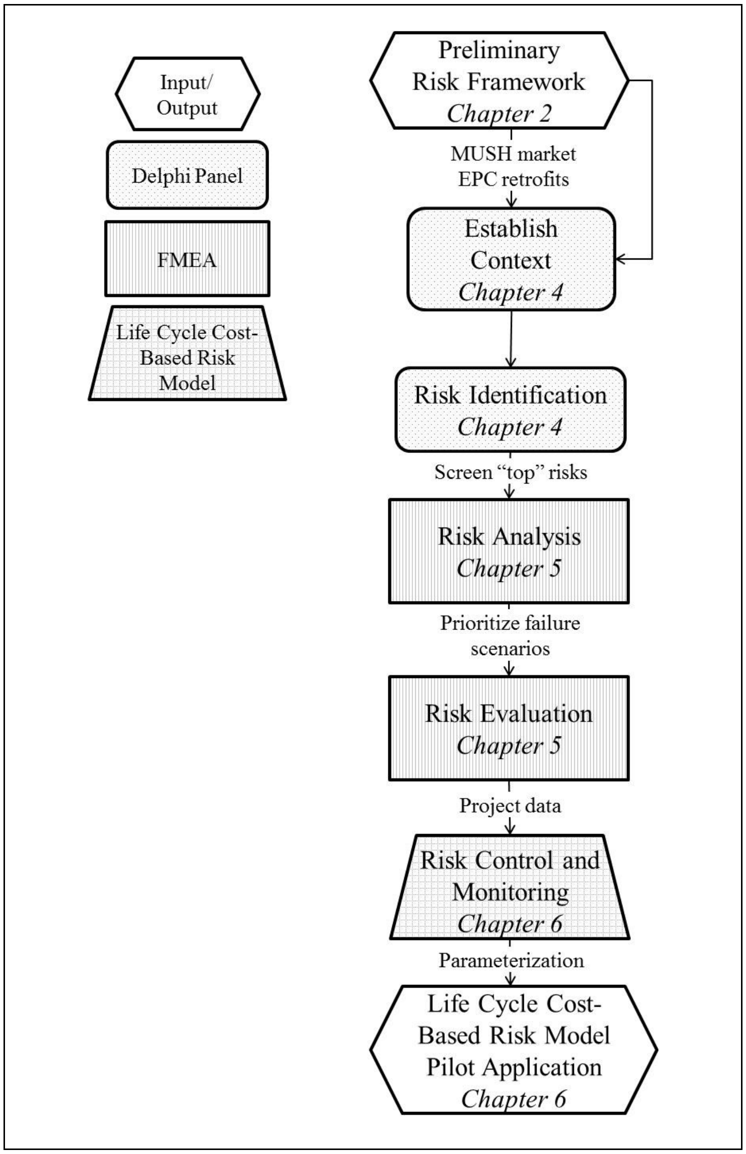


Figure 4-1. Risk Management Process and Methods Mapped to Dissertation Chapters

concurrent development of a refinement to the preliminary risk framework presented in Chapter 2 and an EPC retrofit process model. Both outputs from this chapter help to frame the Chapter 5 work. The refined risk framework identifies the two risk categories assigned the greatest importance by research participants, and the risks belonging to the selected risk categories provide the basis for scenario development by identifying risk causes and potential mitigation strategies. The EPC retrofit process model serves as the process map for conducting the scenario-based failure mode and effects analysis (SFMEA), establishing the context for the panel's analysis.

Chapter 5 is primarily concerned with the development and implementation of an analytical and evaluative framework using SFMEA for the risks identified in this chapter. The complete SFMEA serves as the framework to develop a life cycle cost-based risk model. That model is implemented in Chapter 6 through a pilot application to an actual case study location – a correctional facility that recently underwent EPC retrofit activity. Application of the model results in completing the risk management process.

4.1.1 Glossary

Frequently used terms which may be used interchangeably in this chapter are defined as below:

- ESCO: energy service company, contractor;
- Owner: building owner, client;
- Qualitative Information: expert knowledge, expertise, experience-based judgment, case-based reasoning, ESCO advice;
- Quantitative Information: published information, databases, simulation results, documents/reports, checklists, procedures, figures, pictures; and
- Retrofit Measures: energy conservation measures (ECMs).

4.1.2 Chapter Objectives

The primary goal of this chapter is to identify project-level risks to ESCOs undertaking EPC retrofits in MUSH market facilities. The work is premised on the preliminary risk framework that was described in Chapter 2. Primary data to achieve this goal consists of expertise that was elicited from ESCO professionals using the Delphi technique. In order to achieve these goals, this chapter has the following objectives:

- Refine the preliminary (a priori) risk framework by eliciting knowledge from a panel of ESCO experts about risk identification and prioritization for further analysis;
- Determine the presence of an effect between each panelist's amount of ESCO experience, risk tolerance, position type, and project focus and the risk identification decisions made by each panelist;
- To identify the key decisions made under conditions of uncertainty and risk during the retrofit process; and
- To connect information sources used throughout the retrofit process with the decisions that are made in early project phases.

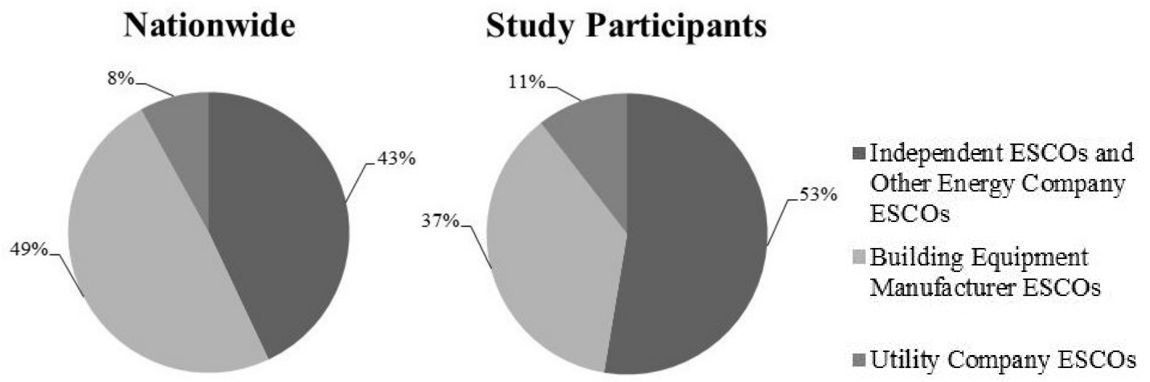
4.2 EXPERTISE ELICITATION

Primary data collection consisted of eliciting domain expertise from 19 ESCO professionals following the strategy described in Chapter 3. Panelists were selected based on their expertise, also as described in Chapter 3, and responded to a two round Delphi questionnaire consisting of three categories of questions: (1) participant risk tolerance, (2) professional experience and determinants of expertise, and (3) risk management process. This section includes a discussion of the recruitment and selection of panelists, a summary of their levels of expertise, and key findings and inferences drawn from the data collection effort.

4.2.1 Delphi Panelist Recruitment and Selection

Participants were selected for this study using purposive sampling techniques (Barbour 2001; Oliver 2006; Tongco 2007), in order to focus on experts who are engaged in EPC work with a variety of different ESCOs. The overarching goal of sampling was to ensure that only contractors possessing a high level of knowledge about MUSH market EPC retrofit projects would be included, and that those individuals had roles involved with decision-making during the retrofit process. Expert sampling was therefore a cornerstone of the combination approach used; however, identifying and gaining access to such experts was difficult in many cases. To help recruit such individuals, a sequential sampling technique known as snowball sampling was used. This method has been shown to assist in the recruitment of participants who are difficult to access for a variety of reasons (Sadler et al. 2010). Upon completion of the questionnaire, panelists were asked to provide referrals to other domain experts who met pre-determined expert selection criteria and who would be likely to participate in this study. Experts were also identified in connection with critical cases, which consisted of correctional facility EPC retrofits from the past three to five years.

Even though constructing a representative industry sample was not the goal of participant recruitment and selection activities, the panel was generally representative of the overall ownership share of the ESCO market held by three main business types: (1) independent ESCOs and other energy companies, (2) building equipment manufacturer ESCOs, and (3) utility company ESCOs. Nationwide ESCO industry shares by business type for 2008 (the most recent year for which data were available) are shown in Figure 4-2. The data shown for study participants is based on the proportional representation of each type of business among the panelists. Some observed variation between the study sample and ESCO population is present, likely attributable to the use of snowball sampling and expert sampling in constructing the panel (Sadler et al. 2010).



Note: Due to rounding errors, ownership shares do not add to 100%

Figure 4-2. ESCO Industry Shares by Business Type
(Source: Larsen et al. 2012a – nationwide data)

4.2.2 Conduct of the Delphi Panel and Achievement of Consensus

Consensus was not sought for Part I and Part II questions, as their focus was on determinants of risk tolerance and expertise for individual panelists. The ten Part III questions sought to elicit expertise about seven knowledge categories relative to the risk management process: (1) MUSH market-specific risks, (2) risk identification methods, (3) risk identification timing, (4) risk identification responsibility, (5) risk evaluation methods , (6) risk identification, and (7) identification of the most important risk categories. Consensus was a goal of four out of ten Part

III questions; the other six questions were intended to assist with knowledge construction, as described in Chapter 3, and reflective of the decision Delphi technique (Rauch 1979).

After the first Delphi round, consensus was achieved for three of the four consensus-based questions (75%), as shown in Table 4-1. Consensus was not achieved for question 2b, which was focused on new risks identified by panelists during the first round interviews. Additionally, while consensus was achieved on questions 2c (MUSH market-specific risk categories) and 3e (risk importance ranking), further detail was sought from panelists; further detail was also sought with regard to questions 3a (risk identification methods) and 3d (risk evaluation methods). A second Delphi round was conducted using an online survey platform (Appendix A.3) to facilitate participant responses. As part of the second round, panelists were provided with their first round responses, as well as the consensus measures attained for each question through the first Delphi round. The second round resulted in achieving consensus for question 2b and attaining the additional information needed for questions 2c, 2d, 3a, and 3e; at that point, the Delphi process was terminated. A detailed analysis of all data obtained from both rounds of the Delphi panel is included in Appendix C.1 and Appendix C.2.

Table 4-1. Summary of Part III Questions and Consensus Results

Question Number	**Question Focus**	**Knowledge Goal**	**Delphi Consensus Status**	
			1st Round	**2nd Round**
2a.	Risk Identification	Elicitation	Achieved	
2b.		Elicitation	Not Achieved	Achieved
2c.	MUSH Market-Specific Risks	Elicitation	Achieved[a]	Achieved[a]
3a.	Risk Identification Methods	Construction	Not Needed[a]	
3b.	Risk Identification Timing	Construction	Not Needed	
3c.	Risk Identification Responsibility	Construction	Not Needed	
3d.	Risk Evaluation Methods	Construction	Not Needed[a]	
3e.	Identification of Most Important Risk Categories	Elicitation	Achieved[a]	Achieved[a]
4a.		Construction	Not Needed	
4b.		Construction	Not Needed	

Notes:
a\ Additional information was sought in the second Delphi round.

The results of the Delphi process provided the data for this portion of the research and consisted of recorded conversations with panelists, which were subsequently transcribed by the researcher, as well as field notes collected during the interviews. Each recording was played back then transcribed; transcripts were reviewed at least twice during data analysis. Respondents were contacted when information was unclear or difficult to understand, either due to the quality of the recording or due to the context within which the information was provided. Frequent notes were included with the transcripts in order to identify important statements and identify emerging patterns based on the content of the data.

4.2.3 Determination of Risk Tolerance and Expertise

The TIAA-CREF Asset Allocation Evaluator (AAE) was used to assess each panelist's attitudes toward risk by using the analog of allocating assets in a financial portfolio (TIAA-CREF 2013). This was considered to be an important element of data collection and analysis because individual responses to the questionnaire may be dependent on participants' attitudes. Panelists were provided the six questions from the AAE as Part I of the Delphi questionnaire. A complete discussion of the AAE, its use in this study, and panelists' responses are provided in Appendix C; however, a summary of panelists' risk tolerance profiles, as evaluated by the AAE, is provided in Table 4-2. It should be noted that only 18 panelists completed the AAE as one refused to answer these questions.

Eleven questions making up Part II of the Delphi questionnaire sought information about panelists' relevant experience. The respective level of expertise possessed by each panelist was determined using the rubric based on Hallowell and Gambatese (2010) and Duah (2014) that was

Table 4-2. Research Participant Risk Tolerance Profiles		
Risk Tolerance	**% of Respondents**	**Firm Types**[a]
Conservative	17%	M, U
Moderately Conservative	11%	M, U
Moderate	28%	E, M
Moderately Aggressive	33%	E, M
Aggressive	11%	E

Notes:
a\ E = Independent ESCO; M = Manufacturer-Based ESCO; U = Utility-Based ESCO

described in Chapter 3. The complete list of determinants of expertise for each panelist is presented in Appendix B; a summary of selected expertise criteria is provided in Table 4-3.

Table 4-3. Summary Expertise Attributes of Delphi Members			
Attribute	**Minimum Value**	**Mean/Mode**	**Maximum Value**
Total Points[a]	4.5 (31%)	Mean = 8 (55%)	12 (83%)
Total Categories[a]	5 (50%)	Mean = 7.2 (72%)	10 (100%)
Years involved with EPC projects	5	Mean = 16	33
Total number of projects	10	Mean = 81	300
Proportion MUSH market projects	33%	Mean = 90%	100%
Number of building systems impacted/project	3-4	Mode = 5-7	10+

Notes:
a\ Points and categories refer to Tables 3-1 and 3-2

4.3 DATA COLLECTION – DISCUSSION AND INFERENCES

This section discusses the analysis of consensus and non-consensus data obtained through the comprehensive expertise elicitation strategy, focused on questions related to the risk management process. The data obtained through the Delphi rounds was analyzed based on consensus of elicited knowledge, consensus in modifications to the risk categories and risks in the preliminary risk framework, elements of knowledge elicitor training (literature review and industry interactions), quantitative information, and inferences and emerging patterns drawn from the data.

Based on the comprehensive elicitation strategy described in Chapter 3 and the analysis of the resultant data, consensus was achieved among all expert panelists regarding the level of ESCO risk in MUSH market projects and in select sub-markets, risk identification, and the relative importance of identified risk categories. The elicited knowledge was mutually acceptable to participants and was deemed to be applicable to ESCO industry practices for EPC retrofit planning and project management. Additionally, knowledge was constructed from six non-consensus questions, which was focused on understanding industry practices related to risk management. This section discusses the results of the analysis and reports findings related to the knowledge categories related to the Delphi questionnaire.

4.3.1 MUSH Market-Specific Risks

Table 4-4 reports on consensus achieved and knowledge constructed by experts relative to the knowledge category of MUSH market-specific risks. Consensus was sought and obtained for this question in order to reject or confirm the assertion that MUSH market projects, specifically correctional facility retrofits, carry additional risks and as such require the construction of a specific risk. Eighty-two percent of the Delphi panelists indicated that there are differences in the risk profiles between MUSH and non-MUSH segments; non-MUSH segments were defined as commercial and industrial (C&I) retrofits. Of the panelists reporting a difference in risks among projects in the two markets, 78% indicated that at least one or more MUSH sub-markets is riskier than C&I, (64% - all MUSH sub-markets; 14% - correctional facilities only, 7% hospitals only). Two other respondents indicated their belief that C&I projects are riskier in all cases.

Table 4-4. Elicited Knowledge: MUSH Market-Specific Risks	
Knowledge Subcategory	**Elicited Knowledge**
Sources of Risk: C&I Projects	• Greater likelihood of building use changes. • Potential revenue losses during retrofit activities. • Greater credit risk. • Preferred short contract periods (e.g., 3-5) years limit the scope of the project to short payback period items.
Sources of Risk: Correctional Facility EPC Retrofits[a]	• Costs related to security protocols, specifically due to reduced daily productivity and the need for additional project staff. • Health and safety protocols that override the ability to cycle HVAC equipment off during low utilization times. • Project conflicts arising from the "militaristic structure" of correctional agencies and external pressures they face, such as reduced budgets, overcrowding, and security. • Difficulties of scheduling and conducting work in a continuously-operated facility. • Security concerns with installed ECMs and vandalism of equipment after installation. • Risks are dependent on the security level of the correctional institution where work is taking place, to include: o Schedule delays due to security protocols; these are typically more stringent in higher security facilities. o Schedule delays arising from the need to relocate inmates from work areas. o Lost time due to correctional officers assigned to project oversight being assigned elsewhere in the facility based on emergent needs.
Sources of Risk: Hospital EPC Retrofits[a]	• Difficulties of scheduling and conducting work in a continuously-operated facility. • Critical areas, such as surgical suites, must remain operational throughout the retrofit project. A highly competent construction manager is needed to manage the work given these concerns.
Notes: a\ Elicited knowledge relative to risks across all MUSH market facility types are presented in the refined risk framework in this chapter. Only the riskiest MUSH building types are included here.	

As a result of the open-ended responses obtained from several participants during the first round, in the second Delphi round panelists were asked to identify which MUSH market facility types had the greatest project risk profiles. Facility types included correctional facilities, hospitals, K-12 schools, mission-critical facilities, and continuously operated facilities; the latter facility type was inclusive of correctional facilities and hospitals which operate continuously by definition. The percentage of responses for each facility type was 67%, 47%, 13%, 53%, and 47%, respectively. When accounting for respondents who did not identify correctional facilities, but did identify the inclusive category of continuously operated facilities, the response frequency increased from 67% to 87%. Additionally, just 7% of respondents believed that MUSH market facility EPC retrofits are no riskier than private sector EPC projects. As a result, it is reasonable to conclude that MUSH market EPC retrofits in general, and correctional facility projects specifically, have a higher project risk profile than other markets and building and types.

4.3.2 Risk Identification Methods, Timing, and Project Responsibility

The first Delphi round encouraged panelists to provide open-ended responses to these questions in order to fully understand the range of techniques and processes used relative to these risk management functions. Additional detail was sought in the second round regarding risk identification methods. Panelists were asked to identify the risk identification methods they typically use; index values for this question came from the open-ended responses in the first round and the work conducted by Grimaldi et al. (2012) and Thaheem and DeMarco (2013). Table 4-5 and Figure 4-3 report on this constructed knowledge.

As can be seen in Figure 4-3, panelists most frequently rely on expertise to identify project risks (80%), followed by brainstorming (73%), and the use of checklists (73%). Techniques that are highly structured and require more staff and analysis time to complete were less favored by panelists. SWOT analysis and FMEA are used much less frequently during risk identification, with frequencies of 27% and 13%, respectively. The results of the second round responses

Table 4-5. Constructed Knowledge: Risk Identification Process

Knowledge Category	Constructed Knowledge
Risk Identification Methods	See Figure 4-3.
Risk Identification Timing	• 100% of respondents indicated that the risk identification process begins early in the project. • 58% of respondents indicated that the risk identification process is iterative, and takes place at designated milestones during the project, particularly during phase hand-offs among project staff.
Risk Identification Responsibility	• 100% of panelists indicated that their organizations have designated individuals to manage the risk identification process; however, their specific job functions varied. • 84% of respondents indicated use of a team approach which typically involved project managers managed the risk identification process specific to their phase of the work (e.g., IGA development, construction, M&V). • Risk review teams were typically multi-disciplinary and included the project developer, energy engineers, the design engineer, the construction manager, assurance engineers (for M&V concerns), and in some cases finance and legal staff members. • Executive management (vice president or above) review of risks was indicated by 26% of the panelists.

validated the risk identification approach taken by this research, combining interviewing with expertise/expert judgment and a de-facto checklist (the a priori risk framework).

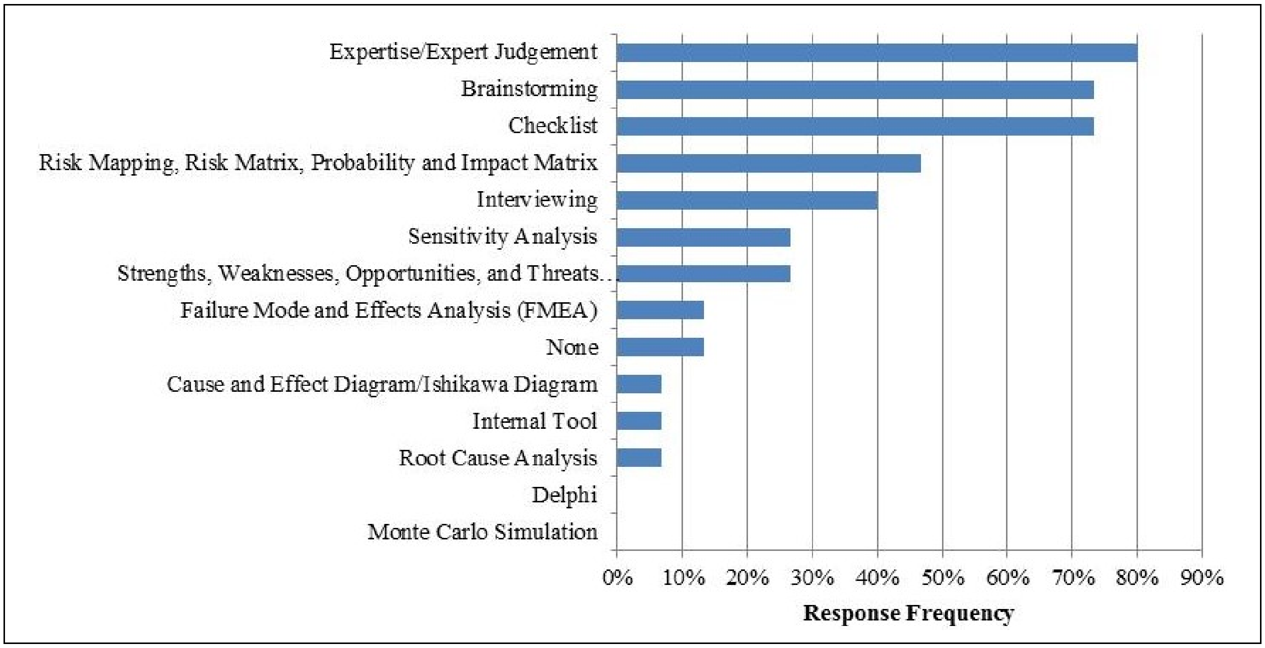


Figure 4-3. Risk Identification Methods Reported in Second Delphi Panel

4.3.3 Risk Evaluation Methods

Table 4-6 reports on panelists' responses regarding risk evaluation methods. The overarching finding was that rigorous analytical methods are employed less than 50% of the time as part of the risk management process, and more robust methods were needed to improve the approach to managing identified risks. One panelist reported a desire to use probabilistic methods, given the variation inherent in some of the data used to model retrofit performance (e.g., climate, equipment service life, energy price escalation, schedule variation); however, difficulty incorporating such methods directly with energy modeling activities was cited as a barrier for wider adoption.

Table 4-6. Constructed Knowledge: Risk Evaluation Methods

Knowledge Subcategory	**Constructed Knowledge**
Risk Evaluation Techniques	• In general, ESCOs do not engage in formal methods of risk evaluation. • The majority of panelists reported using informal or experience-based methods. • One panelist reported some use of probabilistic methods for risk evaluation to include Monte Carlo simulation (via Crystal Ball) and the use of PERT inputs for schedule-related risks. • One panelist reported use of an internally-developed tool that evaluates risks as having either "low" or "high" impacts relative to associated costs. The "high risk" cost value is added to the project contingency if mitigation is not feasible.

As with risk identification, the second round Delphi questionnaire sought further detail about the specific methods used for risk evaluation. Panelists responded to techniques identified during the first round as well as methods identified by Grimaldi et al. (2012) and Thaheem and DeMarco (2013). Those results are depicted in Figure 4-4.

As can be seen in Figure 4-4, the use of expertise and simpler methods to implement was reported most frequently. Brainstorming (60%), expertise/expert judgement (60%), checklist

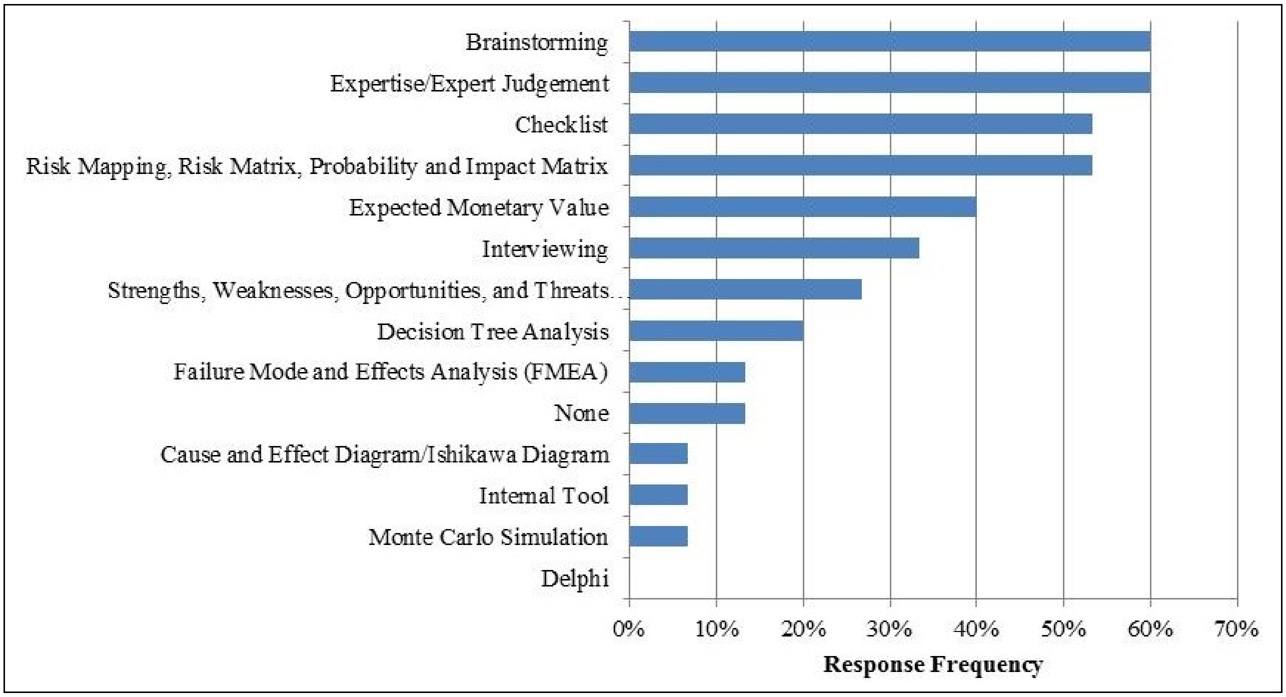


Figure 4-4. Risk Evaluation Methods Reported in Second Delphi Panel

(53%) and risk mapping (53%) were the most commonly-reported risk evaluation methods. Interestingly, 40% of respondents reported using expected monetary value, which relies on a large amount of historical data to implement (Grimaldi et al. 2012). The above average use of this technique may indicate that ESCO professionals seek out and prefer methods that express risk as a conditional cost given scenarios that may or may not occur during a project.

While the data is reported in this chapter as part of data collection and analysis activities, the insights gained are most pertinent to the risk analysis and evaluation strategy development in Chapter 5. Based on the knowledge constructed from the Delphi panel, the risk evaluation strategy used for this research must include the following characteristics and features:

- Incorporate expertise of ESCO professionals, especially key decision makers;
- Utilize scenario-based expected cost measures; and
- Utilize probabilistic functions for evaluation parameters, where feasible.

4.3.4 Risk Identification

Consensus was sought, and obtained in the first Delphi round with regard to the twelve risk categories included in the preliminary risk framework (Table 2-5). Panelists were asked the frequency with which they consider each risk category in their MUSH market EPC retrofit projects, using a seven-point Likert-type scale (Vagias 2006), which utilized the following response categories: (1) 100% - Every Time, (2) ~90% - Usually, (3) ~70% - Frequently, (4) ~50% - Sometimes, (5) ~30% - Occasionally, (6) <10% - Rarely, and (7) 0% - Never.
Positive risk identification was denoted when a panelist indicated that they considered the risk in categories one through six. Consideration was defined as addressing a risk category through contractual means (e.g., inclusion of an energy rate escalation term), via technical means (e.g., conduct a peer review of energy model results), through project management (e.g., specific team member assigned to coordinate activities among planning, engineering, and execution groups), or by financial means (e.g., include a "hedge" factor to account for potential uncertainty).

Consensus was reached for all 12 risk categories (1A-1C and 2-10) as depicted in Table 4-7. Sixty-six risks were identified as belonging to these 12 risk categories. Achieving consensus also confirmed the selection and identification of the 12 risk categories in the preliminary framework.

The distribution of risk identification responses was also examined using a boxplot (Figure 4-5). Review of the boxplot indicates that identification frequency for all 12 risk categories was negatively skewed and the data set contained a number of outliers. These are denoted by "○"(mild outlier) and "*" (extreme outlier) which are defined as Q1-1.5xIQR|Q3+1.5xIQR and Q1-3xIQR|Q3+3xIQR, respectively. The boxplot further reveals that the least amount of

Table 4-7. Identification of Risk Categories in the Preliminary Risk Framework

Risk Category	**Frequency**^{a}
1. Client Selection Factors	
1A. Financial Factors	84% (84%)
1B. Facility/Technical Factors	84% (100%)
1C. People Factors	95% (95%)
2. Project Development	95% (100%)
3. Energy Audit Quality	95% (100%)
4. ECM Selection and Installation	100% (100%)
5. Commissioning	100% (100%)
6. Operations and Maintenance Practices	95% (95%)
7. Measurement and Verification of Savings	100% (100%)
8. Project Management Over the Project Life-Cycle	74% (74%)
9. Construction-Specific Concerns	95% (100%)
10. Volatility of Energy Prices	89% (89%)

Notes:

a\ Value in parentheses is after all outliers were removed. Outliers were defined as Q1-1.5*IQR and Q3+1.5*IQR. Shaded rows include risk categories with increased identification frequency after removal of outliers.

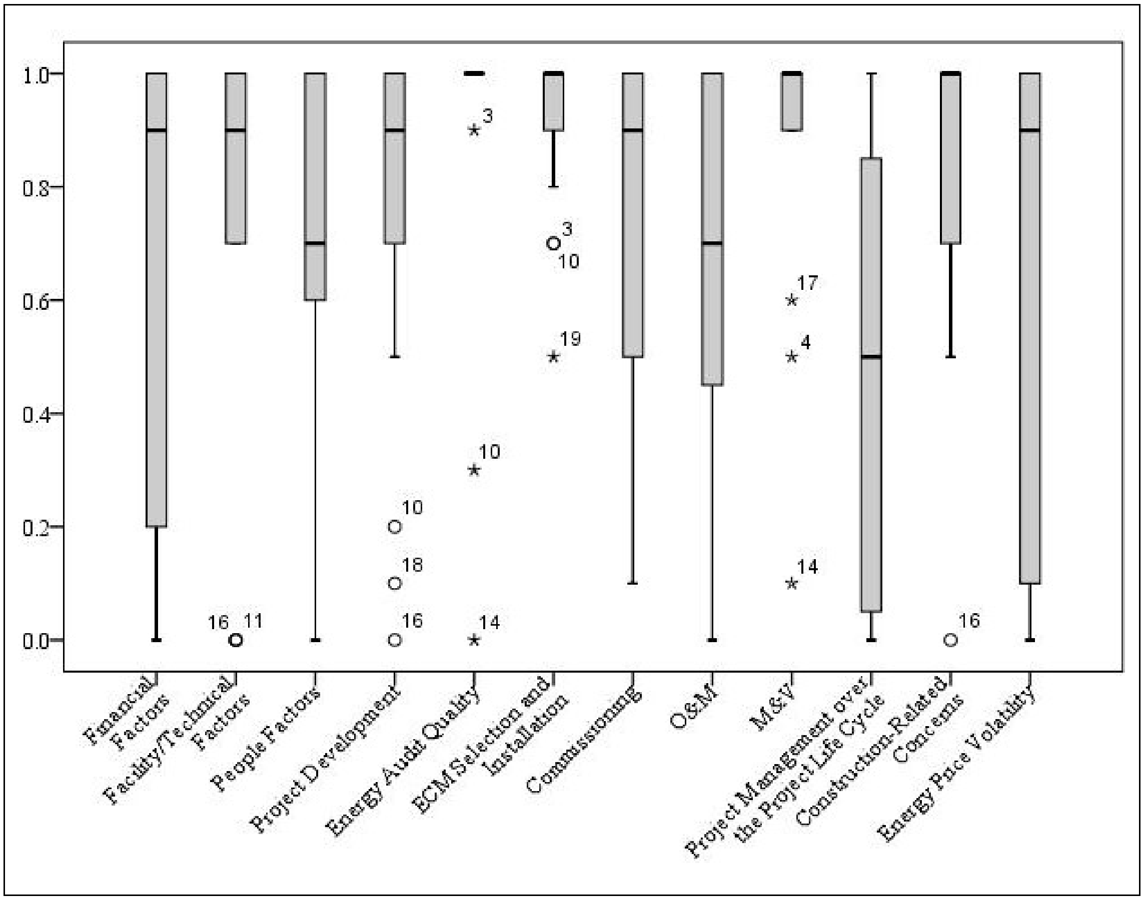


Figure 4-5. Range and Distribution of Risk Consideration Frequency

variation in panelist responses to frequency of risk consideration were with regard to energy audit quality, ECM selection and installation, and M&V.

Panelists were afforded the opportunity to add additional risk categories that did not appear in the a priori framework; 11 additional risk categories were identified. Analysis of transcripts and a summative review of each of the newly-identified risk categories resulted in 10 being classified as individual risks belonging to existing risk categories, and one was retained as a new risk category (Table 4-8). This resulted in an additional 12 risks being identified as belonging to the relevant risk categories, bringing the number of risks identified by Delphi panelists to 78.

Table 4-8. Additional Risks Identified by Panelists

Risk	Disposition	Delphi Consensus Status			
		1st Round		2nd Round	
		N	%	%	Consensus
Political Risks	Moved to individual risk under "Client Selection Risks - People Factors"	4	21%	100%	Achieved
Productivity Losses in Corrections Projects	Moved to individual risk under "Construction Phase Risks"	1	5%	87%	Achieved
Safety		1	5%	60%	Not Achieved
Changing Financial Incentives	Moved to individual risk under "Development Phase Risks"	1	5%	80%	Achieved
Cost of Doing Nothing or Self-Implementing		1	5%	80%	Achieved
Public Procedural Risks		1	5%	73%	Achieved
Time-Based Risk		2	11%	73%	Achieved
Timing		1	5%	73%	Achieved
Design Development	Moved to individual risk under "Energy Audit Quality"	1	5%	67%	Not Achieved
Staff Turnover During Project Lifecycle	Moved into individual risk under "Project Management Over the Project Life Cycle"	1	5%	80%	Achieved
Perception of the Performance Contracting Industry	Create New Risk Category	2	11%	100%	Achieved

Consensus was not achieved in the first Delphi round for the newly identified risk category, or the other ten risks in Table 4-8. As a result, during the second Delphi round panelists were asked the rate their consideration frequency of the new risk category, “Perception of the Performance Contracting Industry,” and they were asked for their concurrence with the other ten risks. Consensus was achieved for the inclusion of the new risk category, with 100% agreement during the second round. Consensus was also achieved for eight of the ten risks identified by panelists. Design development (67%) and safety (60%) did not meet the threshold value for participant agreement (70%), and were thus excluded from further analysis.

4.3.4.1 Identification of Most Important Risk Categories

The questionnaire included three subcategories for this knowledge category: (1) risk importance scoring of top three risk categories, (2) identification of risk causes belonging to each risk category, and (3) identification of risk control strategies. Delphi panelists were asked to identify the most important risk categories among those presented to them during the interview. The purpose of this review was to identify the risk categories that would be analyzed and evaluated in Chapter 5. Consensus was sought on this question, and panelists were asked to assign a de-facto risk importance score rank by identifying the three risk categories that they believed to have the greatest contribution to failing to meet guaranteed performance. There were 57 such available votes (59 were actually recorded because one panelist identified five important risk categories). A Pareto histogram of the relative importance scores for each risk category is provided in Figure 4-6. From the Pareto histogram, six risk categories were identified and ranked in the upper two quartiles for risk importance scores: (1) energy audit quality, (2) project development, (3) ECM

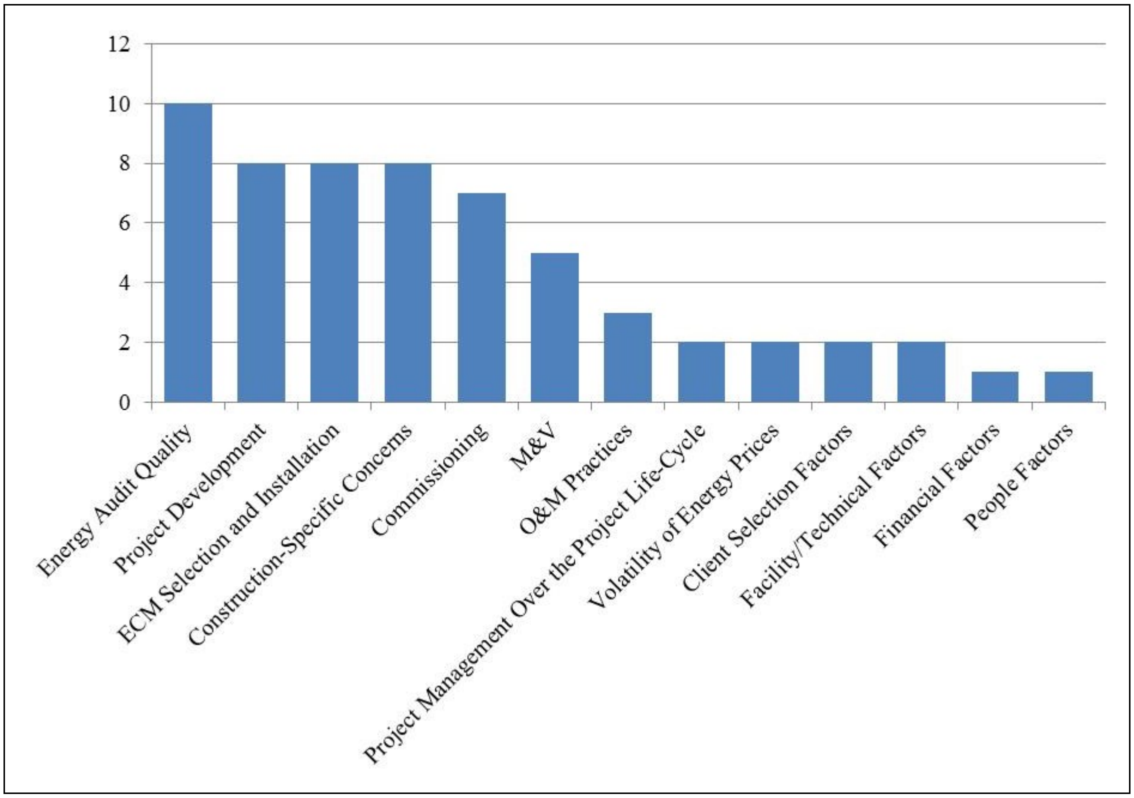


Figure 4-6. Pareto Histogram of Relative Importance Scores for Risk Categories

selection and installation, (4) construction-specific concerns, (5) commissioning, and (6) measurement and verification (M&V).

Risk consideration frequencies (Table 4-7) were reviewed for these six risk categories, and they were ranked again. The results of ranking using quartile analysis/Pareto histogram of risk importance scoring and ranking due to risk consideration frequencies are shown in Table 4-9.

The use of consideration frequencies eliminated the variation in risk category importance ranks. As a result, during the second Delphi round, panelists were asked to rank each of the six risk categories from 1 (most important) to 6 (least important). Results are shown in the rightmost column of Table 4-9. Consensus was achieved if two of the three ranking measures had rank order agreement for a given risk category. By that measure, four risk categories achieved consensus (energy audit quality, ECM selection and installation, commissioning, and M&V), while two did not (construction specific concerns and project development).

Table 4-9. Risk Importance Ranking from Delphi Panel Data

Risk Category	**Pareto/Quartile**[a]	**Consideration Frequency**[a,b]	**Delphi Round 2**[a]
Energy audit quality	1 (10)	4/1 (95%/100%)	1 (2.4)
ECM selection and installation	2 (8)	1/1 (100%/100%)	2 (3.0)
Construction-specific concerns	2 (8)	4/1 (95%/100%)	6 (3.9)
Commissioning	4 (7)	1/1 (100%/100%)	4 (3.6)
Project development	5 (5)	4/1 (95%/100%)	3 (3.1)
M&V	5 (5)	1/1 (100%/100%)	5 (3.7)

Notes:
a\ Numbers in parentheses are the raw values (e.g., non-ranked) for each variable.
b\ Values are ranks with outliers retained (left of slash) and with outliers removed (right of slash).

4.3.4.2 Panelist Characteristics Influencing Determination of Most Important Risk Categories

As was seen in Table 4-9, the disagreement across the three risk category ranking measures could be the result of the framing problem described by Kahneman (1981), Russell and Thaler (1985), Tversky and Kahneman (1986), and Klotz (2011). If this is indeed the case, it would be expected to find no relationship among the three variables: (1) risk importance score (Pareto/quartile analysis), (2) risk consideration frequency, and (3) round 2 Delphi scores. First correlation was used to determine the relationship between the risk importance score and risk consideration frequency, since both of these variables included all 12 risk categories. Since neither variable is normally distributed, Spearman's rank order correlation was chosen for this analysis instead of Pearson's correlation (Onwuegbuzie et al. 2007). This test has the additional benefit of being relatively insensitive to outliers, which is cited as a methodological concern with Pearson's correlation (Chok 2010). Results of the analysis indicated a strong positive monotonic relationship between risk importance score and risk consideration frequency (ρ=0.701, n=12,

$p<0.05$). Before analyzing the relationship among the three variables, a Spearman correlation coefficient was again calculated for the same variables as before, but now including only the six levels of the variables included in Table 4-9. No evidence of a significant correlation was detected in this test ($\rho=0.441$, $n=6$, $p=0.381$). This is likely a result of the extremely small dataset; as such, analysis of the relationship among the three variables was not conducted. Based on the initial finding of a strong and significant relationship between risk importance score and risk consideration frequency, it is reasonable to reject the presence of a framing effect for responses to these variables.

Other characteristics which may affect selection of the most important risk categories include panelist's length and nature of professional ESCO experience and their risk tolerance level. These reflect some of the underlying conditions of the status quo and professional biases as described by Klotz (2011) with respect to energy efficiency programs. Like the analysis of the presence of a framing problem, the purpose of this research is not a comprehensive characterization of the impacts of cognitive biases; however, it is important to recognize when the potential for such bias exists in data sets such as this one, collected using primarily qualitative means.

Given the non-normal distribution of the dependent variable (DV), risk consideration frequency, Spearman's correlation was again used to detect a relationship among the selected DV and four indicator variables (IV), one of which was measured two ways: (1) panelist's length of professional ESCO experience, (2) risk tolerance level (raw risk score from the TIAA-CREF AAE), (3) risk tolerance level (transformed raw risk score into the ordinal scale described in

Table 4-2), (4) job level, and (5) project phases worked on. The variables are described in Table 4-10 and the results of the correlation analysis are detailed in Table 4-11.

Table 4-10. Panelist Characteristic Indicator Variables

Variable	**Type**	**Values**
Length of Professional ESCO Experience	Scale	Years of experience
Risk Tolerance (Scale)	Scale	TIAA-CREF AAE scores - 0-96
Risk Tolerance (Ordinal)	Ordinal	TIAA-CREF AAE scores – 1 (conservative) through 5 (aggressive)
Job Level	Nominal	1 – technical staff; 2 – management; 3 – executive
Project Phases	Nominal	1 – pre-execution; 2 – execution or later; 3 – both; 4 - other

Table 4-11. Spearman's Rho and Significance Values – Panelist Characteristics

	Indicator Variables				
Dependent Variable	**Length of Professional ESCO Experience**	**Risk Tolerance (Scale)**	**Risk Tolerance (Ordinal)**	**Job Level**	**Project Phases**
Risk Consideration Frequency - All Risk Categories	$\rho = 0.150$ $p<0.05$	$\rho = 0.017$ *Not Sig*	$\rho = 0.050$ *Not Sig*	$\rho = -0.121$ *Not Sig*	$\rho = -0.144$ $p<0.05$

Based on the results of the correlation analysis, when examining the full data set (i.e., all 12 risk categories), risk consideration frequency and length of professional ESCO experience have a slightly positive, significant relationship ($\rho = 0.150$, N=216, $p<0.05$); the relationship with project phases that the panelist regularly works in is slightly negative and significant ($\rho = -0.144$, N=216, $p<0.05$). The individual relationships between risk consideration frequency and job level and risk consideration frequency and risk tolerance were insignificant. Collectively, only 4.3% of the variation in the DV is explained by both significant IVs. If bias is present, as indicated by the two significant IV relationships, their net effect is very small; therefore this is not deemed a concern with this data set.

It was initially believed that the most likely reason for the lack of an observed correlation between risk tolerance and risk consideration frequency was due to differential understanding of the context of the decision problem on the part of the panelists. The effects of this "framing problem" have been well-documented in the literature (Tversky and Kahneman 1981; McNeil et al. 1982; Russell and Thaler 1985; Tversky and Kahneman 1986). The potential presence of a framing problem was tested, and as reported earlier in this section did not seem to be present, thereby eliminating contextual issues as a possible reason for the observed lack of correlation. Kahneman and Tversky's (1979) Prospect Theory stated that individual decision maker behaviors are often shaped by the fact that losses hurt more than gains feel good, thereby implying an inherent bias toward risk aversion. Berny and Townsend (1993) and Raftery et al. (2001) found that construction and technical project managers tended to be risk-averse. While the risk tolerance questionnaire administered to the Delphi panelists suggested that ESCO professionals have wide-ranging risk tolerances, the data on risk identification frequency was positively skewed for each risk category, indicating that even the most risk averse panelists frequently give consideration to the identified risks on their projects. The researcher, therefore surmises that the lack of correlation between panelist risk tolerance and risk consideration behavior is the result of the average tendency of participants to give a high degree of consideration to risks, regardless of their individual attitude or tolerance toward risk.

4.3.4.3 Role of Contractual Language and Occupant Behavior in Risk Importance

Delphi panelists provided insight into which risk categories could be mitigated through contractual means. This typically took one of two forms, either through directly allocating a greater share of the risk to a third-party via contract language (e.g., the client, a subcontractor) or by including a safety factor into the contract to address such risks. Of the thirteen risk categories (12 from the preliminary framework and one from the refined framework), seven contained aspects that could be controlled contractually: (1) facility/technical factors, (2) people factors, (3) energy audit quality, (4) construction-specific concerns, (5) O&M practices, (6) M&V, and (7) energy price volatility. Specific aspects of these risk categories that panelists identified as being controlled through contractual means are discussed below:

- Possible future changes in the facility's use profile and attendant changes in energy consumption that relate to facility/technical factors are frequently addressed in project contract documents.
    - One panelist identified a situation where a public healthcare facility changed from being used for medically fragile individuals to persons with developmental disabilities.
    - The latter population was more active than the original population, requiring longer schedules for lighting and space conditioning in the new facility use scheme.
    - Such change was managed contractually via language limiting the ESCOs' responsibility for increased energy consumption resulting from the changed facility use.
- Human behaviors and activities (risks due to people factors) that are inconsistent with the retrofit design were also mentioned as being mitigated contractually.
    - ESCOs may employ continuous commissioning to quickly identify and remedy such issues.

    - The use of continuous commissioning and the responsibility of the client to manage occupant behavior are frequently specified in the contract.
- Energy audit quality-rated risks are often addressed contractually when the audit work is outsourced to a third party firm.
- Construction-related risks are controlled in a similar manner to energy audit quality risks when a third party firm is involved; many ESCOs contract the actual retrofit construction and equipment installation activities to a third party. The use of an approach similar to integrated project delivery was noted by two panelists as a means to control construction-related risks through contractual means.
- As described by panelists, O&M and M&V responsibilities are frequently outlined in the contract and include the requirement to adhere to designated equipment maintenance schedules, the requirement to maintain operation of any control systems, and the responsibilities, types, and duration of M&V activities.
- Over half of the panelists stated that energy price volatility is addressed contractually through the use of mutually agreed-upon energy escalation rates and the specification of the savings guarantee in terms of energy units (e.g., therms, kWh, CCF) saved, not dollars saved.

As stated previously in this section, risks related to the behaviors and activities of occupants, as well as general changes regarding building operation are frequently addressed contractually. Despite the use of this control strategy, several panelists alluded to the fact that it can be difficult to detect such behavioral changes. One participant indicated the use of continuous commissioning in order to monitor and provide timely feedback regarding unexpected energy consumption changes, which often result from behaviors attributed to the rebound effect, as described by Hertwich (2005), Herring and Roy (2007), and Strand (2011). Several panelists indicated that they do not realize these issues on their projects, and they frequently use the project development phase and their expertise to help control these risks. Many ESCOs indicated that they offer free training regarding appropriate O&M practices and the use of the specific technologies they install as part of the retrofit, as well as training related to the new features and enhancements made to the facility once the project is complete. This is done to supplement contractual requirements and help build a positive relationship with the customer in order to avoid potential disputes once the project is in the energy savings phase.

4.3.4.4 Selection of Risk Categories for Further Analysis

Based on the previous analysis, four risk categories were identified for potential further analysis: (1) energy audit quality, (2) ECM selection and installation, (3) commissioning, and (4) M&V. This enabled the remainder of the research to focus on empirical analysis and evaluation of a targeted group of risks that represent those that have the greatest potential impact on the outcome of EPC retrofit projects.

Commissioning-related risks primarily consisted of net effects resulting from the failure to commission and the extra costs of commissioning associated with implementing and managing a controls program. Risks related to M&V included measurement concerns (improper measurement, lack of sub meters, and use of an improper baseline) and issues related to the M&V plan (failure to include O&M, understatement of system performance by neglecting the effects of NEBS, and poorly-designed protocols that inaccurately reflect system performance). In both cases these risks are realized during and after execution, at which point the contract has been signed and energy savings have been guaranteed. As a result, there is limited opportunity for the ESCO to pursue change orders during these project phases. Furthermore, some of the early phase risks identified by Delphi panelists (i.e., before the contract is signed) incorporated commissioning- and M&V-related issues, thereby enabling their treatment during the next steps of this research, risk analysis and evaluation. As a result, no further evaluation of these risk categories or their related risks is planned as part of this research.

As described earlier in this chapter, the energy audit phase of EPC retrofits consists of conducting the facility audit, conducting an analysis of previous utility bills, and development of the energy model based on facility information. This leads to two critical decisions arising from this phase: (1) establishment of the facility's utility baseline and (2) identification of areas of improvement which serve as inputs to the retrofit design phase. Proper establishment of the baseline is critical as it directly impacts energy savings calculations and an improper baseline can lead to disputes (Mozzo 2001; Mills et al. 2006; Sankey 2007). As depicted in Figure 4-13, the baseline also impacts M&V-related risks and the execution phase. The retrofit design determines the selection and installation of ECMs as well as the technical scope of the project, and influences the complexity and cost of the M&V plan. As a result, both the energy audit quality and ECM selection and installation risk categories were selected for further analysis and evaluation.

Based on the foregoing, risks related to the energy audit quality and ECM selection and installation are the focus of risk analysis and evaluation activities in chapters 5 and 6.

Table 4-12 includes expertise elicited from panelists with regard to causes of and control measures used for energy audit quality-related risks and equipment selection and installation-related risks. Achieving consensus among panelists was not a goal for the two knowledge categories addressing individual risks (e.g., risk causes) and their associated control measures (e.g., mitigation strategies) because the intent was to fully-describe the risk-based decision making process with regard to the top two identified risk categories. Since risk causes and mitigation strategies would be subject to review by SFMEA panelists as part of the risk scenario

Table 4-12. Risk Causes and Control Measures for Top Risk Categories

Risk Category	Risk Causes	Risk Control Measures
Energy Audit Quality	Existing Conditions • Facility age – code update • Misunderstanding existing conditions, such as possible presence of asbestos Facility Stakeholder Concerns • Differing stakeholder needs Inexperience • Failure to understand facility operations and EPC goal – lack of EPC experience Information and Analysis • Calculation errors • Conducting the IGA too quickly • Energy model calibration error • Inaccurate/incorrect or disputed baseline • Information availability and accuracy • Missing information • Missing risk assessment for each ECM Project Complexity and Guaranteed Savings • Establishment of the guarantee amount - difficult balance between providing a large-enough project to generate client excitement and ESCO value and hedging on savings • Overstatement of issues leading to mismatch with technical needs; understatement of issues leading to reduced project value	Existing Conditions • Complete set of facility drawings • Conduct a code review Information and Analysis • Complete set of facility drawings • Contingency factors • Identify risks for each ECM being evaluated and the entire ECM portfolio • Include potential but unverified concerns in the IGA • Interview all facility staff and back-brief them on the findings to "ground truth" the audit results and uncover any missing information • Third-party internal review based on historical projects Project Complexity and Guaranteed Savings • Contingency factors • Third-party external reviews • Use stipulation and IPMVP Option A wherever appropriate

Table 4-12 (cont'd)

Risk Category	**Risk Causes**	**Risk Control Measures**
ECM Selection and Installation	Contractual Concerns • Owners and/or project designers and engineers are used to design-bid-build in the public sector and are not used to designing based on fixed budgets and do not understand EPC cost structures • Disconnect between the design and audit intent – improper efficiency target; different operating schedule implemented than what was planned; different control system installed • Subcontractor quality and reliability • Unqualified and unsafe contractors create additional risks ECM-Specific Issues • Cheapest equipment sometimes selected – leads to sub-optimal O&M savings • ECM package constructability and feasibility • ECMs are not aligned with the IGA findings • Failure to perform as designed • Uncertainty in factors used to predict performance Facility Factors • Installation location Occupant Concerns • Comfort complaints can add extra work after construction is complete • Lighting is difficult to demonstrate before installation; owner and occupants can be unhappy with light quality after a retrofit Project Complexity and Guaranteed Savings • "Low-hanging fruit has been picked" – increasing complexity of ECMs • Lowest-cost solutions may create value concerns during O&M Security Concerns (Correctional Facilities) • Accessibility to inmates/physical security	• Information – equipment-specific Contractual Concerns • Assign a team member to align outsourced design team with internal energy auditing team • Coordinate phase handoffs between project developer and energy engineer • Designate a team member to coordinate contractor and ESCO team members. • Pre-qualify subcontractors • Robust CM practices • Use ESCO's own forces for complex aspects of system design, whenever possible • Use EMR ratings to assess subcontractor safety ECM-Specific Issues • Identify risks for each ECM being evaluated and the entire ECM portfolio • In-house design teams for specialty ECMs (e.g., lighting) that can have complex design and performance issues Project Complexity and Guaranteed Savings • In-house design teams for specialty ECMs that can have complex design and performance issues

construction process, assessing the validity of the knowledge constructed by Delphi panelists was possible.

4.3.5 Define Energy Performance Contract Retrofit Project Phases and Key Decisions

Energy performance contract retrofit projects can generally be organized into five phases - (1) project development, (2) energy audit, (3) retrofit design, (4) project execution, and (5) energy performance, although some variation occurs depending on the procurement process used. Tetreault and Regenthal (2011) identified a preliminary and final audit phase, separated by the design phase for the federal Energy Savings Performance Contracting (ESPC) model and the European Association of Energy Services Companies identified a four phase model that moves directly from a preliminary audit to detailed engineering analysis and design (Petersen 2009). The final phase model was developed through data collected from the Delphi panel and literature reviewed as part of knowledge elicitor training. The generalized five phase model is depicted in Figure 4-7. Each project phase contains a brief description of key actions taken and decisions (in italics) made by the ESCO during that phase, which informs the development of the retrofit process model. This information was the result of analysis of Delphi data using the elicitation strategy developed for this project, as mentioned above. A brief description of each phase is provided after Figure 4-7.

4.3.5.1 Project Development

The project development phase includes tasks related to the assessment of a request for proposal (RFP) or other procurement documentation. This phase culminates with the ESCO's decision

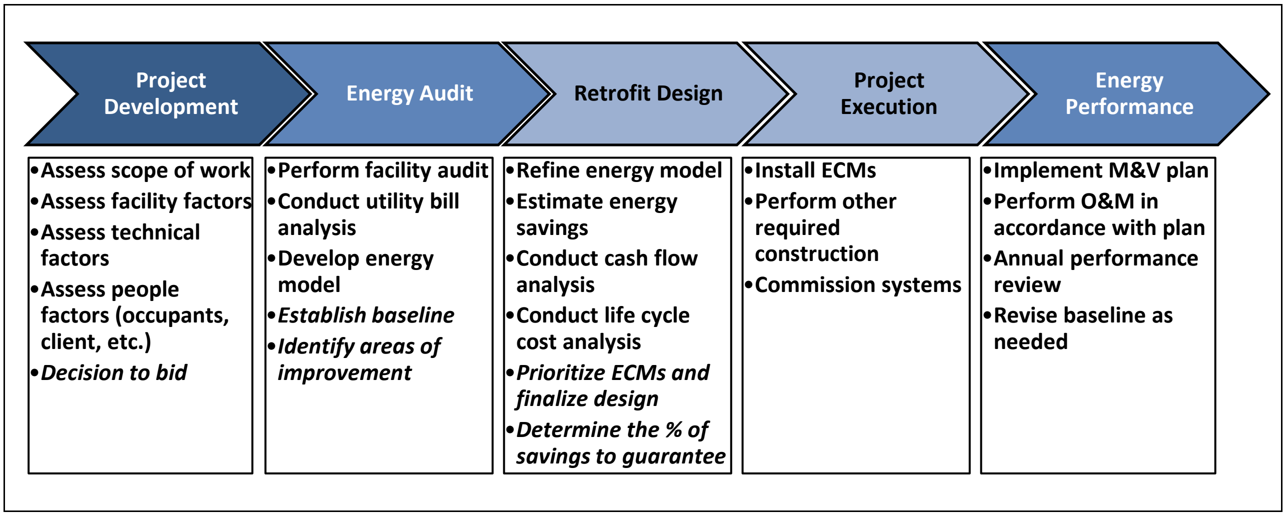


Figure 4-7. Energy Performance Contract Retrofit Phases

whether or not to bid on the work. This "go/no-go" decision is typically based on an analysis of factors related to the facility and technical aspects of the project, the finances of the client, and the people involved in the project (e.g., building owners, occupants, client staff), and includes an analysis of the project scope of work.

Facility and technical factors include characteristics of the building or buildings to be retrofitted. These may include potential changes in future occupancy and use of the facility and unknown latent conditions, such as the presence of hazardous materials, infrastructure that needs to be abandoned, or mechanical and electrical equipment that is not code compliant. These issues may be evaluated through a preliminary or walk-through energy audit.

People factors can include the existence of an existing business relationship between the ESCO and owner (be it previously successful or unsuccessful), human behavior that overrides the energy savings benefits of the retrofit (i.e., the rebound effect) and that is, therefore, inconsistent with M&V plans, improper O&M activities undertaken by customer as a result of limited capacity to understand and/or perform the work, and project interference with building operations due to the unique nature of building occupants or operating schedules. Examples of the latter concerns include preservation of clean, conditioned air during retrofit activities for medically-fragile occupants, and movement restrictions due to differing security levels inside a correctional facility.

Financial factors include concerns about the client's ability to secure financing and make lease payments throughout the project life cycle. The project development phase culminates in an ESCO's decision whether or not to bid on a project.

4.3.5.2 Energy Audit

As described in Chapter 2, energy audits do not necessarily conform to a third-party standard; however, ASHRAE has developed a standard for energy audits, categorized as Level 1, Level 2, and Level 3 (ASHRAE 2011; Baechler, Strecker, and Shafer 2011). A Level 1 audit may be considered a preliminary audit, consisting of a rapid assessment of building performance, installed technologies, and an assessment of potentially-applicable incentives and grant programs. Such audits may be performed during the project development phase to assist the ESCO in deciding whether to bid or to assist them in developing their RFP response. Both the Level 2 and Level 3 audits require a more detailed analysis of building systems, consisting of an assessment of energy sources and end uses, discrepancies in system operations, a thorough analysis of utility bill data, and identification of potential ECMs for each system, to include a range of possibilities, associated costs, and prioritization of ECMs based on limiting factors such as cost, infrastructure capacity, building end-use, and system interactions. The key difference with the Level 3 audit, also termed the investment grade audit (IGA), is the collection of operating data across longer time periods, the use of whole-building energy simulation modeling, and modeling of each ECM for performance and life cycle cost characteristics (ASHRAE 2011).

The energy audit also serves to identify building conditions that may increase the project cost if detected during project execution. This can include the presence of outdated infrastructure which requires an upgrade to be compliant with current standards, the presence of hazardous materials requiring remediation during retrofit activities, a decision whether supporting infrastructure (e.g., steam pipes, ductwork) for systems to be retrofitted should be removed or abandoned in-place, a review of missing details on as-built drawings, or an assessment of unknown site conditions.

A key aspect of the energy audit phase is the development of, and multi-party agreement to, the facility's energy baseline. This process involves an assessment of utility bill data, a review of facility operating parameters and the condition of building equipment, a review of the building's operating profile (e.g., hours of operation, ventilation and conditioned air requirements, the presence of occupants requiring controlled indoor environments), and fitting the energy model to observed operating parameters and utility consumption. Ultimately, the goal of the energy audit phase is to identify areas of improvement for the building and assess a variety of strategies to provide those improvements. Determination of the utility baseline and identification of areas for improvement are the two key decisions made during this project phase.

4.3.5.3 Retrofit Design

The primary goal of the retrofit design phase is to prioritize ECMs and develop a final engineering design based on energy models and economic analyses. This ensures that the design meets the owner's project requirements (OPR) and that it provides sufficient savings during the performance period to fully pay for the retrofit and associated work. By refining the energy model to develop an estimate of energy savings and completing a cash flow analysis for the life of the project and a life cycle cost analysis of selected retrofit measures, ECMs can be prioritized based on their ability to meet energy-related, non-energy-related, and financial OPR. Completion of the retrofit design phase results in two key decisions: (1) a prioritized list of potential ECMs and the resulting final retrofit design and (2) a determination of the amount of savings to be offered as the guarantee (often referred to as deration).

4.3.5.4 Project Execution

Selected ECMs are installed along with any other required construction during the project execution phase. While this may include necessary upgrades in order to be in compliance with building codes, removal of hazardous materials, or upgrading infrastructure to support the newly-installed retrofit measures, this can also include measures not directly-related to ECMs such as capital improvements to the building envelope. To illustrate the concept of how the consequence of a risk cause can change during the project's life cycle, asbestos-containing material that is discovered during the project execution phase results in an unrecoverable project cost for the ESCO, whereas the costs associated with that same issue when discovered during project development or the energy audit phase can potentially be recovered.

As mentioned previously, the facility type and its operating profile may limit construction to specific times or create additional restrictions on construction activities. Hospitals frequently require additional protection of indoor air quality during construction; schools may limit construction activities to non-occupied times; and correctional facilities often have detailed and lengthy procedures for daily check-in and check-out, tool security, and relocation of inmates during construction activities.

Besides installation of retrofit measures, the other primary activity during the project execution phase is the commissioning of newly-installed systems and existing systems that were impacted by the new ECMs. This is required to ensure that the building and its systems operate optimally and in accordance with the OPR. Additional savings in EPCs have also been demonstrated through a robust commissioning program (Stum 2000; Jennings and Skumatz 2006).

4.3.5.5 Energy Performance

Once the ECMs have been installed and commissioned, the project moves into the energy performance phase. During this phase, the M&V plan is implemented. This plan should be developed at the same time the engineering design is finalized, and needs to be agreed to by the owner and the ESCO. Chapter 2 included a description of the four options for M&V included in the International Performance Measurement and Verification Protocol (IPMVP) including a discussion about the role of stipulation. Briefly, options A and B focus on the M&V of individual systems (Option A utilizes partially-measured isolated systems, and may include stipulation, where Option B utilizes fully-measured isolated systems), Option C requires whole-building M&V (includes existing and retrofitted components), and Option D requires calibrated whole-building simulation and is used when baseline data is not available.

An important corollary to executing the M&V plan is ensuring that system O&M is performed to required levels. Improperly-maintained systems can lead to missed opportunities for energy savings due to sub-optimal performance. O&M may be performed by the owner, through their own forces or through contract, or the ESCO may provide a service contract separately from the EPC contract.

Annual assessments of energy performance are used to determine whether the guarantee is being met by the ESCO; insufficient energy performance results in the ESCO remunerating the owner in the amount of the shortfall. With mutual agreement among the parties, the energy baseline may be revised during this phase; typically this occurs if the operating profile of the building has changed (e.g., end-use, hours of operation, specific occupant requirements), if required O&M is not being performed by the owner, or if the owner makes any additional changes to the building that are outside the scope of the EPC contract.

4.3.6 Risk Categories by Project Phase

Over the course of a typical EPC retrofit project with a 12-15 year performance period, decisions regarding the project design are made during the earliest parts of the project life cycle. Since EPC retrofits generally contain little to no opportunity for ESCO-driven change orders, there is limited opportunity for cost recovery once the performance contract is signed. As a result, it is posited that performance risks are generally greater during the latter phases of the project, after the energy savings guarantee is signed. The most important risk management actions would likely take place during the earliest project phases, when decisions are made that have long-term impacts on project performance and can effectively mitigate risk by including them in the project's pro forma before the energy savings guarantee is signed. Figure 4-8 summarizes the relationship between cost and the ability to influence design, risk, and uncertainty. Polygon X on Figure 4-8 describes a space termed the "window of opportunity" (Horsley et al. 2003), a limited period of time during which the project design can be improved so that performance is enhanced, project costs are reduced, and project-related risks are most effectively managed (Kmenta and Ishii 2001; Kishk et al. 2003).

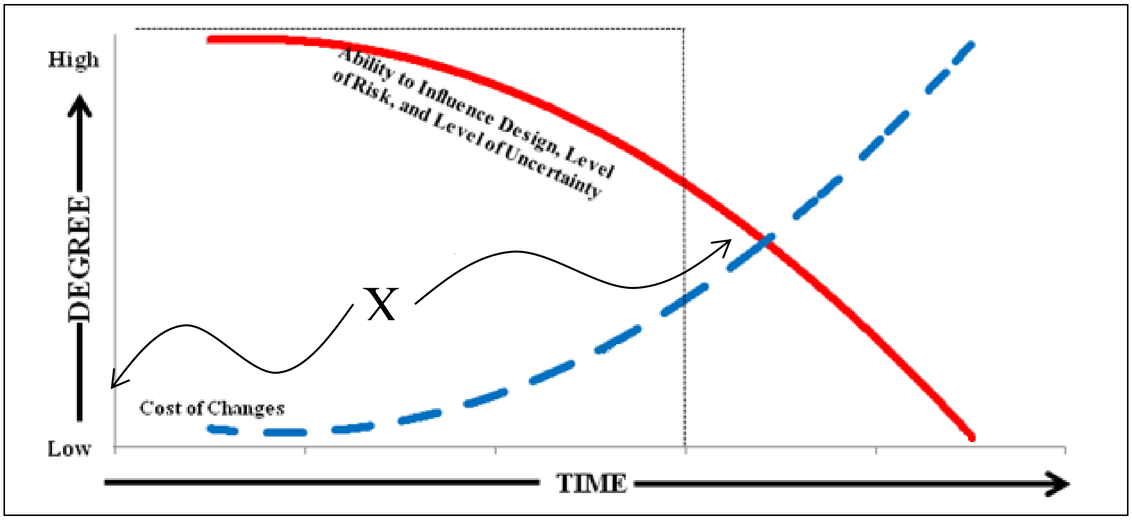


Figure 4-8. Project Decisions and Costs Over the Project Life Cycle
(Adapted from Kmenta and Ishii 2001; Horsley et al. 2003; Kishk et al. 2003)

Based on elicited expertise related to the knowledge categories pertaining to risk identification and risk importance scoring, each risk category was assigned to the project phases where they occur and a mean risk importance score was recorded. Project life cycle phase assignments and risk importance scores are provided in Table 4-13. This relationship is depicted graphically in Figure 4-9, which provides a conceptual understanding of how risk is realized over the life cycle of a typical MUSH market EPC retrofit project. As expected, the risk importance score is highest in the earlier phases, since decisions made here have lasting impact over the length of the performance contract; this corresponds to the time when the cost of changes is the lowest and the ability to influence project performance is the greatest. An assessment of the overall project risk profile, with regard to the level of performance risk, is provided in Chapter 6 as part of the pilot application of the risk model.

Table 4-13. Risk Category Importance by Project Phase

Risk Category	**Project Phase**	**Mean Risk Importance Score**[a]
Financial Factors [b]	Project Development	7
Facility/Technical Factors [b]		
People Factors [b]		
Project Development		
Energy Audit Quality	Energy Audit	10
ECM Selection and Installation	Retrofit Design	5
Volatility of Energy Prices		
Commissioning	Project Execution	7.5
Construction-Specific Concerns		
O&M Practices	Energy Performance	4
M&V		
Project Management Over the Project Life Cycle[c]	Not Assigned	2

Notes:

a\ The mean score is the average frequency of all risk categories in a given project phase.

b\ While listed separately, these risk categories were treated as one for the purposes of calculating the mean score, since they were sub-factors of "client selection risks."

c\ A single phase score was not assigned because this risk category occurs in each project phase.

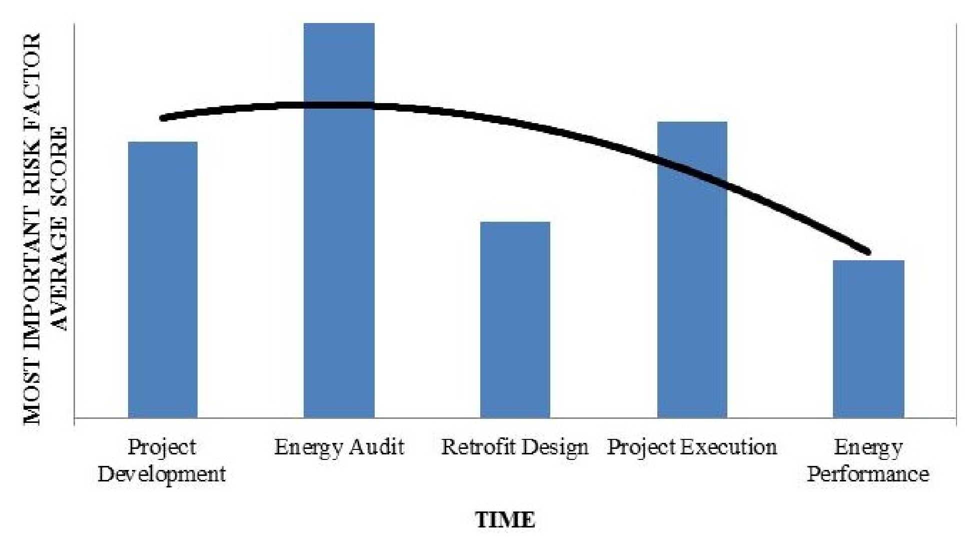


Figure 4-9. Most Important Risk Category Average Score by Project Phase

4.4 REFINED ENERGY PERFORMANCE CONTRACT RISK FRAMEWORK

The a priori risk framework presented in Chapter 2 was refined as a result of data collection and analysis as described in section 4.3. This a posteriori framework informed the development of two other deliverables of this research. The EPC retrofit process model, discussed later in this chapter, is premised largely on the expertise elicited from the Delphi panel and the information encapsulated in the refined risk framework. The ESCO risk framework also provided the inputs to the first steps in the SFMEA process, by providing potential risk causes from which the panel developed risk scenarios and by providing risk controls and mitigation strategies for evaluation.

4.4.1 Changes from Preliminary Framework

Based on data collected from the Delphi panel, the preliminary risk framework was refined in three ways: (1) risk categories and risks were modified, (2) risk causes and mitigation strategies were added, and (3) risk category identification frequencies and relative risk importance scores were added. Table 4-14 depicts the refined (a posteriori) risk framework, and its components and modifications from the preliminary risk framework are presented below.

Table 4-14. Refined Risk Framework for ESCOs Undertaking MUSH Market EPC Retrofit Projects

Risk Category	Delphi %[a]	Quart[b,c]	Risks and Causes	Controls/Mitigation
Client Selection Factors	84% (84%)	1(3)	Financial Factors • Customer may not be able to get financing. • Unacceptable customer debt ratio.	• Utilize standardized qualification method.
	84% (100%)	1(3)	Facility/Technical Factors • Building staff overrides equipment schedules or set points. • Changes in future occupancy and use. • Clients either prefer or have mandated shorter contract lengths which limit technical scope of work. • Facility age – code update requirements. • Interference with building operations due to unique schedules or facility needs (e.g., schools, hospitals, and prisons). • Unknown latent site and facility conditions.	• Address concerns contractually. • Conduct code review. • Conduct a feasibility study.
	95% (95%)	1(3)	People Factors • Improperly-performed O&M by client's forces. • Occupants that require special management during project execution. • "Rebound effect" - human activity inconsistent with M&V.	• Address concerns with potential behavior of occupants contractually. • Offer training to operators and building occupants.
Project Development	95% (100%)	3	• Client self-implementation of specific work packages. • Cost to do nothing and operate inefficiently. • Costs incurred from project start-up; long development phases can lead to difficult to recover costs. • Lack of experience in a given market and/or with utility rebate programs can add significant workload. • Long procurement times for MUSH products can outdate pricing by a year or longer. • Political issues – owner's project decision makers in MUSH market may be elected, term-limited, etc. and cause a project to lose continuity. • Potential utility rebates may expire before the project is awarded. • Public entities frequently change contract documents, terms, and conditions. • Some procurement methods require completion of an audit before a contract is awarded. • Timing of public projects can cause delays resulting in price increases.	• Document conversations among parties. • Track approvals given to the project. • Use escalation factor for price growth if procurement takes too long.

Table 4-14 (cont'd)

Risk Category	**Delphi %**[a]	**Quart**[b,c]	**Risks and Causes**	**Controls/Mitigation**
Energy Audit Quality	95% (100%)	3	Existing Conditions • Facility age – code update. • Misunderstanding existing conditions, such as possible presence of asbestos. Facility Stakeholder Concerns • Differing stakeholder needs. Inexperience • Failure to understand facility operations and EPC goal – lack of EPC experience . Information and Analysis • Calculation errors. • Conducting the IGA too quickly. • Energy model calibration error. • Inaccurate/incorrect or disputed baseline. • Information availability and accuracy. • Missing information. • Missing risk assessment for each ECM. Project Complexity and Guaranteed Savings • Establishment of the guarantee amount - difficult balance between providing a large-enough project to generate client excitement and ESCO value and hedging on savings. • Overstatement of issues leading to mismatch with technical needs; understatement of issues leading to reduced project value.	Existing Conditions • Complete set of facility drawings. • Conduct a code review. Information and Analysis • Complete set of facility drawings. • Contingency factors. • Identify risks for each ECM being evaluated and the entire ECM portfolio. • Include potential but unverified concerns in the IGA. • Interview all facility staff and back-brief them on the findings to "ground truth" the audit results and uncover any missing information. • Third-party internal review based on historical projects. Project Complexity and Guaranteed Savings • Contingency factors . • Third-party external reviews. • Use stipulation and IPMVP Option A wherever appropriate.

Table 4-14 (cont'd)

Risk Category	Delphi %[a]	Quart[b,c]	Risks and Causes	Controls/Mitigation
ECM Selection and Installation	100% (100%)	3	Contractual Concerns • Owners and/or project designers and engineers are used to design-bid-build in the public sector and are not used to designing based on fixed budgets and do not understand EPC cost structures. • Disconnect between the design and audit intent – improper efficiency target; different operating schedule implemented than what was planned; different control system installed. • Subcontractor quality and reliability. • Unqualified and unsafe contractors create additional risks. ECM-Specific Issues • Cheapest equipment sometimes selected – leads to sub-optimal O&M savings. • ECM package constructability and feasibility. • ECMs are not aligned with the IGA findings. • Failure to perform as designed. • Uncertainty in factors used to predict performance. Facility Factors • Installation location. Occupant Concerns • Comfort complaints can add extra work after construction is complete. • Lighting is difficult to demonstrate before installation; owner and occupants can be unhappy with light quality after a retrofit. Project Complexity and Guaranteed Savings • "Low-hanging fruit has been picked" – increasing complexity of ECMs. • Lowest-cost solutions may create value concerns during O&M. Security Concerns (Correctional Facilities) • Accessibility to inmates/physical security.	• Information – equipment-specific. Contractual Concerns • Assign a team member to align outsourced design team with internal energy auditing team. • Coordinate phase handoffs between project developer and energy engineer. • Designate a team member to coordinate contractor and ESCO team members. • Pre-qualify subcontractors. • Robust CM practices. • Use ESCO's own forces for complex aspects of system design, whenever possible. • Use EMR ratings to assess subcontractor safety. ECM-Specific Issues • Identify risks for each ECM being evaluated and the entire ECM portfolio. • In-house design teams for specialty ECMs (e.g., lighting) that can have complex design and performance issues. Project Complexity and Guaranteed Savings • In-house design teams for specialty ECMs that can have complex design and performance issues.

Table 4-14 (cont'd)

Risk Category	Delphi %[a]	Quart[b,c]	Risks and Causes	Controls/Mitigation
Commissioning	100% (100%)	2	• Commissioning is often taken out of the project if cost overruns are projected. • Failure to commission can effect system performance. • Implementing and managing a controls program can add extra cost and delay to commissioning and closeout.	• Balance amount of commissioning with project specifics to save costs. • Commission every point of a building automation system. • Commission with the customer. • ESCO self-performs commissioning. • Improve communications and collaboration with controls vendors.
Operations and Maintenance Practices	95% (95%)	1	• Cheapest equipment sometimes selected – leads to sub-optimal O&M savings. • Missed opportunities to verify ECM performance if fail to commission. • Missed opportunities to ensure that calibration, operation, and maintenance procedures are well-understood and documented.	• Delineate ESCO and owner responsibilities for O&M in the contract. • Stipulate factors that the ESCO does not have control of.
Measurement and Verification of Savings	100% (100%)	2	• Failure to include O&M in the M&V plan may lead to missed savings. • Improper measurement. • Lack of sub meters. • M&V protocols that do not capture non-energy benefits of EPCs may understate overall system performance. • Poorly-designed M&V sampling protocols may not accurately reflect the overall performance of the ECM package. • Use of an inaccurate baseline.	• Internal M&V review process. • Review M&V plan at the same time as energy savings are being calculated. • Stipulate factors that the ESCO does not have control of.
Project Management Over the Project Life-Cycle	74% (74%)	1	• ESCO personnel turnover. • Handoffs to different managers at each phase; can often be a long time between handoffs.	• Document everything properly.

Table 4-14 (cont'd)

Risk Category	Delphi %[a]	Quart[b,c]	Risks and Causes	Controls/Mitigation
Construction-Specific Concerns	95% (100%)	3	• Change orders are generally not allowed. • Cost growth. • Facility operating profile may limit times of the year when work can be done – long waits until then and short construction seasons may be common. • Long lead times for equipment. • Poor project handoffs among engineers and CMs. • Schedule growth. • Unknown site and facility conditions. • Unqualified or unprofessional sub-contractors. • Work productivity losses due to correctional facility security procedures.	• Build safety factors into proposals. • Early involvement of CM in project team. • Pre-qualify subcontractors. • Strong construction management. • Utilize a mandatory handoff process.
Volatility of Energy Prices	89% (89%)	1	• Changing prices can reduce project value. • Difficult to predict energy rate increases more than 2-3 years from the present time.	• Guarantee a quantity of energy saved, not energy costs. • Frequently monitor energy rates. • Use an acceptable energy rate escalation factor in the contract. • Use a floor rate to protect against large rate decreased.
Perception of the Performance Contracting Industry	100% (100%)	N/A[d]	• Lack of knowledge regarding EPC enabling statutes by the ESCO limits some customers' understanding of how they can use EPC. • Unethical behavior negatively impacts the industry as a whole.	

Notes: a\ Percent values indicate the frequency of risk category identification by Delphi panelists. The value in parentheses is the frequency with outliers removed.

b\ Quartile rankings come from Delphi panelists voting for the top three risk categories they believe can most negatively impact performance.

c\ Client selection factors were presented to Delphi panelists as three separate risks; however, many indicated that these should be treated as a single risk. The value in parentheses indicates the quartile ranking when each individual client selection factor was considered collectively as a single consolidated risk category.

d\ None of the panelists identified this risk category as being among those they believe most negatively impact project performance, therefore no quartile score could be calculated.

4.4.1.1 Risk Category and Risk Modifications

Risk categories and their associated risks were modified, deleted, moved to different categories, or added to the framework, based on the elicited expertise of the Delphi panel. Examples of such modifications include:

- The risk that the “client may go out of business before full contract payment” under the client pre-qualification/financial factors risk category was removed. Response from panelists was overwhelming that ESCOs typically have little concern about a client’s long-term ability to make payments since at that point, they are paying the financier and not the ESCO. Additionally, most panelists replied that in the MUSH market the greater concern is the ability for a public entity to secure financing, due to diminished bond ratings or a debt ratio that is too high. As a result, two new risks which better reflect concerns related to public client financing were added to this risk category: (1) customer may not be able to get financing and (2) unacceptable customer debt ratio.
- Several panelists provided additional details specific to MUSH market retrofits with regard to the “project development” risk category. These included risks such as lack of experience in a given market (specifically mentioned for corrections retrofits) and issues specific to the complex and often political nature of these projects. Those risks included long procurement times for MUSH projects, the political nature of public agency decision makers (e.g., elected, term-limited) that can cause a loss of continuity for the project, and the fact that some public procurement methods require the completion of a technical audit before the contract is awarded, thereby placing additional financial risk on the ESCO.
- The “project management over the project life cycle” risk category was better developed through the Delphi panel. This was included in the preliminary risk framework based on

Hansen (2006) and the preliminary ESCO expert interview; however, details were not well-developed at that time. Panelists provided that detail and several also identified that risk management activities are reviewed coincident to project phase transitions.

- Two panelists identified a risk which could not be placed with a corresponding risk category, thus a new one was added to the framework. “Perception of the Performance Contracting Industry” was added as a risk category that addressed concerns arising from ESCOs lack of knowledge surrounding legislative authorization for EPC programs, thereby limiting the scope of projects they can provide to their clients. Additionally, unethical practices were raised as a concern that can manifest itself on individual projects through client mistrust and miscommunication.

4.4.1.2 Potential Risk Causes and Risk Controls/Mitigation Strategies

During the process of providing risk importance scores, panelists were asked to provide causes and potential control strategies for their top three ranked risk categories. This was important not only in comprehensively defining each risk category, but also in providing inputs to the risk scenario development process described in Chapter 5.

4.4.1.3 Risk Category Identification Frequency and Relative Risk Importance

Risk identification frequency and relative risk importance scores, as described above, were added to the risk framework to provide a measure of the Delphi panel’s specific risks of concern. This is particularly useful for future research when identifying and evaluating project risks with panels comprised of different experts, and can help to facilitate cross-case comparisons between this data set and others.

4.4.2 Relationship Among Delphi Data, Risk Framework, and Retrofit Process Model

The expertise elicited from Delphi panelists was used as the primary data source for developing the EPC retrofit process model, as well as the refined risk framework. During analysis, patterns emerged relative to the relationships between the incidence and detection of project risks across project phases and the types of information used in making key decisions. Panelists provided information that allowed risk categories to be matched to the quantitative information and expertise used when making decisions throughout the retrofit process, which established a link between the two outputs of this chapter, depicted in Figure 4-10.

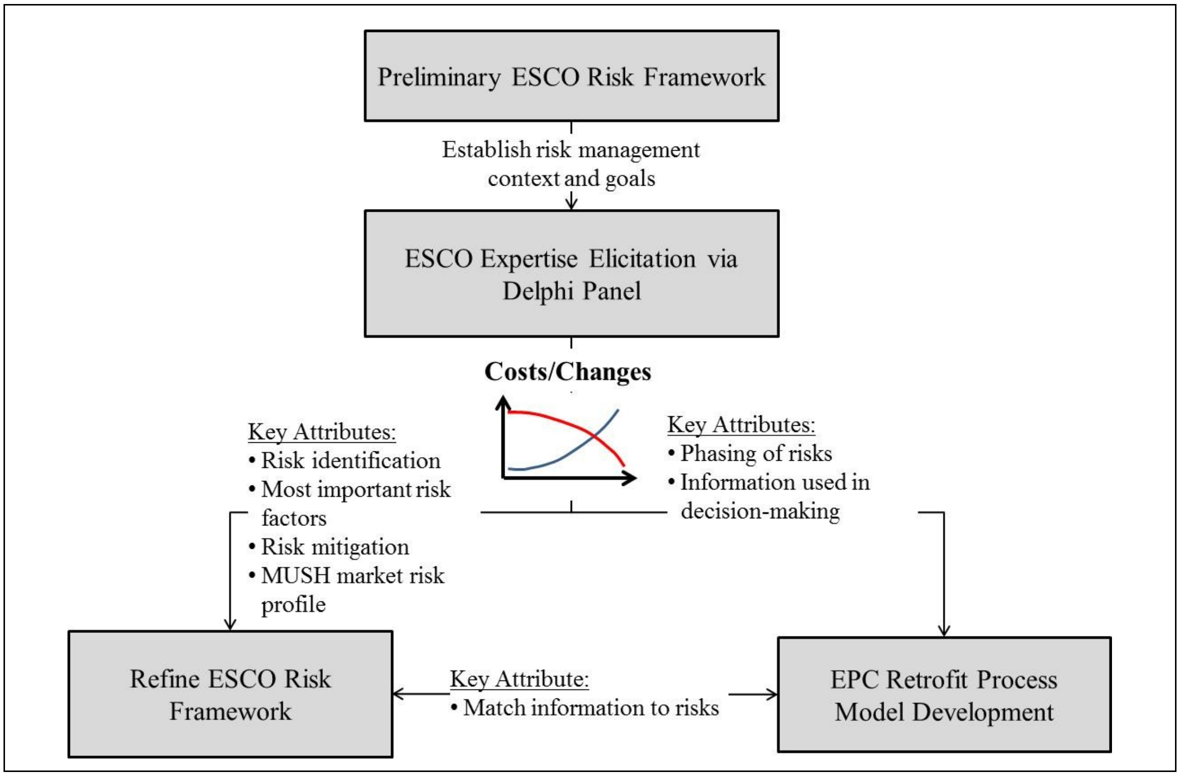


Figure 4-10. Relationship Between EPC Process Model and ESCO Risk Framework

4.5 EPC RETROFIT PROCESS MODEL DEVELOPMENT

ESCOs use a variety of information sources when developing and executing EPC retrofits. These sources can be categorized as being either quantitative information (e.g., energy model outputs, databases, design guidelines) or expert knowledge, as defined by Duah (2014). In order to fully understand the context in which risks are borne by ESCOs when undertaking EPC retrofits, it is critical to examine how different types of information are used during the retrofit process.

Information quality and availability is critical to the proper analysis and evaluation of risks throughout the project life cycle (Zavadskas et al. 2010). Knowledge acquisition has been given as a critical function during risk identification (Chapman 1998; Thaheem and De Marco 2013) and as the first step during qualitative risk analysis (Chapman 2001). An EPC retrofit process map that specifies information sources and project risks over the project life cycle assists in connecting the work undertaken during a retrofit with its related risks.

Ultimately, there are three overarching needs for the development of an EPC retrofit process model:

- Panelists ranked energy audit quality as the most important risk category across all three measures used: (1) Pareto/quartile, (2) consideration frequency, and (3) Delphi round 2. The IGA is essentially a comprehensive information collection and analysis task during which time facility information and financial information are used to design retrofit measures, specify M&V elements, and calculate the performance guarantee. As a result, the connection between information sources, project phases, and key decisions must be well-understood;
- As part of developing a comprehensive understanding of the context in which EPC retrofit decisions are made, the ways in which information is used when making decisions needs to be understood; and

- Information availability and quality has also been identified as a potential barrier to the wider adoption of energy efficient retrofits.

4.5.1 Information is a Barrier to Energy Efficient Retrofit Adoption

Cagno et al. (2013) reviewed several frameworks that have been proposed to explain the energy efficiency gap – the difference between potentially profitable energy efficiency retrofits and those that are actually realized. Issues related to information were present in all of the frameworks reviewed by the authors, either as a primary element or as an underlying issue that influences primary framework elements. Sorrell et al. (2000) (cited by Cagno et al. 2013), provided a major contribution by developing a framework focused on four economic (market and non-market failures) and non-economic (behavioral and organizational) theories. Information and its use in decision making was identified as a key barrier in three out of the four frameworks.

Cagno et al. (2013) further refined Sorrell et al.'s (2000) original taxonomy by conducting a comprehensive literature review focused on missing elements, overlaps, and implicit interactions. The authors proposed further empirical investigation of information barriers, to include lack of information on costs and benefits, unclear information provided by technology suppliers, mistrust of information, and information issues related to energy contracts arising from poor communication and unclear information provided by energy suppliers.

While this research is not concerned with identifying or classifying such information barriers, their presence needs to be accounted for in order to understand the EPC retrofit decision process.

As a result, the final model must include connections among sources and types of information, EPC retrofit project phases, and their attendant decisions made under conditions of risk.

4.5.2 Need for Expert Information

The taxonomy proposed by Sorrell et al. (2000) included two information-related barriers as part of the behavioral theoretical framework. This classification involved the ways in which people make decisions based on imperfect information. Very often decisions are made using “rules of thumb” or heuristics, as a result of imperfect information and the ways in which information is presented. This was described by Klotz (2011) as part of a broader discussion of cognitive biases in the use of such information. Ma et al. (2012) classified the selection of appropriate ECMs as a multi-objective optimization problem, and they stated that the problem can be developed and solved either using a model-based approach or through the use of an expert system. The latter option uses information elicited from disciplinary experts, rather than relying on modeled outcomes.

This use and reliance on expert-based information provides the entry-point to the system for cognitive biases due to information quality, availability, and the use of heuristics.

Duah (2014) and Syal et al. (2014) identified the critical role that expert information plays in the energy efficient retrofit process. Expertise is frequently used as a part of the EPC retrofit decision process, particularly during risk identification and evaluation, which was noted by the Delphi panel and in the literature (Banaitiene and Banaitis 2012). The reliance on expert knowledge, whether in a formal or informal context, is therefore an important element of the EPC retrofit process model, and its sources and use should be included.

4.5.3 Review of Existing Models

A variety of energy efficient construction process models can be found in the literature (Horsley, France, and Quatermass 2003; Juan et al. 2009; Kolokotsa et al. 2009; Jones and Bogus 2010; Samuel 2011; Ferreira et al. 2013; Syal et al. 2014). These are broadly applicable across a range of building types and energy efficiency goals, including new construction of university dormitories delivered using a private finance initiative, single family residential retrofits, new construction and retrofit projects that seek to improve indoor environmental quality, and commercial buildings. While none of these models address EPC retrofits or explicitly address MUSH market buildings, they do provide a basis for developing the EPC retrofit process model. The decision frameworks developed by Syal et al. (2014) and Ma et al. (2012) were reviewed to assist with the development of the model.

Syal et al. (2014) initially developed an energy retrofit decision process (ERDP) model to understand the types of information and their interrelationships as part of developing an intelligent decision support system (IDSS) to support enhanced residential energy efficient retrofits. The ERDP model focuses on key decisions related to the identification, prioritization, and installation of retrofit measures (Figure 4-11). Since the focus of the IDSS developed by Syal et al. (2014) is the provision of expert information to homeowners as part of the overall energy efficient retrofit process, the model focuses on aspects related to selecting and installing retrofit measures. As a result, the project development process, to include the energy audit and contractual decisions, are not included in the model. The ERDP model does, however, provide an excellent example of the integration of quantitative and qualitative information as well as the use of expert knowledge during its development process.

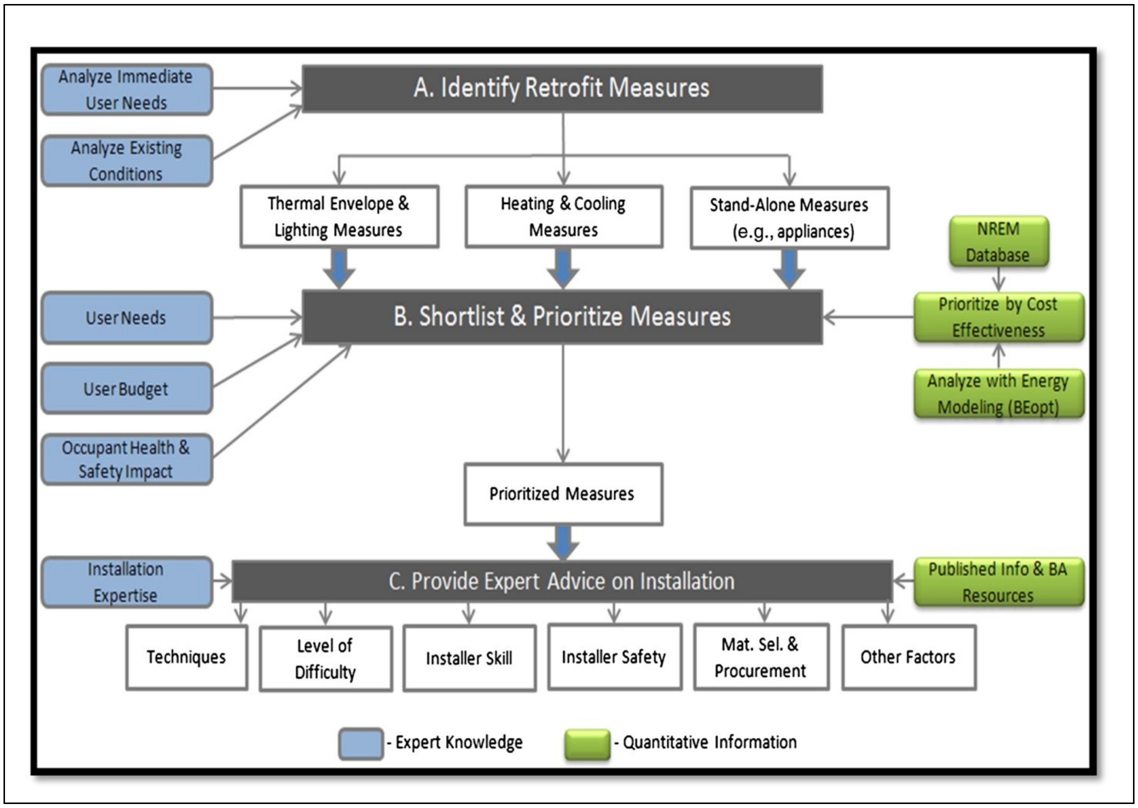


Figure 4-11. Residential Energy Retrofit Decision Process Model
(Source: Syal et al. 2014)

Ma et al. (2012) developed a process model for the identification and implementation of retrofit measures across a variety of building types (Figure 4-12), which provides significant focus to pre- retrofit activities and the types of information and resources needed to support retrofit activities. The model also recognizes the critical role played by M&V once retrofit measures have been installed. While this process model expands on the ERDP developed by Syal et al. (2014) through consideration of pre-retrofit and post-retrofit activities within the context of information needed for decision making, risk assessment is presented as a single step in the decision process. Analysis of data using the knowledge elicitation strategy reveals that risk assessment is an iterative process that occurs during all EPC retrofit project phases, with primary emphasis during project development, energy audit, and retrofit design phases. This evidences the need to fully incorporate risk assessment throughout the EPC retrofit process model.

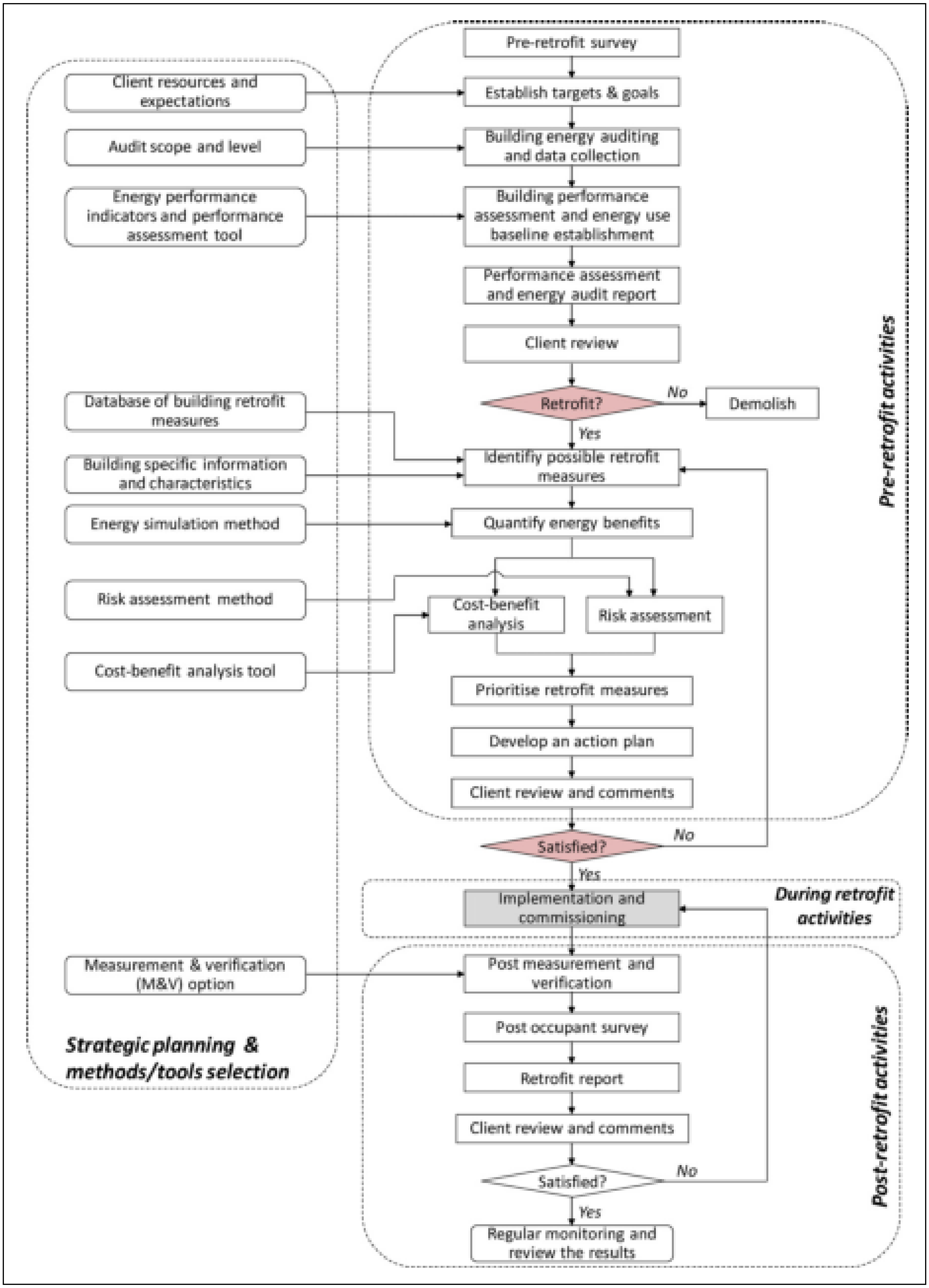


Figure 4-12. Sustainable Building Retrofit Process Model
(Source: Ma et al. 2012)

4.5.4 Information Needs

As described above, the EPC retrofit process is complex and lengthy. Decisions must be made during each project phase with regard to the technical, financial, and political aspects of these projects, and robust risk assessment is required to ensure that these decisions are made appropriately. Furthermore, the success of these projects relies on a significant amount of quantitative information and expert knowledge applied across a broad range of subjects. Ma et al. (2012) described six key elements that can impact the success of sustainable building retrofits: (1) policies and regulations, (2) client resources and expectations, (3) building-specific information, (4) other uncertainty factors , (5) human factors, and (6) retrofit technologies.

Samuel (2011) developed a framework for information needed to address barriers to residential energy efficient retrofit based on construction phases where these barriers and information needs are present. Information was classified as addressing barriers related to project performance, cost, and construction management and installation.

Both papers point to the need for an information framework in creating the EPC retrofit process model. While these models do not inherently provide comprehensive treatment of the information needs for EPC retrofits, they provide an example of the connection between needed information and the decisions they support. This highlights the potential to use elements of the preliminary risk framework to serve as the information model for the EPC retrofit process model.

4.6 EPC RETROFIT PROCESS MODEL ELEMENTS

Based on a review of elicited and constructed knowledge from the Delphi panel, a large number of ESCO risks in EPC retrofits are based on information and its use (Table 4-14). Decisions are made throughout the project life cycle that rely on appropriate and timely information, and many of those decisions can have significant implications on project risks. The development of an EPC retrofit process model is a preliminary effort to categorize the information needed throughout the EPC retrofit process, aligned with key decisions and their relationship to project-level risks.

4.6.1 Conceptual Grounding

A key underpinning of the EPC retrofit process model is the relationship among the ability to influence design, risk, and uncertainty; the cost to do so; and potential performance impacts, measured as cost savings on an EPC retrofit, at different stages in the project life cycle. This relationship, as depicted in Figure 4-8, evidences the notion that cost and performance risks can be efficiently controlled by effective decision making early in the project.

As described in Table 4-14, many of the causes for the two top-ranked risk categories (particularly IGA quality-related risks) given by the Delphi panelists resulted from inexperience, lack of information, improper information, or misinterpretation by ESCO professionals. Key to depicting the role of information in the retrofit decision process is connecting decisions made during critical project phases with information upon which those decisions are made.

4.6.2 Key EPC Retrofit Decisions and Information by Project Phase

The previous sections of this chapter were focused on the use of elicited expertise and constructed knowledge to construct a refined risk framework for ESCOs undertaking MUSH market EPC retrofits. This knowledge also contributed to understanding the connection among key project decisions and risk categories, the risk profile of each phase, and the types of information utilized in such projects. That information is brought together through the development of the EPC retrofit process model.

The EPC retrofit process model is depicted in Figure 4-13. Key elements include EPC retrofit project phases, quantitative information, expert knowledge, key decisions, and risks. Each of these model elements are described in the sections below, organized by project phase.

4.6.3 Project Development

The preliminary risk framework identified three sub-factors related to the "client selection" risk category. These were financial factors, facility/technical factors, and people factors. Project development risks also occurred during this phase, which consisted of contractual- and client-related issues as well as issues with external parties.

4.6.3.1 Decisions Made During the Project Development Phase

The principal decision made by the ESCO during the project development phase is the decision to bid based on project- and customer-specific characteristics. The risk importance score for the project development phase risk category (score=7) ranked third, behind energy audit risks (score=10), and project execution (score=7.5).

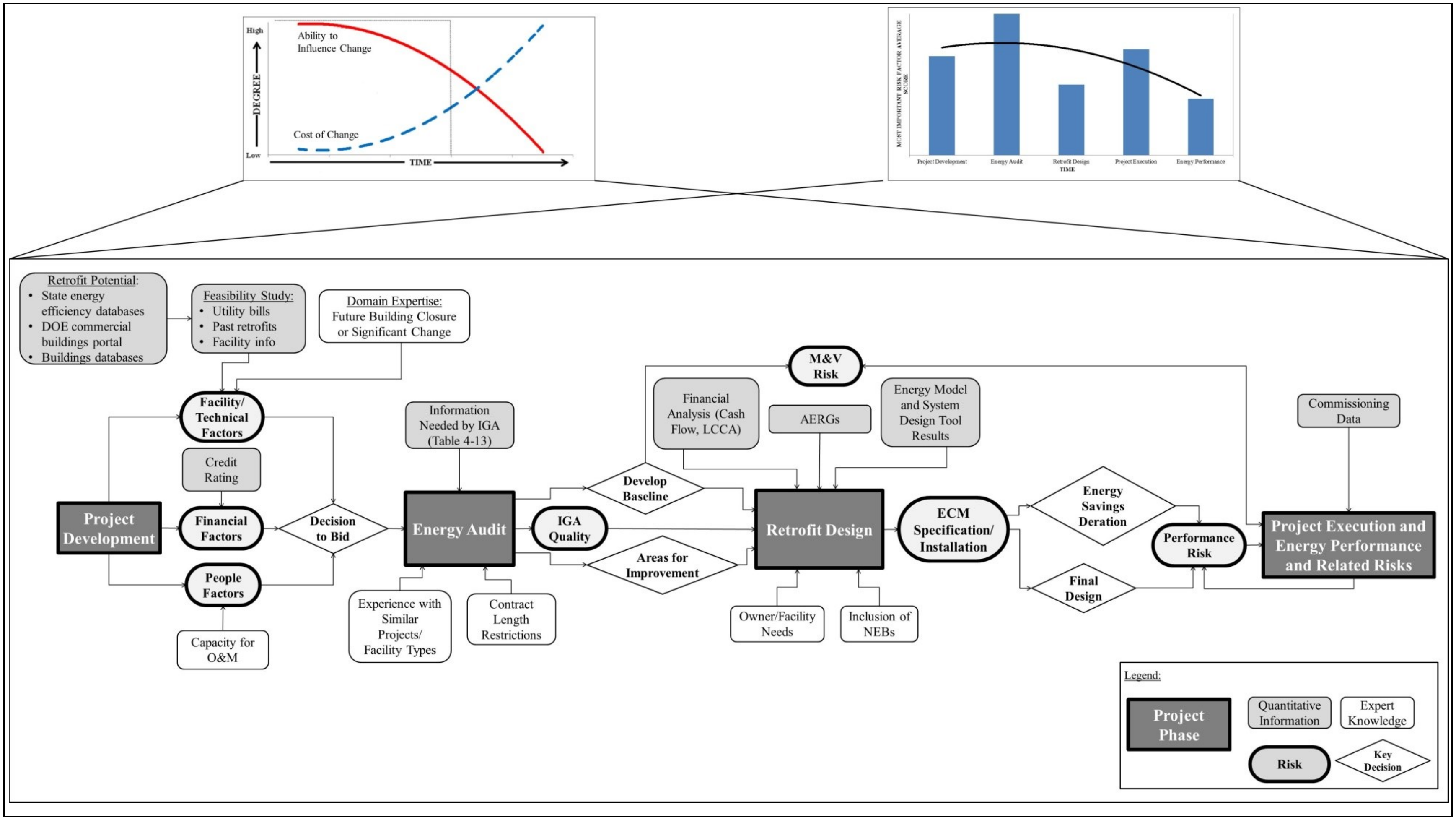


Figure 4-13. Energy Performance Contract Retrofit Process Model

4.6.3.2 Quantitative Information

Key information needs and sources as identified by the panelists included:

- The preliminary project feasibility study, often conducted as a conceptual, or Phase I energy audit, which relies on the following information sources:
    - Utility bills;
    - Past retrofits;
    - Facility information (e.g., conditioned gross facility square footage, building ages, locations of hazardous materials [e.g., asbestos], and code non-compliant infrastructure); and
    - Rapid assessment of retrofit potential. This rapid assessment is based on information about utility rebates and incentives that the project may potentially qualify for, and benchmarking of the facility against similar facilities in similar climate zones, as found in the U.S. Department of Energy Commercial Buildings Portal and available buildings databases.
- The customer credit rating is used primarily to determine the client's ability to access capital. Most panelists indicated use of public data for this purpose, to include the Data Universal Numbering System (DUNS) (Dunn & Bradstreet 2014). Panelists who conducted EPC retrofits for the U.S. Department of Housing and Urban Development reported mandatory use of the Public Housing Assessment System (PHAS), a tool that measures the performance of public housing agencies across the United States (U.S. Department of Housing and Urban Development 2014).

4.6.3.3 Expert Knowledge

Panelists reported reliance on expert knowledge when assessing risk categories in the project development phase and in support of the decision to bid. Expert knowledge was used as follows:

- Customer capacity to undertake O&M - This was specifically reported as a concern in K-12 school retrofits, where schools typically have a small maintenance staff that often has limited training in operating complex systems. This was also listed as a concern in some correctional facility retrofits, owing to small physical plant and maintenance staff complements at many facilities. Panelists reported that there are no rules to determine whether a client is adequately prepared to undertake O&M activities; rather, the determination is made on a case-by-case basis and a review of retrofit technologies and the qualification of the client's building operations staff.
- Assess the likelihood of the building being closed or significantly changing its use profile (e.g., days/hours of operation, occupant population) during the performance period - This determination is often based on past experience with similar facility types, the same owner (e.g., state agency, school board), and a general knowledge of environmental and fiscal conditions affecting the facility's future use.

4.6.4 Energy Audit

The principal activity during the energy audit phase is the conduct of the IGA and reporting of results. As a result, this phase is primarily concerned with information collection and analysis. The Delphi panel was clear that this phase requires significant time and attention and should be approached deliberately and comprehensively. One panelist identified a "tension" between the business development function and the need to spend time to conduct a thorough IGA, and attributed the cause of many potential risks to rushing through the IGA.

4.6.4.1 Decisions Made During the Energy Audit Phase

While decisions made in this phase are primarily related to the conduct of the IGA, the audit results have a significant impact on "downstream" project phases (e.g., those that occur after the IGA is finalized). As a result, phases that are beyond the "window of opportunity" described by Horsley et al. (2003) are shaped by activities and decisions arising from the energy audit phase. The two primary decisions resulting from the energy audit phase are development of the energy baseline and identifying areas for improvement for the retrofit design. An incorrect or disputed baseline can give rise to miscalculations during retrofit design, and errors related to M&V during project execution. Problems with identifying areas for improvement can have similar negative effects, and can result in missed opportunities for other retrofit measures that are not included.

4.6.4.2 Quantitative Information

This phase benefits from a diversity of information types and sources, as shown in Table 4-15. The sheer scope and volume of the information required by the IGA can lead to missing equipment during surveys, lighting miscounts, and inaccurate or missing information necessary to effectively assess the current state of facility energy use. Much of this information is provided by the client and it can often be difficult for the ESCO to recognize when information is missing or out of date. This information includes facility as-built drawings, equipment operating schedules, and utility bills, as well as that obtained through direct observation (e.g., facility

Table 4-15. Quantitative Information Needed During Energy Audit Phase

Information Description	**Information Description**
• Monthly utility bill data o Electricity – usage (kWh), demand (kW and kVa), power factor penalties (if assessed), and the total bill ($); o Other fuels – billing period, consumption units (e.g., CCF, gallons), cost per unit, and the total bill ($); and o Energy use normed to BTUs to permit cross-fuel source comparisons.	• Emissions reductions resulting from energy efficiency.
	• Benchmark data based on EPC retrofit goals.
	o Cost of delay (CoD), where *CoD= -(energy cost savings for period + O&M savings for period) + initial investment prorated*
• Energy consumption per unit of product (for industrial facilities).	• Cost avoidance (Ca), normalized to changed conditions (e.g., increased conditioned gross floor area), where *Ca = (baseline cost X current energy cost) – current costs*
• Facility information: o Conditioned gross square footage of building(s); o Operational profile, end-use(s), occupant types, building ages, age(s) of previous retrofits; and o Known locations of hazardous materials (e.g., asbestos) and code non-compliant infrastructure.	o O&M costs (e.g., training, staff time on O&M-related activities).
	o O&M service log (e.g., frequency and severity of required O&M activities).
	o Inventory of all energy-consuming equipment (location, use, operational profile, descriptive information, nameplate information).
	• Technical requirements of and eligibility for utility rebate, incentive, and grant programs.
• Current and estimated future energy prices.	• Emissions reductions resulting from energy efficiency.
• Technical requirements of and eligibility for utility rebate, incentive, and grant programs.	• Benchmark data based on EPC retrofit goals.

condition, light fixture counts) and informal information collected from building occupants and managers (e.g., desired indoor environmental conditions, confirmation of IGA findings).

4.6.4.3 Expert Knowledge

Expert knowledge is a significant factor for the success of the energy audit phase. Two primary types of expert knowledge are utilized:

- Experience with similar project and facility types – Panelists, particularly those involved with correctional facility EPC retrofits, identified past project experience as a critical factor to the success of the project. These projects have a great deal of unique factors, including reduced productivity due to daily check-in and check-out procedures and population control issues once inside the facility, security needs for all retrofit activities and technologies, and the hierarchical nature of corrections departments that can create a "command and control" approach to these projects. These factors, among others, need to be proactively recognized and understood during the energy audit phase to minimize risks in later project phases.
- Contract length restrictions - While the length of the project performance period is used as quantitative information when completing energy models and financial analyses, expertise is required during early project phases to understand customer preferences and legislatively-mandated contract length terms, and their impact on the scope of work.

4.6.5 Retrofit Design

Activities during the retrofit design phase are directed toward the final retrofit design. This is primarily an analytical phase, where data obtained during the energy audit phase are subjected to further analysis focused on ECM and facility technical, energy, and project financial parameters. Risks related to ECM selection and installation are realized here, as are risks related to volatility of energy prices and the way in which these costs are escalated.

4.6.5.1 Decisions Made During the Retrofit Design Phase

The key decisions occurring during the retrofit design phase are the final design of the selected ECM package based on findings from the IGA and the percentage of accrued savings to be guaranteed. One panelist commented on the latter issue, stating that he discusses the difference between modeled savings and guaranteed savings (often termed "deration") with clients as a risk mitigation strategy. His belief was that this approach allows him to share risks with the client by negotiating the deration against client-driven scope that does not have an associated energy savings component. This can result in agreeing to a higher energy escalation factor, or stipulating savings that would normally be measured and verified, as a way to deliver the client's desired scope while minimizing the ESCOs risk exposure.

These decisions directly impact the project's performance risk; that is, the ability for the project to return the guaranteed savings without requiring the ESCO to incur additional costs during the project execution and energy performance phases.

4.6.5.2 Quantitative Information

Information used to develop the package of retrofit measures includes:

- Financial analysis (cash flow, LCCA), based on the following information:
    - Current and estimated future energy prices;
    - Technical requirements of and eligibility for utility rebate, incentive, and grant programs;
    - Equipment replacement and O&M costs ;
    - Cost of delay;

    - Cost avoidance; and

- Outputs from computational energy models such as DOE2, eQuest, and TRNSYS, which are used to predict retrofit performance based on facility-specific factors. Panelists indicated that limited probabilistic ability of such tools prevents the development of predictive, scenario-driven model runs to address key uncertainties when designing ECMs. Heo et al. (2012) proposed a Bayesian method to address such concerns; however, most panelists were unaware of such options.
- Results of system design tools such as Trane TRACE that are directed toward specific types of equipment or particular manufacturers.
- Advanced Energy Retrofit Guides, such as those published by ASHRAE (ASHRAE 2012) and the U.S. Department of Energy (U.S. Department of Energy 2013b).

4.6.5.3 Expert Information

Two primary forms of expert information used during the retrofit design phase are:

- Owner and facility needs. Energy service company professionals must balance project needs with the intent and requirements of the facility owner, and of the facility itself. For example many public buildings, particularly schools and correctional facilities, have had a decades-long history of deferred capital expenditures. As a result, significant roof and building envelope problems persist in these buildings and clients often wish to include major upgrades as part of the EPC scope of work, despite the absence of a direct payback from these measures. ESCO professionals report negotiating such scope with clients, either through discussion of deration, as described above, or through the use of project contingency fees in the later years of the performance period, once guaranteed savings have been assured.

- Non-energy benefits (NEBs). While some NEBs can be, and are treated like energy savings (i.e., water savings), the inclusion of most in an EPC retrofit relies on previous experience of the ESCO with these measures, and willingness by the project team to attempt creative approaches to finding additional savings opportunities. NEBs are most often addressed through stipulation, and panelists reported an unwillingness to attempt M&V protocols for less-clearly defined benefits.

4.6.6 Project Execution and Energy Performance

4.6.6.1 Decisions Made During the Project Execution and Energy Performance Phases

Decisions made during these phases take place outside of the “window of opportunity” described by Horsley et al. (2003) when decisions can have maximum positive impact on design, level of risk, and overall project performance at minimal cost. These phases are, therefore, not the primary focus of the EPC retrofit process model, since decisions made once construction begins have limited ability to positively influence the project and are likely to incur higher costs. Despite that fact, decisions are made during earlier project phases that are realized during project execution and energy performance, such as design elements that are inconsistent with IGA results, thereby requiring equipment substitution or field changes during construction or updates and revisions to the energy baseline.

Project performance during these latter two phases can directly influence M&V risks by creating inconsistences with the planning documents that served as an input to performance guarantee calculations and by creating conditions that necessitate changes to the baseline. Performance during project execution and performance can also directly affect performance risk. According to multiple panelists, since the driver for EPC projects is being able to meet the performance guarantee, cost controls are of paramount importance and tend to be the deciding factor when the ESCO detects a need to make changes during execution and performance.

The totality of the project occurring up until execution and performance phases influences the risks that are inherent in these later stages. As a result, specific interactions among earlier risk categories in the earlier project phases and later project risk categories are not depicted in the retrofit process model. Panelists identified the following risk categories as occurring during these phases:

- Project execution, includes commissioning- and construction-related risks.
- Energy performance, includes risks related to O&M practices and M&V.

4.6.6.2 Quantitative Information

While the Delphi panel identified risks related to failure to commission or improper commissioning, they also regarded the commissioning process as an information gathering and verification step. In many cases it is the only time that equipment can be verified against the design intent and performance specifications, creating an opportunity to minimize risks through a process that itself bears its own risks. It is treated here as a source of quantitative information; however, its placement during later project phases indicates a higher cost and lower potential impact of changes made as a result of commissioning-related information.

4.7 CHAPTER SUMMARY

This chapter presented data from the Delphi panel related to risk identification as well as causes and mitigation factors used. The refined risk framework and EPC retrofit process model were developed from this information. These outputs are important in the development of a risk analysis and evaluation method in Chapter 5. The retrofit process model will be used to guide participants in the SFMEA panel as they construct and evaluate risk scenarios, paying attention to the time-bound nature of decisions and realized risks throughout the project life cycle. The refined risk framework provides additional input to the SFMEA panel relevant to risk identification and mitigation measures. Additionally, the Delphi panelists provided an assessment of the most important risk categories for ESCOs undertaking EPC retrofits. Two risk categories, energy audit quality, and ECM selection and installation were selected for further analysis and evaluation via the SFMEA process in Chapter 5.

CHAPTER 5

RISK-BASED LIFE CYCLE COST MODEL

5.1 INTRODUCTION

Chapter 4 described the collection and analysis of data via a Delphi panel consisting of 19 energy service company (ESCO) industry experts. The panel provided information regarding risk identification, unique risk aspects of municipality, university, school, and hospital (MUSH) market retrofits, and a prioritization of the top risk factors that can negatively affect the success of energy performance contracting (EPC) projects. Consensus was reached on these issues by panel members. The data was used to develop two related outputs, which served as inputs to the work conducted in this chapter. First, the preliminary framework for ESCO risks in MUSH market EPC retrofits, presented in Chapter 2, was refined in Chapter 4 through modifications made as a result of elicited and constructed knowledge from the Delphi panel. Second, the EPC retrofit process was modeled in Chapter 4, which incorporated sources of information used in making key decisions during each project phase. These outputs were developed as inputs to the failure mode and effects analysis (FMEA) method used to analyze and evaluate risks related to investment grade audit (IGA) quality and energy conservation measures (ECM) selection and installation, described in this chapter. While data collection efforts in Chapter 4 were focused broadly on MUSH market retrofits, efforts undertaken in this chapter have a primary focus on correctional facility EPC projects.

5.1.1 Glossary

Frequently used terms in this chapter are defined as below:

- EC: expected cost; a measure of risk that assesses the probability of the occurrence and missed detection of a fault, in terms of cost over the life cycle of the fault condition (Gilchrist
- 1993); calculated as EC= P_{cause} x P_{effect} x Cost;
- EC_{PV}: Present value of the expected cost;
- ELCV: expected life cycle value; the amount of risk (expressed as expected cost) effectively mitigated at a given cost, over the project life cycle; calculated as ELCV = EC - $Cost_{mitigation}$ - $Risk_{remaining;}$
- FMEA: failure mode and effects analysis;
- Life Cycle Cost: The systematic consideration of all costs and revenues associated with the acquisition, use and maintenance and disposal of an asset (Kishk et al. 2003);
- Life Cycle Cost-Based FMEA: FMEA analysis that uses cost as a measure of criticality, includes scenario-based FMEA;
- Posterior Probability: The conditional probability of an end effect occurring after considering all intermediate effects preceding it; P_{effect};
- Prior Probability: The probability of risk cause occurring before taking into account further evidence in the risk scenario; cause probability; $P_{cause;}$
- Risk Scenario: A cause-effect chain describing a root cause, end effect, and potentially intermediate effects, which lead to the calculation of an EC value;
- Risk Scenario Map: Multiple related scenarios organized together in a map to describe a particular system or function of interest;

- RPN: risk priority number; traditional measure of risk criticality utilized by FMEA that multiplies ordinal rankings (1-10 scale) of risk occurrence, risk severity, and risk detection to prioritize risks for further treatment;
- Scenario-Based FMEA: FMEA method that analyzes risk by constructing cause-effect chains to describe failures rather than defining a single cause-single failure mode relationship; and
- Single Present Value: SPV; calculates the present value of a future cash amount, for one-time amounts; SPV factor is calculated as $\text{SPV} = \frac{1}{(1+d)^t}$ where d is the discount rate and t is the year at which SPV is calculated.

5.1.2 Chapter Objectives

The primary goal of this chapter is the analysis and evaluation of ESCO risks in MUSH market EPC retrofits. The research activities described in this chapter focused on a sub-market of MUSH by analyzing these risks in correctional facility projects. Based on the selection criteria presented in Chapter 2, scenario-based failure mode and effects analysis (SFMEA) was utilized to meet the objectives of this chapter. These criteria included the ability of the method to address life cycle costs through risk evaluation, to favor the use of expert knowledge, to provide insight during project design and development stages. Results of the SFMEA were used to develop a life cycle cost-based risk criticality and mitigation framework, which is the main output of this chapter. The framework was then parameterized and developed into a life cycle cost-based risk model which is pilot tested in Chapter 6. The following objectives guide the work in this chapter:

- To implement risk analysis and evaluation through the use of SFMEA, utilizing previously elicited and constructed knowledge to establish a framework for risk analysis;

- To analyze risk criticality and understand the methodological relationships between risk priority number (RPN) and expected cost (EC) through the use of elicited expertise;
- To evaluate risks through developed risk control strategies; and
- To parameterize the risk analysis and evaluation framework developed in this chapter and construct a risk model to assess the cost-based risk of project-level factors related to the investment grade audit (IGA) and the selection and installation of energy conservation measures (ECMs).

5.2 RISK ANALYSIS AND EVALUATION FRAMEWORK DEVELOPMENT PROCESS

The building blocks for constructing the risk analysis framework include a priori knowledge, represented by the preliminary risk framework (Chapter 2) and a posteriori knowledge which was obtained through elicited expertise; the latter was the subject of the outputs from Chapter 4. This information was needed to identify risks and prioritize them for further analysis. Additionally, qualitative data regarding risk causes and controls/mitigation strategies was collected and analyzed during this step. This chapter presents efforts to quantify this data through a risk analysis and evaluation process, which is depicted in Figure 5-1.

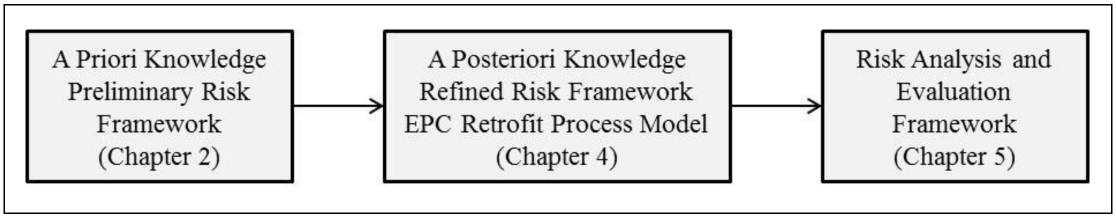


Figure 5-1. Risk Analysis and Evaluation Process

As discussed in chapters 2 and 3, the quantitative risk analysis technique selected for this research was SFMEA, described by Kmenta and Ishii (2000), Kmenta (2002), Kmenta and Ishii

(2004), and Rhee and Spencer (2009). Reasons for selection included the ability of the technique to analyze risks based on expert knowledge, its systematic and comprehensive approach to analyzing potential failures, and SFMEA's theoretical grounding in Bayesian belief networks (BBN), enabling the development of probabilistic measures of risk which are applied to cause-effect scenarios. Strengths of applying this technique to the research specifically relate to the ability for experts to develop risk scenarios based on their collective expertise and evaluate them using likelihood estimates of occurrence and costs. Using cost as a consequence measure is particularly suitable for construction engineering and management professionals, as this is a regularly-calculated and monitored metric. In a survey of 271 construction professionals from 56 countries, Thaheem and DeMarco (2013) found that expected monetary value was favored as a risk analysis technique by approximately 30% of respondents; furthermore, 65% of respondents reported seeking risk software outputs related to cost. Cost has also historically been a significant focus of quantitative risk analysis techniques, generally applied to the cost estimate (Edwards and Bowen 1998).

The development of the framework for the SFMEA consists of five steps: (1) review selected risk categories in the refined risk framework; (2) construct failure scenario maps; (3) evaluate risk criticality for each scenario; (4) recommend and evaluate mitigation strategies; and (5) calculate the expected life cycle value (Figure 5-2). A panel of four ESCO and retrofit professionals was assembled to conduct the analysis represented by each step of the framework. Panelist recruitment and selection, as well as final panel composition, is discussed in section 5.3. Each step of the process is described in detail in the sections below.

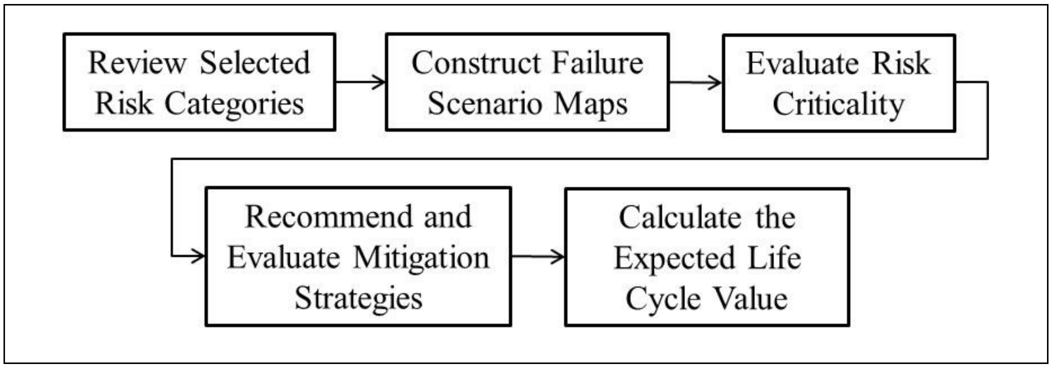


Figure 5-2. Risk Analysis and Evaluation Framework Development Steps

5.2.1 Review Selected Risk Categories

Risk causes related to the IGA quality and ECM selection and installation risk factors from the refined framework were reviewed. Panelists reviewed the 27 potential risk causes for both categories and made a consensus-based decision whether to evaluate them further. Decision criteria included the group’s agreement that the listed items accurately reflected root causes of project-level risks, that the items were assigned to the correct risk category, and that the items were not duplicated within the same risk category. The selection of potential root causes was subject to validation during the next step, construct failure scenario maps.

5.2.2 Construct Failure Scenario Maps

Failure scenarios are the central element of SFMEA. As opposed to traditional failure mode and effects analysis (FMEA), where the unit of analysis is the relationship between a single failure cause and single failure mode, scenarios enable the creation of a cause-effect chain (Kmenta and Ishii 2004). This chain consists of a root cause, an end effect, and possibly one or more intermediate effects (Figure 5-3). The root cause defines the first order event that gives rise to the elements of the failure scenario. The end effect is the verbal description of the risk consequence of the given scenario. Intermediate effects may further define the cause-effect relationship, and

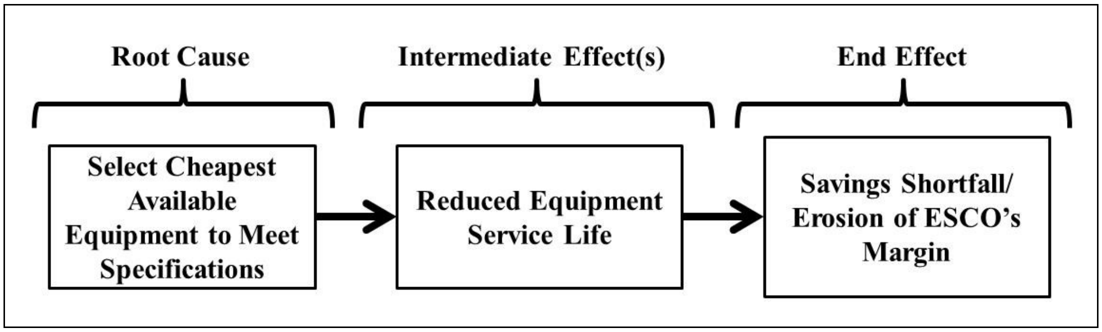


Figure 5-3. Example Failure Scenario

are placed between the root cause and the end effect. These describe the sequence of events that connect the root cause to the end effect in higher order scenarios (e.g., where the root cause does not lead directly to the end effect). The probability of the cause and that of the end effect given any intermediate effects, termed the conditional probability of the end effect, constitutes the risk likelihood.

As a scenario is constructed and evaluated, panelists may lengthen the chain in either direction either as a result of detecting and including a new root cause, new intermediate effects, or a new end effect. Multiple related scenarios may be organized into a risk map which describes the interrelationships among causes, intermediate effects, and end effects in a single system. This permits the creation of a one-to-many relationship among causes and effects, as one root cause can lead to several end effects and one end effect can have many root causes. Figure 5-4 depicts a scenario map which includes the scenario from Figure 5-3, and demonstrates how the cause-effect chain may be lengthened, how additional intermediate effects may be evaluated, and the one-to-many relationship potential among causes and end effects in failure scenario maps.

Panelists were provided with example scenario maps and undertook an iterative process that began with the identification of a single root cause followed by intermediate and end effects

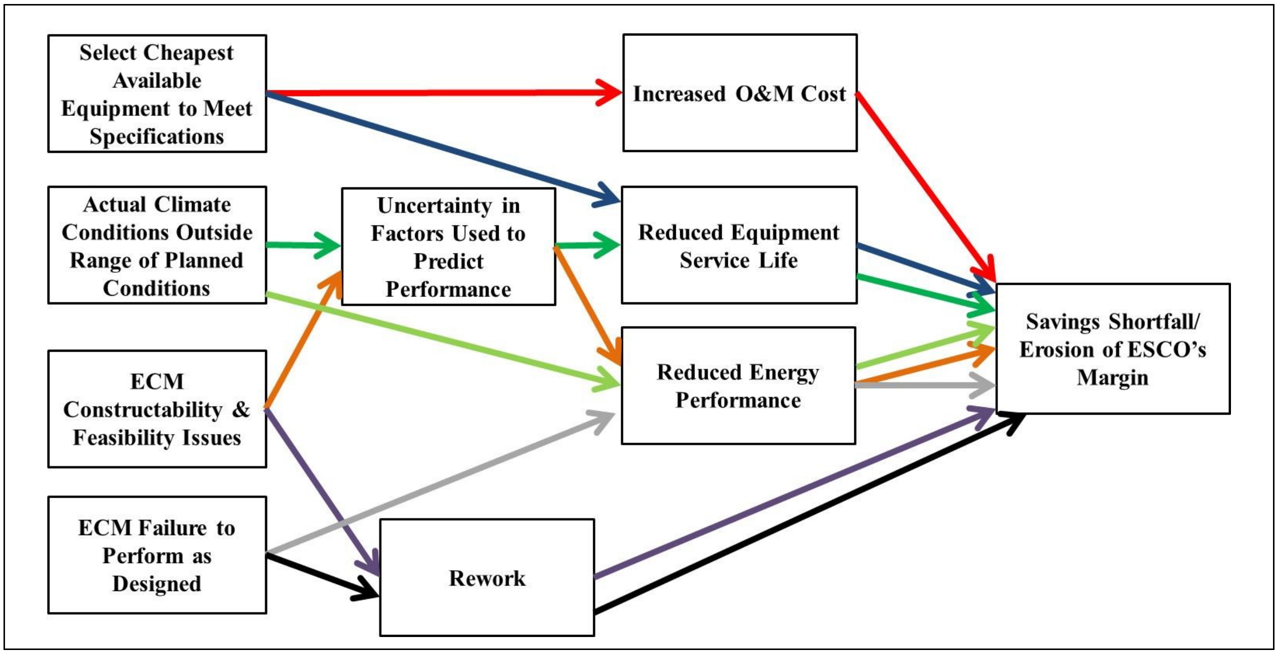


Figure 5-4. Example Failure Scenario Map

connected to that root cause. The scenario maps were revised repeatedly throughout the facilitated process as long as consensus was achieved among panelists.

5.2.3 Evaluate Risk Criticality

The assessment of risk criticality in FMEA entails identifying the risks that have the greatest overall impact on the system under review. As described in Chapter 2, criticality is assessed in traditional FMEA through the calculation of the RPN, which is the product of three independent measures of the failure mode: (1) occurrence (O), (2) severity (S), and (3) detection (D) (Stamatis 2003; Gargama and Chaturvedi 2011; Liu et al. 2013). Each measure is ranked on an ordinal scale with values ranging between 1 and 10, therefore, the RPN score ranges from 1 to 1,000. Several methodological concerns have been raised with the calculation of the RPN and its use to inform decisions under conditions of risk. Three such concerns include the use and improper arithmetic operation of ordinal values (Imbeah and Guikema 2009), duplicate values of the RPN that have very different characteristics (Gilchrist 1993; Kmenta and Ishii 2004), and a lack of linguistic terms regarding priority for managing critical failures identified through RPN values (Bowles 2004; Abdelgawad and Fayek 2010). Alternate criticality measures proposed to address these shortcomings include cost-based techniques (Gilchrist 1993; Kmenta and Ishii 2000; Rhee and Ishii 2002; Rhee and Ishii 2003; Kmenta and Ishii 2004; von Ahsen 2008).

Cost-based risk criticality measures have focused on the use of EC, which is defined as the product of the probability that a cost will be incurred and the cost (Gilchrist 1993; Kmenta and Ishii 2004). The determination of EC relies on an assessment the probability of the risk cause (prior probability) and the conditional probability of the end effect (posterior probability). With cost as the measure of consequence, Bayesian statistics are applied to calculate the EC value for each scenario (Figure 5-5).

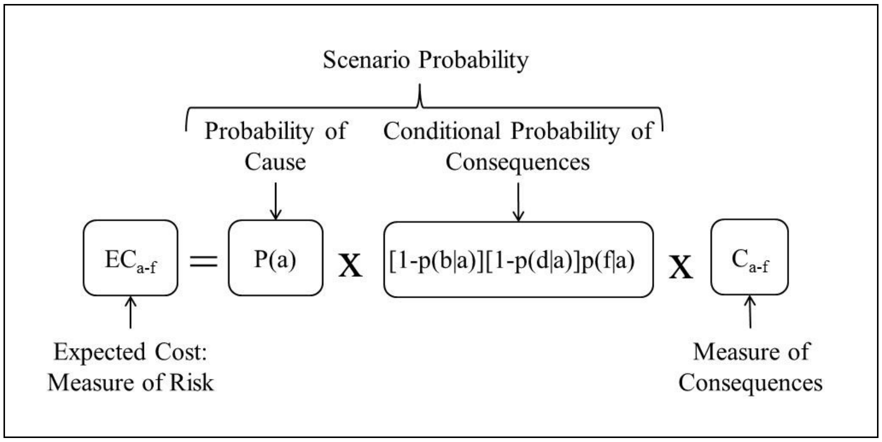


Figure 5-5. Calculation of Expected Cost
(Source: Kmenta and Ishii 2004)

Through its incorporation with risk scenarios, EC can also be used to assess costs over the project life cycle, as depicted in Figure 5-6, which shows a risk scenario map that was created to evaluate a root cause originating during the energy audit phase. As a result of intermediate

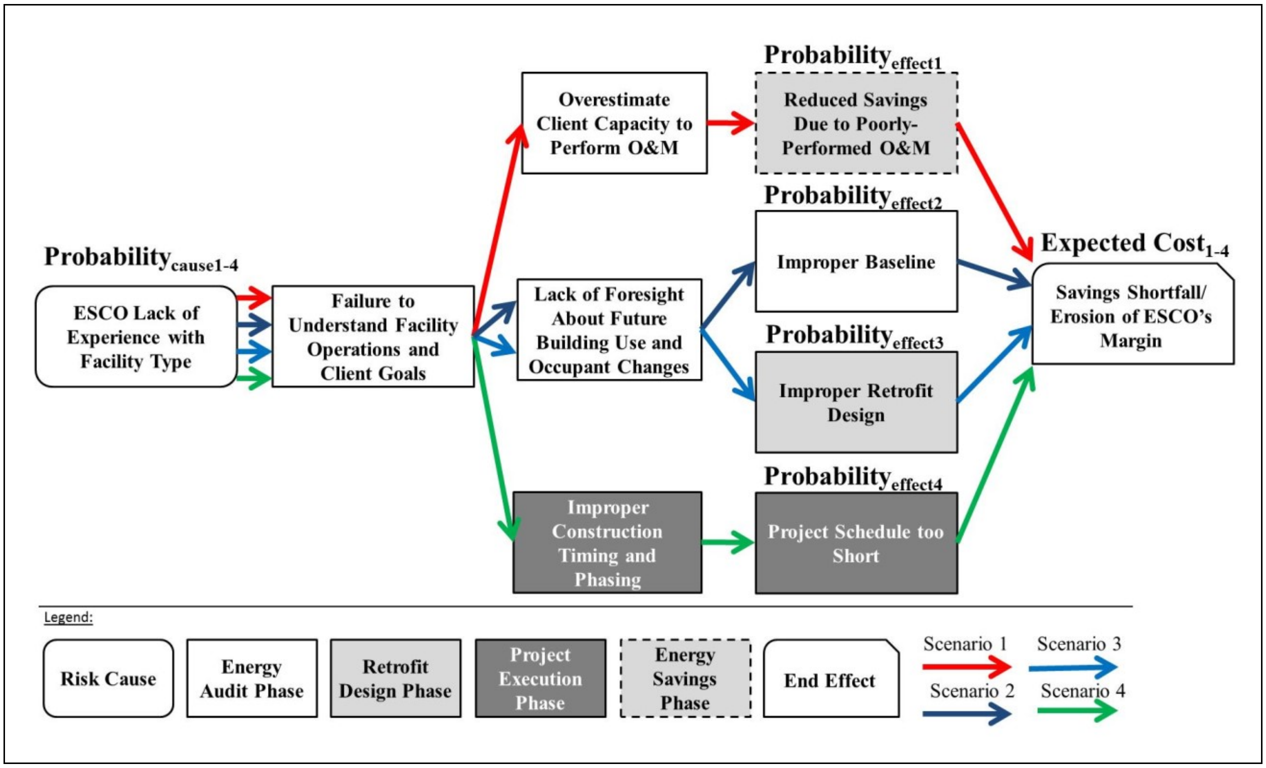


Figure 5-6. Use of Risk Scenarios and Expected Cost Over Project Life Cycle

effects, this map enables the assessment of EC for four scenarios which leads to the analysis of risks in four of the five EPC retrofit project phases.

Given the calculus of the conditional probability of the end effect, each scenario is evaluated based on risk events occurring throughout the project life cycle. For example, the EC for scenario 4 is calculated as the products of the probability of the ESCO having limited experience with a given facility type (identified in this case as correctional facilities), the conditional probability of a savings shortfall/erosion of the ESCO margin given the project schedule being too short, the effect of improper construction timing and phasing, a failure to understand facility operations and client goals resulting from the root cause, and the cost impact of the end effect. This method effectively analyzed an energy audit phase risk (ESCO's lack of experience) as it is realized during the project execution phase, when a short project schedule is detected during construction activities.

Kmenta and Ishii (2004) gave the latter point as another methodological improvement of SFMEA over the RPN method. Several definitions of detection are offered in the literature and in practice (Palady 1995; Stamatis 2003; AIAG 2008), which creates confusion as to which definition actually measures the contribution towards risk. Because of this confusion, several authors have suggested eliminating the detection score from FMEA (Bowles 1998; Society of Automotive Engineers 2001; Bowles2004) due to a high degree of subjectivity of the ranking and large variation among detection scores. The risk scenario map presented in Figure 5-6 addresses detection through the conditional probability of the end effect, given its placement in project space and time, and utilizes the same concept of probability as was used to assess the scenario's root cause. Again, the Bayesian calculus of SFMEA then multiplies the conditional probability by the scenario cost, thereby ensuring that the issue of risk detection is quantified appropriately.

In order to adequately address the time value of money inherent in this analysis, and to truly enable this method to evaluate life cycle costs, the resultant EC for each risk scenario must be discounted based on the time in the project life cycle where the risk is realized. The single present value (SPV) factor is used to calculate the present value of a one-time future amount given a discount rate. The equation to determine the present value of a given EC using SPV is (Fuller and Petersen 1995):

$$\mathrm{EC}_{\mathrm{PV}} = EC_t \mathrm{X} \frac{1}{(1+d)^t}$$

where EC_{PV} = the present value of the EC, EC_t = the future expected cost at time t, d = the discount rate, and t = the time in years when the risk is realized.

For the purposes of the remainder of this chapter, the non-discounted value of EC will be used for comparing the cost-based and RPN-based measures of risk criticality. The EC_{PV} is useful when evaluating the life cycle cost implications associated with the risk scenarios, both individually and in the aggregate. It is particularly necessary when providing information to aid decisions about selecting mitigation measures, which incur costs in current dollars and evaluating those costs and benefits in light of expected costs that have been discounted to the period where the risk is realized. The EC_{PV} will be used in Chapter 6 during pilot application of the model.

The risk analysis and evaluation framework evaluated occurrence, severity, and detection ranks and incorporated the RPN, despite criticisms of the method. This was done to enable empirical analysis of the relationship between the RPN and EC and to evaluate the appropriateness of the selected risk criticality measure. Kmenta and Ishii (2004) used 10,000 simulated FMEAs to evaluate the two methods against one another. This was done to provide robustness to the arguments in favor of EC first posed by Gilchrist (1993); however, the analysis was premised on three assumptions: (1) there is a relationship between occurrence and probability that is consistent, (2) cost can be expressed as a function of severity and this relationship can be consistently mapped, and (3) a relationship exists between detection and the probability of non-detection. These three relationships were used to derive complementary EC values for each of the 1,000 possible RPN combinations. Through the elicitation of expertise related to contributory measures of risk (O, S, and D for RPN and prior and posterior probabilities and cost for EC), this research facilitates the evaluation of the relationship of the two risk criticality measures using panel-derived data and test the conclusions of the original study (Kmenta and Ishii 2004).

5.2.4 Recommend and Evaluate Mitigation Strategies

The refined risk framework included control measures and mitigation strategies for some of the potential risk causes. These were provided by Delphi panelists during knowledge elicitation and construction, as described in Chapter 4. These measures were not intended to be an inclusive list, rather, panelists were provided the opportunity to respond to open-ended questions about the approaches they take to controlling risks once they have been identified. As a result, some risks had multiple mitigation strategies listed in the framework while others had none. Once the data from the SFMEA panel was analyzed, a separate ESCO expert (one of the original Delphi panelists) with significant risk management experience was asked to provide mitigation strategies for each risk scenario. These consisted of selections among strategies that were contained in the refined risk framework, the ability to add others to the list, and the ability to add new measures, particularly in the cases of potential causes that had no associated controls or mitigation strategies. Each mitigation strategy was assigned an efficacy score, which is a measure of the amount of the initial risk that is controlled by investing in mitigation. This is an important feature of calculating the ELCV, below.

5.2.5 Calculate the Expected Life Cycle Value

The expected life cycle value (ELCV) is defined as the amount of risk that has been effectively mitigated, when subtracting the cost of mitigation and the remaining risk in the project due to mitigation strategies with less than 100% efficacy. It can be calculated based on the EC in current dollars or the EC_{PV}, accounting for the year where the risk is realized and discounted to the present year. Formulaically, it appears as follows:

$ELCV = EC - Cost_{mitigation} - Risk_{remaining}$ or $ELCV_{PV} = EC_{PV} - Cost_{mitigation} - Risk_{remaining}$

where $Risk_{remaining} = (1-Efficacy_{mitigation}) \times EC$ or $Risk_{remaining} = (1-Efficacy_{mitigation}) \times EC_{PV}$

The ELCV can be calculated for each risk scenario, for each scenario map, or for the total project risk (e.g., the sum of all scenario maps). This measure provides decision support to project teams when evaluating the cost-effectiveness of selected mitigation strategies, in light of the incremental change in costs when risk scenarios are controlled or mitigated.

5.3 SCENARIO-BASED FMEA DATA COLLECTION AND ANALYSIS

This section describes expertise elicitation efforts to complete the risk management process for ESCOs undertaking correctional facility EPC retrofits, begun with risk identification in Chapter 4. This data was also used to parameterize the risk analysis and evaluation framework described in section 5.2, such that a life cycle cost-based risk model could be constructed from an analysis of the data. Primary data collection efforts were conducted using a panel of four domain experts, thus, expert knowledge was again sought as the central element of this research. This section includes a discussion of panelist recruitment and selection, as well as the collection and analysis of data leading to framework parameterization.

5.3.1 SFMEA Panel Composition

The recommended panel for conducting a FMEA includes individuals with ownership of the system and process being evaluated (Stamatis 2003). Panelists must reflect the multiple disciplines represented in the process and system under review (Teng and Ho 1996; Stamatis 2003; McDermott et al. 2009). As a result, while recommended panel sizes range from four to nine (Stamatis 2003; McDermott et al. 2009), the most critical aspect of its composition is that key project functions and technical disciplines are represented, to include end users of the process being analyzed (i.e., customers). An experienced team leader is important to help guide the team's deliberative processes by functioning as a facilitator, allowing panel participants to make final decisions during the FMEA.

Following this guidance, a panel was assembled that reflects domain-level expertise in the key components of the system under review, namely the conduct of the IGA and the selection and installation of ECMs. As a result, the following experts were recruited to the panel:

- Corrections business development manager, representing a national independent ESCO;
- Construction manager, representing a regional independent ESCO;
- Correctional agency physical plant division manager, representing a state agency client; and
- Commissioning manager, representing a manufacturer based ESCO and MUSH market client.

As part of the qualification process, panelists completed parts I and II of the Delphi questionnaire (risk tolerance and professional experience/determination of expertise), with additional questions focused on the level of their positions and the project phases they typically support; those results are depicted in Table 5-1.

Table 5-1. FMEA Panel Participant Risk Tolerance and Expertise Determination

Attribute	**RP-01-E**	**RP-02-E**	**RP-03-O**	**RP-04-M**
Job Level	Management			
Project Phases Supported	All	All	All	All except PD[a]
Risk Tolerance	Aggressive	Moderate	Moderate	Moderately Conservative
Total Points	5	3.5	4	2[b]
Total Categories	6	4	5	2
Years involved with EPC projects	25+	3[c]	20	<1
Total number of projects	53+	15	6	2
Proportion MUSH market projects	100%	75%	100%	100%
Number of building systems impacted/project	>10	5	5	3

Notes:
a\ PD = project development
b\ This panelist had <1 year of experience with EPC projects; however, this participant had over 9 years of experience as a commissioning manager, having worked on 49 projects during that time. During that time this panelist also developed standards and procurement guidance for initiating performance contracting projects as an owner's representative. This individual has an additional 35+ years of experience in mechanical construction.
c\ This panelist had 3 years of experience with EPC projects; however, this individual had 4 years of experience in commissioning and over 15 years of mechanical construction experience.

An expert facilitator was retained to co-lead the SFMEA panel, along with the researcher. This was critical to ensure that the panel achieved its stated goals and thoroughly analyzed risk scenarios in a comprehensive and timely manner. The researcher explained the goals of the SFMEA and shared the specifically-developed forms with the facilitator prior to convening the panel. A fellow researcher was included as a secondary recorder and analyst to ensure that SFMEA details were transcribed accurately and to assist with performing life cycle cost-based calculations during the FMEA panel.

Data collection activities of the expert panel utilized a custom FMEA worksheet that was developed specifically for the SFMEA process used in this research. The data collection strategy was depicted in Figure 3-3 and consisted of facilitated, open-ended responses from panelists with consensus as the goal for elicited risk measures (i.e., O, S, D, probabilities, and cost). If consensus could not be reached, median values of the range of panelists' responses were used. The median was selected as it has the tendency to minimize the effects of outliers (Agresti and Findlay 2009). With a small data set (N=4), outliers could unduly influence results, therefore, a more robust measure of central tendency was needed.

5.3.2 Data Analysis and Results

This section discusses significant findings from the collection and analysis of risk analysis and evaluation data. The complete data set compiled from SFMEA panel members is located in Appendix D.

5.3.2.1 Risk Scenarios and Scenario Maps

Panelists agreed upon seven root causes identified in the refined risk framework for the IGA risk category; three potential causes were reconfigured as intermediate effects, and three were not considered by the panel (Table 5-2). Upon review of the ECM selection and installation risk category section of the refined risk framework, panelists agreed upon nine root causes; four potential causes were reconfigured as intermediate effects, and two were not considered (of which one was deemed to be a duplicate entry) (Table 5-2).

Table 5-2. Potential Root Causes

Potential Risk Root Cause	**Panel Disposition**
Energy Audit Risk Category	
Facility age – code update	Retain
Misunderstanding existing conditions	Retain
Differing stakeholder needs	Retain
Failure to understand facility operations and EPC goal – lack of EPC experience	Retain as Two Root Causes
Calculation errors	Remove
Conducting the IGA too quickly	Retain
Energy model calibration error	Retain as Intermediate Effect
Inaccurate/incorrect or disputed baseline	Retain as Intermediate Effect
Information availability and accuracy	Retain
Missing information	Retain as Intermediate Effect
Missing risk assessment for each ECM	Remove
Establishment of the guarantee amount - difficult balance between providing a large-enough project to generate client excitement and ESCO value and hedging on savings	Remove
Overstatement of issues leading to mismatch with technical needs; understatement of issues leading to reduced project value	Retain
ECM Selection and Installation Risk Category	
Owners are used to design-bid-build in the public sector and are not used to designing based on fixed budgets and do not understand EPC cost structures	Retain
Disconnect between the design and audit intent – improper efficiency target; different operating schedule implemented than what was planned; different control system installed	Retain as Intermediate Effect
Subcontractor quality and reliability	Retain
Unqualified and unsafe contractors create additional risks	Retain
Cheapest equipment sometimes selected – leads to sub-optimal O&M savings	Retain First Half - Second Half as Intermediate Effect
ECM package constructability and feasibility	Retain
ECMs are not aligned with the IGA findings	Remove – Duplicate with ECM package feasibility
Failure to perform as designed	Retain
Uncertainty in factors used to predict performance	Retain as Intermediate Effect
Installation location	Remove
Comfort complaints can add extra work after construction is complete	Retain as Intermediate Effect
Lighting is difficult to demonstrate before installation; owner and occupants can be unhappy with light quality after a retrofit	Retain
"Low-hanging fruit has been picked"	Retain
Lowest-cost solutions may create value concerns during O&M	Retain as Intermediate Effect
Accessibility to inmates/physical security	Retain

Once root causes were agreed upon, panelists constructed 12 risk scenario maps, consisting of 77 individual risk scenarios. The risk scenario maps are provided in Appendix D; two example scenario maps are provided in Figure 5-7, and a list of scenarios, their causes, intermediate effects, and end effects is provided in Table 5-3. The 77 scenarios included effects from each of the five EPC project phases identified in Chapter 4, thereby making an assessment of project life cycle costs feasible through the implementation of this risk analysis and evaluation framework.

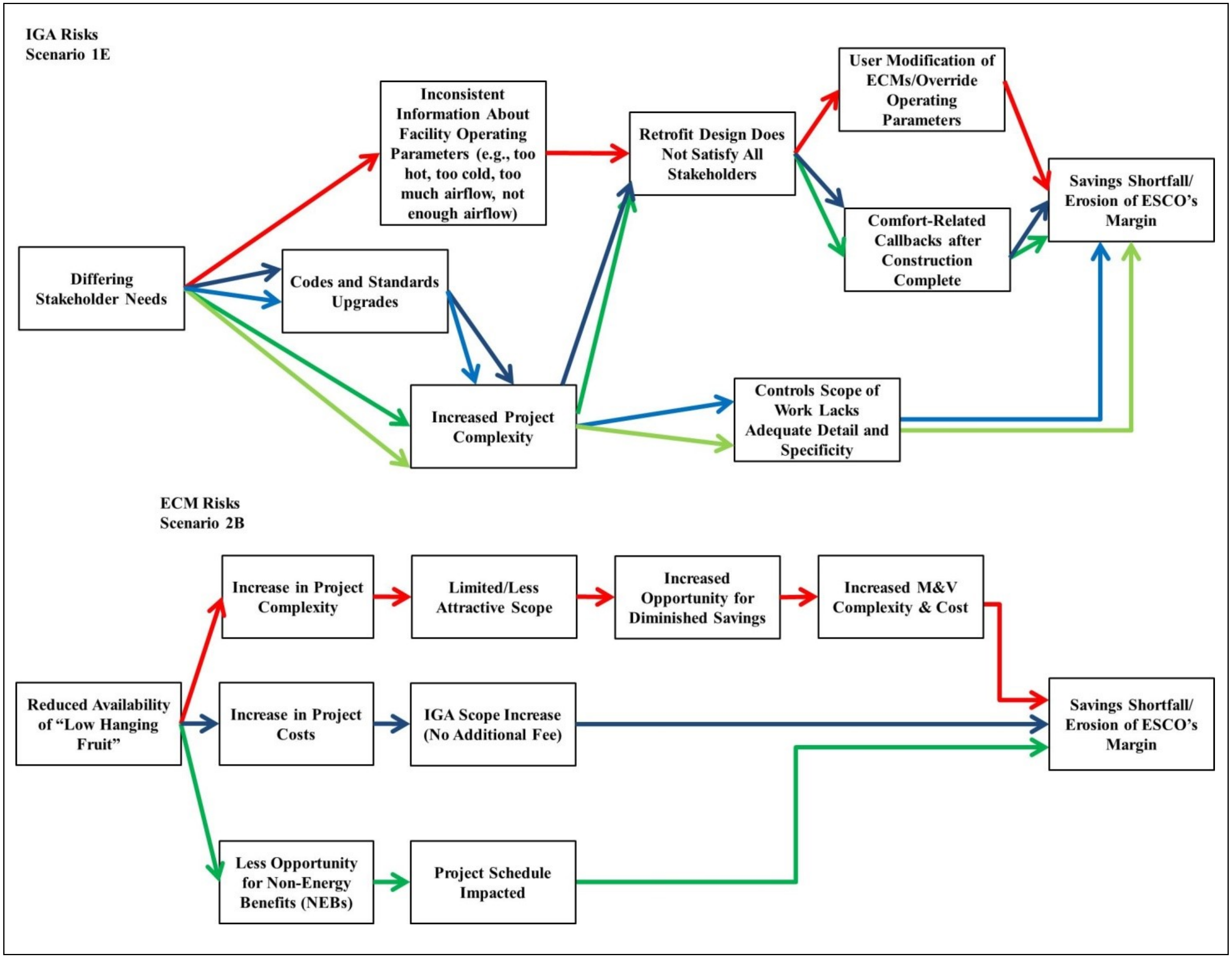


Figure 5-7. Example Risk Scenario Maps Developed by SFMEA Panel

Table 5-3. SFMEA Risk Scenarios

	Risk Cause	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect
1A1	Misunderstanding Existing Conditions	Presence of Asbestos-Containing Materials (ACM)			Remove/Modify
1A2	Misunderstanding Existing Conditions	Presence of Asbestos-Containing Materials (ACM)			Manage in Place
1A3	Misunderstanding Existing Conditions	Presence of Lead-Based Paint			Remove/Modify
1A4	Misunderstanding Existing Conditions	Presence of Lead-Based Paint			Manage in Place
1A5	Misunderstanding Existing Conditions	Presence of Fuel-Related Contaminants			Remove/Modify
1A6	Misunderstanding Existing Conditions	Presence of Fuel-Related Contaminants			Manage in Place
1A7	Misunderstanding Existing Conditions	Presence of Buried Infrastructure			Remove/Modify
1A8	Misunderstanding Existing Conditions	Presence of Buried Infrastructure			Manage in Place
1B1	Facility Age and Current Code Requirements	Fire Suppression and Alarm System Upgrades			Modify Affected System(s)
1B2	Facility Age and Current Code Requirements	Electrical System Upgrades			Modify Affected System(s)
1B3	Facility Age and Current Code Requirements	Plumbing System Upgrades			Modify Affected System(s)
1B4	Facility Age and Current Code Requirements	Mechanical System Upgrades			Modify Affected System(s)
1B5	Facility Age and Current Code Requirements	Universal Access (ADA) Upgrades			Modify Affected System(s)

Table 5-3 (cont'd)					
	Risk Cause	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**
1B6	Facility Age and Current Code Requirements	OSHA-Related Upgrades			Modify Affected System(s)
1B7	Facility Age and Current Code Requirements	Specialty-Standard Upgrades			Modify Affected System(s)
1C1	Overstatement of Issues	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin
1C2	Overstatement of Issues	Improper Equipment Repurposing			Difficulty Getting Financing
1C3	Overstatement of Issues	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin
1C4	Overstatement of Issues	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin
1C5	Understatement of Issues	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin
1C6	Understatement of Issues	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin
1C7	Understatement of Issues	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin
1C8	Understatement of Issues	Missed Opportunities	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin

Table 5-3 (cont'd)

	Risk Cause	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect
1D1	ESCO Lack of Experience with Facility Type	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M		Missed Opportunity for O&M Contract
1D2	ESCO Lack of Experience with Facility Type	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Reduced Project Value for ESCO
1D3	ESCO Lack of Experience with Facility Type	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Savings Shortfall/ Erosion of ESCO's Margin
1D4	ESCO Lack of Experience with Facility Type	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Baseline	Savings Shortfall/ Erosion of ESCO's Margin
1D5	ESCO Lack of Experience with Facility Type	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Retrofit Design	Savings Shortfall/ Erosion of ESCO's Margin
1D6	ESCO Lack of Experience with Facility Type	Failure to Understand Facility Operations and Client Goals	Improper Construction Timing and Phasing	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin
1D7	ESCO Lack of Experience with Facility Type	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin
1D8	ESCO Lack of Experience with Facility Type	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin
1D9	ESCO Lack of Experience with Facility Type	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin

Table 5-3 (cont'd)

	Risk Cause	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**
1D10	ESCO Lack of Experience with Facility Type	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin
1D11	ESCO Lack of Experience with Facility Type	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Occupant Use of Equipment for Other Purposes	Legal Impacts
1E1	Differing Stakeholder Needs	Inconsistent Information About Facility Operating Parameters (e.g., too hot, too cold, too much airflow, not enough airflow)	Retrofit Design Does Not Satisfy All Stakeholders	User Modification of ECMs/Override Operating Parameters	Savings Shortfall/ Erosion of ESCO's Margin
1E2	Differing Stakeholder Needs	Codes and Standards Upgrades	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin
1E3	Differing Stakeholder Needs	Codes and Standards Upgrades	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity	Savings Shortfall/ Erosion of ESCO's Margin
1E4	Differing Stakeholder Needs	Increased Project Complexity	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin
1E5	Differing Stakeholder Needs	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity		Savings Shortfall/ Erosion of ESCO's Margin
1F1	IGA Conducted Too Quickly	Miss Critical Functions and Savings Opportunities			Savings Shortfall/ Erosion of ESCO's Margin
1F2	IGA Conducted Too Quickly	Miscount Existing Equipment (e.g., Lights)			Savings Shortfall/ Erosion of ESCO's Margin

Table 5-3 (cont'd)					
	Risk Cause	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**
1F3	IGA Conducted Too Quickly	Miscount Existing Equipment (e.g., Lights)	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin
1F4	IGA Conducted Too Quickly	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin
1F5	IGA Conducted Too Quickly	Missing Facility Information	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin
1F6	IGA Conducted Too Quickly	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin
1F7	Facility Information Unavailable/ Inaccurate	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin
1F8	Facility Information Unavailable/ Inaccurate	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin
2A1	Security Concerns	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment	Rework	Savings Shortfall/ Erosion of ESCO's Margin
2A2	Security Concerns	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment		Savings Shortfall/ Erosion of ESCO's Margin
2A3	Security Concerns	Technology Breakage/ Damage Possibility by Occupants	Equipment Impacts	Total Costs of Operation	Savings Shortfall/ Erosion of ESCO's Margin
2A4	Security Concerns	Technology Breakage/ Damage Possibility by Occupants	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin

Table 5-3 (cont'd)					
	Risk Cause	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**
2A5	Security Concerns	Occupant Use of Equipment for Other Purposes			Legal Impacts
2B1	Reduced Availability of "Low Hanging Fruit"	Increase in Project Complexity	Limited/Less Attractive Scope	Increased Opportunity for Diminished Savings	Savings Shortfall/ Erosion of ESCO's Margin
2B2	Reduced Availability of "Low Hanging Fruit"	Increase in Project Costs	IGA Scope Increase (No Additional Fee)		Savings Shortfall/ Erosion of ESCO's Margin
2B3	Reduced Availability of "Low Hanging Fruit"	Less Opportunity for Non-Energy Benefits (NEBs)	Project Schedule Impacted		Savings Shortfall/ Erosion of ESCO's Margin
2CD1	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	Failure to Meet Owner Project Requirements	Rework		Savings Shortfall/ Erosion of ESCO's Margin
2CD2	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	Failure to Meet Owner Project Requirements	Comfort Complaints		Savings Shortfall/ Erosion of ESCO's Margin
2CD3	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	Failure to Meet Owner Project Requirements			Savings Shortfall/ Erosion of ESCO's Margin
2CD4	Operational Concerns	Failure to Meet Owner Project Requirements	Reduce Project Scope		Savings Shortfall/ Erosion of ESCO's Margin
2CD5	Safety Concerns	Failure to Meet Owner Project Requirements	Safety Incident		Legal Impacts

Table 5-3 (cont'd)

	Risk Cause	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**
2E1	Unqualified Subcontractors	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin
2E2	Unqualified Subcontractors	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin
2E3	Unqualified Subcontractors	Unsafe Working Conditions/Injuries	Safety Incident		Legal Impacts
2E4	Unreliable Subcontractors	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin
2E5	Unreliable Subcontractors	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin
2E6	Unreliable Subcontractors	Project Schedule Impacted			Savings Shortfall/ Erosion of ESCO's Margin
2F1	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	Require ESCO to use Fixed Overhead & Profit Rates	Overstate Project Soft Costs		Savings Shortfall/ Erosion of ESCO's Margin
2F2	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	Divide Procurement into Separate Phases	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin
2F3	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	Incorrect Vendor Selection	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin

Table 5-3 (cont'd)					
	Risk Cause	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**
2G1	Select Cheapest Available Equipment to Meet Specifications	Increased O&M Cost			Savings Shortfall/ Erosion of ESCO's Margin
2G2	Select Cheapest Available Equipment to Meet Specifications	Reduced Equipment Service Life			Savings Shortfall/ Erosion of ESCO's Margin
2G3	Actual Climate Conditions Outside Range of Planned Conditions	Uncertainty in Factors Used to Predict Performance	Reduced Equipment Service Life		Savings Shortfall/ Erosion of ESCO's Margin
2G4	Actual Climate Conditions Outside Range of Planned Conditions	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin
2G5	ECM Constructability & Feasibility Issues	Uncertainty in Factors Used to Predict Performance	Reduced Energy Performance		Savings Shortfall/ Erosion of ESCO's Margin
2G6	ECM Constructability & Feasibility Issues	Rework			Savings Shortfall/ Erosion of ESCO's Margin
2G7	ECM Failure to Perform as Designed	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin
2G8	ECM Failure to Perform as Designed	Rework			Savings Shortfall/ Erosion of ESCO's Margin

5.3.2.2 Expected Cost and Risk Priority Number

Panelists assigned measures of risk criticality to the 77 developed risk scenarios described in Table 5-4. Measures were first assigned individually by each panelist; group consensus was then developed from their individual responses. During the process of assigning prior probabilities, panelists identified several facility-related factors that impact the way these probabilities were assigned. Table 5-4 summarizes the facility factors that were identified and their impacts on the calculation of prior probabilities.

Table 5-4. Impact of Facility Factors on Prior Probabilities

Risk Scenario	Facility Factor	Criteria	Prior Probability
1A1/2	Presence of asbestos	Built/renovated before 1985	1.00
		Built/renovated 1985-2000	0.75
		Built/renovated after 2000	0.25
1A3/4	Presence of lead-based paint	Built before 1980	1.00
		Built after 1980	0.00
1A5/6	Presence of fuel contamination	Fuel tanks in vicinity of ECM work	0.85
		Fuel tanks not in vicinity of ECM work	0.00
1A7/8	Presence of buried infrastructure	Assume for all correctional facilities	0.80

Cost was calculated as the proportion of the ESCO margin that would be at risk if the given risk scenario was left unmitigated. The end effect “savings shortfall/erosion of ESCO’s margin” appeared in most scenarios. Remaining end effects included “difficulty getting financing,” “reduced project value for ESCO,” “legal impacts,” “remove/modify,” “manage in place,” and “modify affected system(s).” Panelists agreed in all cases that these consequences could be adequately addressed in terms of the proportion of the ESCO’s project margin that would potentially be at risk. In order to convert relative costs to actual costs, which was required to calculate EC, a $2,000,000 project with a 20% margin was assumed.

After EC-related metrics were scored, panelists repeated the process of individually and collaboratively recording RPN-related scores. Customized scales for O, S, and D were developed for this research, following guidance in Stamatis (2003) and McDermott et al. (2009). The scales are included in Appendix D.

5.3.2.3 Most Critical Risks

The consensus measure (median) was applied to panelists' individual assessments of EC and RPN. Values of EC and RPN were ranked from 1 (highest criticality value) to 77 (lowest criticality value); the ten most critical risks are identified in Table 5-5.

Table 5-5. Consensus Assessment of Most Critical Risks

Risk Scenario	**RPN Rank**	**RPN**	**Risk Scenario**	**EC Rank**	**EC**
2A2	1	410	2B1	1	$153,600.00
2A3	1	410	2F3	2	$104,625.00
2CD3	3	371	2B2	3	$102,400.00
1F7	4	352	1F8	4	$91,350.00
2CD2	5	340	1F7	5	$86,275.00
1F8	6	330	2B3	6	$76,800.00
2F3	6	330	2F1	7	$67,500.00
1A7	8	322	2F2	8	$64,125.00
1D11	9	319	1A1	9	$64,000.00
1D3	10	315	1D8	10	$63,000.00

Notes:
Shaded rows identify instances of the same risk scenario appearing among the ten most critical risks using both EC and RPN

The two-way analysis of RPN and EC yielded 17 discrete risk scenarios. In a traditional FMEA, the most critical risks would be submitted for further analysis with regard to risk mitigation and control techniques. The most important result of this pairwise analysis is that the data makes it clear that there is not a one-to-one relationship between RPN and EC. Only three of the ten most critical risks appeared in both of the ten most critical risks list when using RPN and EC, and in no case was the rank identical for a given risk scenario among the top ten using both assessment scales. Scenarios are approximately evenly divided between those addressing energy audit phase root causes (risk scenarios preceded with a 1) and those related to ECM selection and installation (risk scenarios preceded with a 2). Criticality scores obtained for the two most critical risks (scenarios 2A2 and 2B1) represented approximately the same proportion of available points using each rating technique; values were equal to 41% of the highest possible RPN and 38.4% of the highest possible EC. This relationship degenerates by the time the tenth highest risk is scored – the proportional scores are now 31.5% for RPN and 15.8% for EC.

5.3.2.4 Relationship Between EC and RPN

Further analysis is warranted based on the observed lack of a relationship between EC and RPN after a review of the ten most critical risks derived using each criticality assessment method. Analysis consists of the following two aspects: (1) assessment of two of the relational assumptions given by Kmenta and Ishii (2004) and (2) assessment of the linear relationship between the calculated criticality measures.

Two assumptions made by Kmenta and Ishii (2004) regarding their assessment of the relationship between EC and RPN, using modeled results, are tested in this section: (1) there is a relationship between occurrence and probability that is consistent and (2) cost can be expressed as a function of severity and this relationship can be consistently mapped.

The relationship between occurrence and prior probability (e.g., probability of cause) was analyzed using Spearman's correlation, given that neither variable was distributed normally. A strong, positive, monotonic relationship was detected between occurrence and prior probability (ρ=0.986, N=77, p<0.01). This was expected given that both scales were developed based on the likelihood or frequency of a risk cause occurring on projects, and scoring levels were consistent between the two scales. For example, a rank of 3 on the occurrence scale indicated that a cause occurred in 20 out of 100 projects; this corresponded to a value for P_{cause} of 0.20.

Kmenta and Ishii(2004) stated that a consistent relationship exists between severity and cost; however, the scale of the cost variable may change by industry. For example, failure costs in the aerospace industry are likely to be greater than those in consumer electronics manufacturing. Since there is no available comparison for this data set, the first step is again to determine the degree of relationship among the two variables. Using Spearman's correlation, a strong, positive, monotonic relationship was detected between severity and cost (ρ=0.706, N=77, p<0.01). To determine the ESCO industry-specific scale of the cost variable, the equation of the line describing the relationship between these variables was sought using the curve estimator function of SPSS version 22 (IBM 2014) to determine the best fit curve for the data. Based on a visual review of the scatterplot of severity and cost, three models were selected for inclusion in the curve estimation analysis: (1) cubic, (2) power, and (3) S. Treating cost as the dependent variable and severity as the independent variable yielded regression analysis results as shown in Table 5-6. The power model provided the strongest correlation between the variables (R=0.762) and also explained the greatest amount of variation in cost as a function of severity (R^2=0.580) with the smallest error term of the three models (σ_{est}=0.548). The equation for the curve describing this relationship is given as:

$$\ln(\text{cost}) = \ln(1162.38) + (2.2 \text{ X } \ln(S)).$$

where 1162.38 is a constant and S = the severity score.

Table 5-6. Analysis of the Curve Describing the Severity and Cost Relationship

Parameter Value	**Cubic Model**	**Power Model**	**S Model**
R	0.596	0.762	0.501
R^2	0.356	0.580	0.494
Significance	p<0.01	p<0.01	p<0.01
Standard Error of the Estimate	56,592.9	0.548	0.597

Based on the above analysis, both modeled assumptions made by Kmenta and Ishii (2004) were determined to exist in the data set generated by SFMEA panelists.

The relationship between EC and RPN was further examined in addition to the assumptions reviewed previously. Due to non-normality in the residuals of both variables, Spearman's correlation was again used to detect the presence of a relationship between the two. A moderate, positive, monotonic relationship was detected between EC and RPN (ρ=0.562, N=77, p<0.01). This indicates that 31.6% of the variation in one variable is explained by the value of the other. This may be an artifact of panelists scoring EC and RPN for each risk scenario within the same brief window of time; however, out of 308 scoring opportunities (77 scenarios each scored by four panelists), there were fewer than 20 instances of a panelist verbalizing the use of one value as a reference for the other. Additionally, panelists did not see calculated EC and RPN values in real time; they only saw their probabilities, relative cost, and O, S, and D values in an attempt to minimize bias. Based on the test statistic, 68.4% of the observed variation remains unexplained via this relationship between variables, thereby providing evidence of a relationship that is other than one-to-one between EC and RPN. Visual inspection of the scatterplot describing the relationship between the two criticality measures leads to a similar conclusion (Figure 5-8).

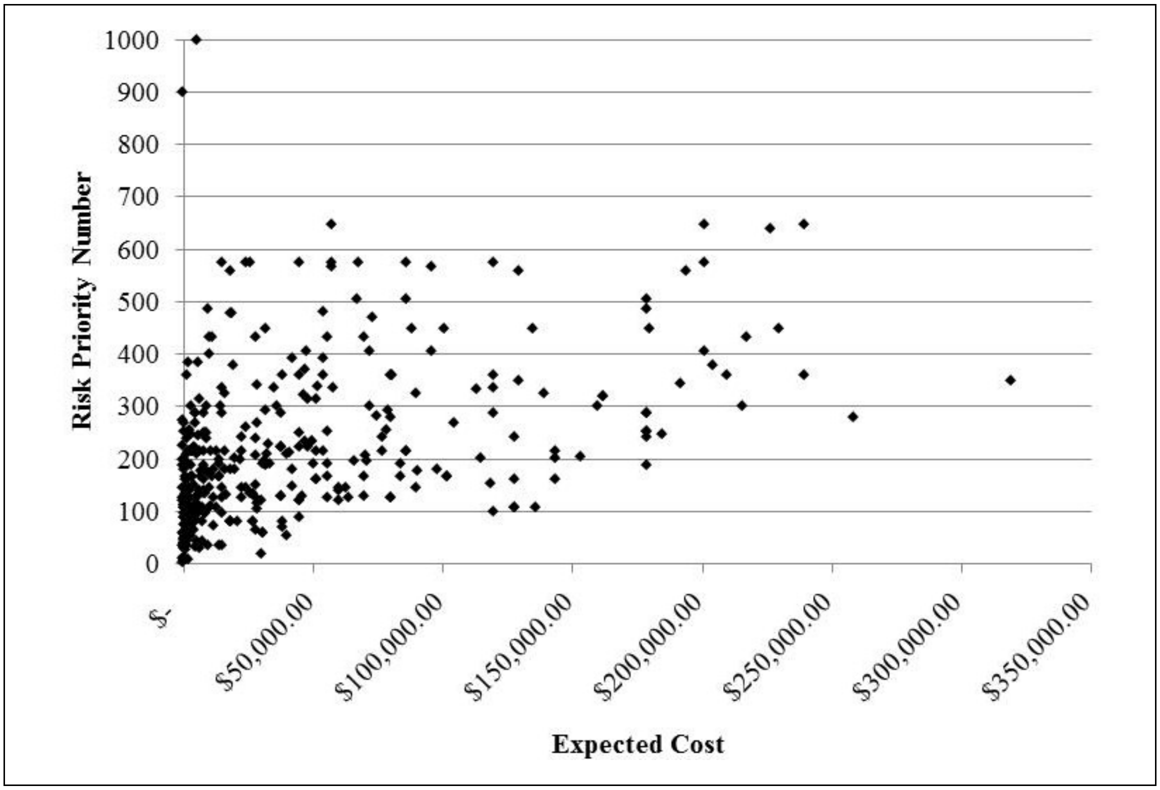


Figure 5-8. EC vs RPN for all Panelist Responses and Consensus Measure (n=380)

Through the 380 instances (5 were eliminated due to panelists not providing individual scores) of calculated values of EC and RPN shown in Figure 5-8 (data from each of the four panelists and the consensus measure, the median value), the failure priorities for the two measures equaled each other in just 11 instances (3.8%), which are described in Table 5-7. As review of the data reveals, only one risk scenario received the same failure priority in more than one set of scores. Risk scenario 1F1 received identical EC and RPN priorities in the consensus case and by panelist RP-04-M; however, their respective scores differed greatly. Panelists RP-04-M assigned the highest possible priority to this scenario whereas the consensus case assigned this a lower-mid range priority rank of 43 out of 77. This also provides an example of the mixed prioritization of results that can occur when utilizing the RPN method of determining risk criticality.

Table 5-7. Instances of Identical EC and RPN Priorities		
Risk Scenario	**Panelist(s)**	**Priority Score**
1C7	RP-04-M	47
1D2	RP-02-E	34
1E2	RP-04-M	68
1FI	Consensus (Median) Case RP-04-M	43 1
2A4	RP-04-M	5
2E3	RP-03-O	71
2F2	RP-02-E	34
2G3	RP-04-M	61
2G7	RP-02-E	34
2G8	RP-01-E	73

Rank order disagreement was reviewed further, with minimum, maximum, and mean values of disagreement ($|\text{Rank}_{\text{RPN}}\text{-Rank}_{\text{EC}}|$) calculated for each panelist and the consensus case. The mean value across these cases was: (1) $|\text{Rank}_{\text{RPN}}\text{-Rank}_{\text{EC}}|_{\text{min}}=0$, since each case had at least one instance of rank order agreement; (2) $|\text{Rank}_{\text{RPN}}\text{-Rank}_{\text{EC}}|_{\text{max}}=61$, where the maximum possible value of rank order disagreement is 76; and (3) $|\text{Rank}_{\text{RPN}}\text{-Rank}_{\text{EC}}|_{\text{mean}}=17$. Within the 96.2% of instances with observed risk priority disagreement, several observations were noted that further indicated the challenges of RPN use.

Instances were observed where identical RPN values had a wide range of EC values, as shown in Table 5-8. In the given example, the same RPN yielded a variance of $72,000 in the EC.

Table 5-8. Identical RPN Values with Large EC Variance								
Scenario	P_{cause}	P_{effect}	**Cost**	**EC**	**O**	**S**	**D**	**RPN**
1C8	0.8	0.1	$20,000.00	$1,600.00	9	9	2	162
2F2	0.8	0.8	$200,000.00	$128,000.00	9	9	2	162

Conversely, identical values of EC also yielded a large variance in RPN scores (Table 5-9).

Table 5-9. Identical EC Values with Large RPN Variance

Scenario	P_{cause}	P_{effect}	Cost	EC	O	S	D	RPN
2F3	0.50	0.2	$100,000.00	$10,000.00	6	8	9	432
2G6	0.25	0.50	$80,000.00	$10,000.00	3	8	6	144

Several instances were also detected where RPN and EC values yielded mixed priorities for risk mitigation, as shown in Table 5-10. The risk scenario with the higher RPN value has a significantly lower EC than the scenario with the higher RPN. This represents information that is difficult to use by managers when making decisions about which risks to prioritize.

Table 5-10. RPN and EC Yield Mixed Risk Management Priorities

Scenario	P_{cause}	P_{effect}	Cost	EC	O	S	D	RPN
1B4	0.80	0.5	$20,000.00	$144,000.00	9	6	3	162
2F3	0.50	0.2	$100,000.00	$10,000.00	6	8	9	432

Finally, given the differences in possible combinations that lead to RPN and EC values, there is the potential for significant variation of EC around a given RPN value. Multiplying O, S, and D yielded 1,000 possible numerical combinations which result in 120 possible unique RPN values (Kmenta and Ishii 2004). The data generated across all five cases in the SFMEA panel resulted in 84 unique values of the RPN; 226 unique values were generated for EC. This creates the expectation that a great deal of EC variation should be seen around each RPN value in the dataset. This is demonstrated in Figure 5-9. The average EC variation around the RPN is 68% of the range of EC values in this study. Variation ranged from 5% to 200%, with the greatest amount of variation generally occurring around the largest RPN values.

While these examples further serve to demonstrate the irregular relationship between EC and RPN, the most important observation for decision making is that EC quantifies risks in monetary terms instead of dimensionless, ordinal scales. As a result, much can be said about the EC value

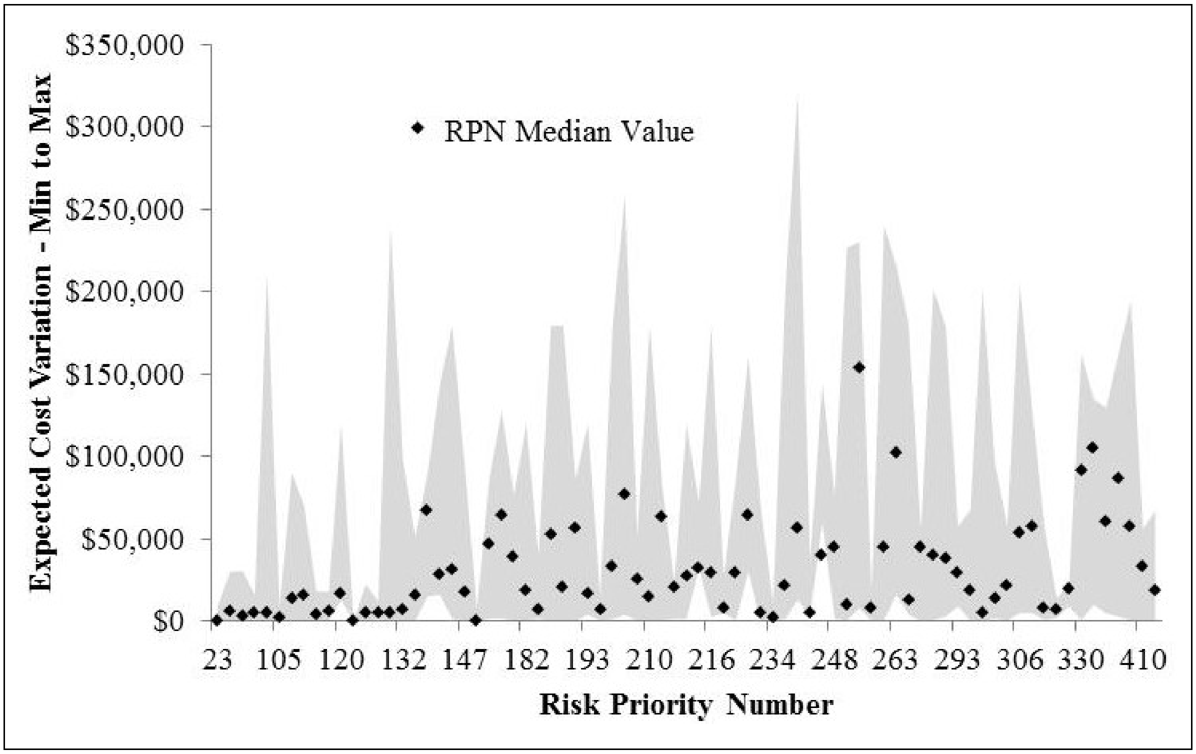


Figure 5-9. EC vs RPN for all Panelist Responses and Consensus Measure (n=303)

when making decisions. For example, an EC of $150,000 is twice as risky as one of $75,000 and the representation in monetary terms means that appropriate mitigation techniques can be selected that yield an optimal cost-benefit relationship.

5.3.2.5 Differences in Panelist Criticality Analysis

The consensus measures used for values of probabilities, cost, and O, S, and D showed significant variation from individual panelist scores for each measure. As discussed in Chapter 4, it was hypothesized that differences in each participant's background contribute to their individual analysis of project-level risks. These background attributes include their risk tolerance, their professional tenure with ESCOs or with conducting EPC retrofits, the level of their job, and the project phases during which they most frequently work. Since the unit of analysis is the individual decision-maker, the SFMEA panel provides only four data points for each measure of interest (e.g., probabilities, costs), where the measure of interest is examined for each of the 77 scenarios. The small size of this data set makes traditional statistical analysis difficult to use in detecting the strength and significance of relationships among these indicator variables. The use of a sample size calculator indicated that a sample size of four would yield a confidence interval of no better than 50%. While this limits the ability to analyze panelist data in such a manner, trend lines of EC values for each scenario were prepared (Figure 5-10).

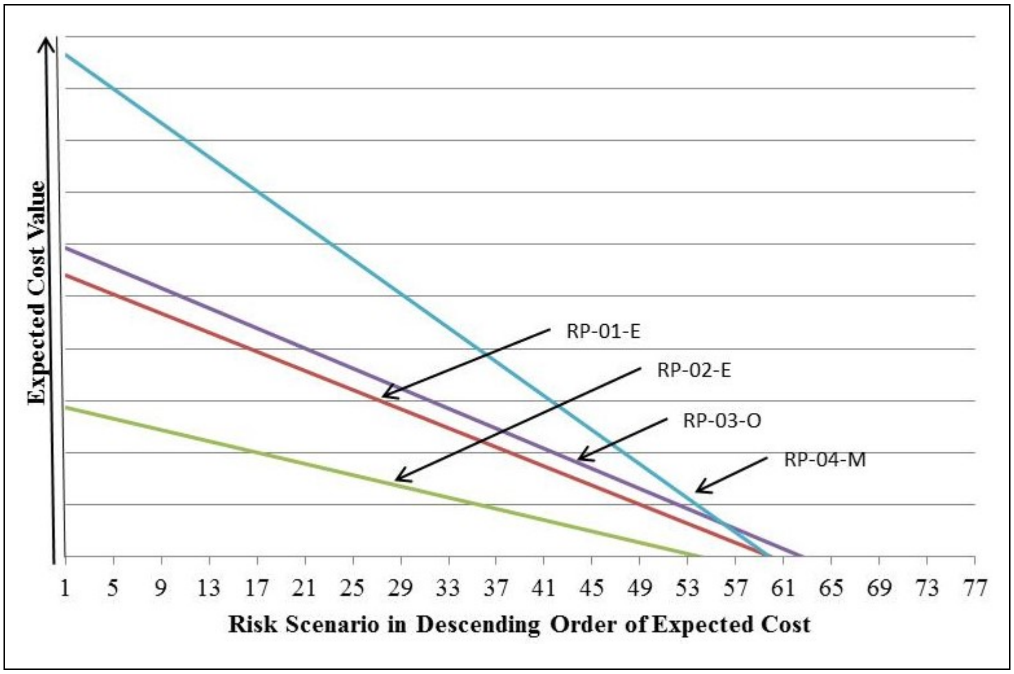


Figure 5-10. Panelist Expected Cost Variation Trend Line Plot

The panelist with the most conservative risk tolerance score (RP-04-M – moderately conservative) generally assigned the greatest EC value to each scenario, except among those with the lowest overall EC values. Panelist RP-03-O had a moderate risk tolerance, and the EC trend was generally where one might expect to see it, in the middle of panelist scores. Deviation was observed from what was expected due to risk tolerance with panelist RP-01-E (aggressive) and panelist RP-02-E (moderate). Risk seekers would be expected to have the lowest trend in EC values; in this case, the aggressive panelist evaluated EC higher than the moderate panelist RP-

02-E. This may be a factor of the moderate panelist scoring lower than expected, rather than the aggressive panelist scoring higher.

The length of professional tenure related to EPC retrofits was evaluated next for each panelist. Panelists RP-01-E and RP-03-O each have 20+ years of ESCO and/or EPC experience, whereas panelists RP-02-E and RP-04-M had less domain experience, despite lengthy backgrounds in mechanical construction. The most experienced panelists had EC trends that were approximately in the middle of observed trend lines; the least experienced panelists had EC trends at the high and low ends of the observed trend lines. The inclusion of length of professional tenure as an interaction variable may explain some of the observed variation when considering just risk tolerance behaviors, as level of experience has been shown to be a critical aspect of the risk management process (Akintoye and MacLeod 1997; Akintoye et al. 1998); however, this cannot be ascertained without further analysis. Table 5-11 provides measures of panelist variance across key risk analysis measures, and indicates that the relationships noted above do not appear to remain true for RPN scores.

Table 5-11. Panelist Variance in Key Risk Analysis Measures

	Response Range				
Key Measure	**Median Value**	**RP-01-E**	**RP-02-E**	**RP-03-O**	**RP-04-M**
P_{cause}	0.20-1.0	0.02-1.0	0.15-1.0	0.20-1.0	0.20-1.0
P_{effect}	0.00-1.0	0.00-1.0	0.00-1.0	0.00-1.0	0.00-1.0
EC	$0-153,600	$0-$259,200	$0-$320,000	$0-$204,800	$0-$240,000
RPN	12-576	4-1,000	18-432	8-448	12-648

5.4 FRAMEWORK DEVELOPMENT

Figure 5-11 represents the design of the risk analysis and evaluation framework used to evaluate ESCO risks when delivering EPC retrofits, with a focus on correctional facility projects. The

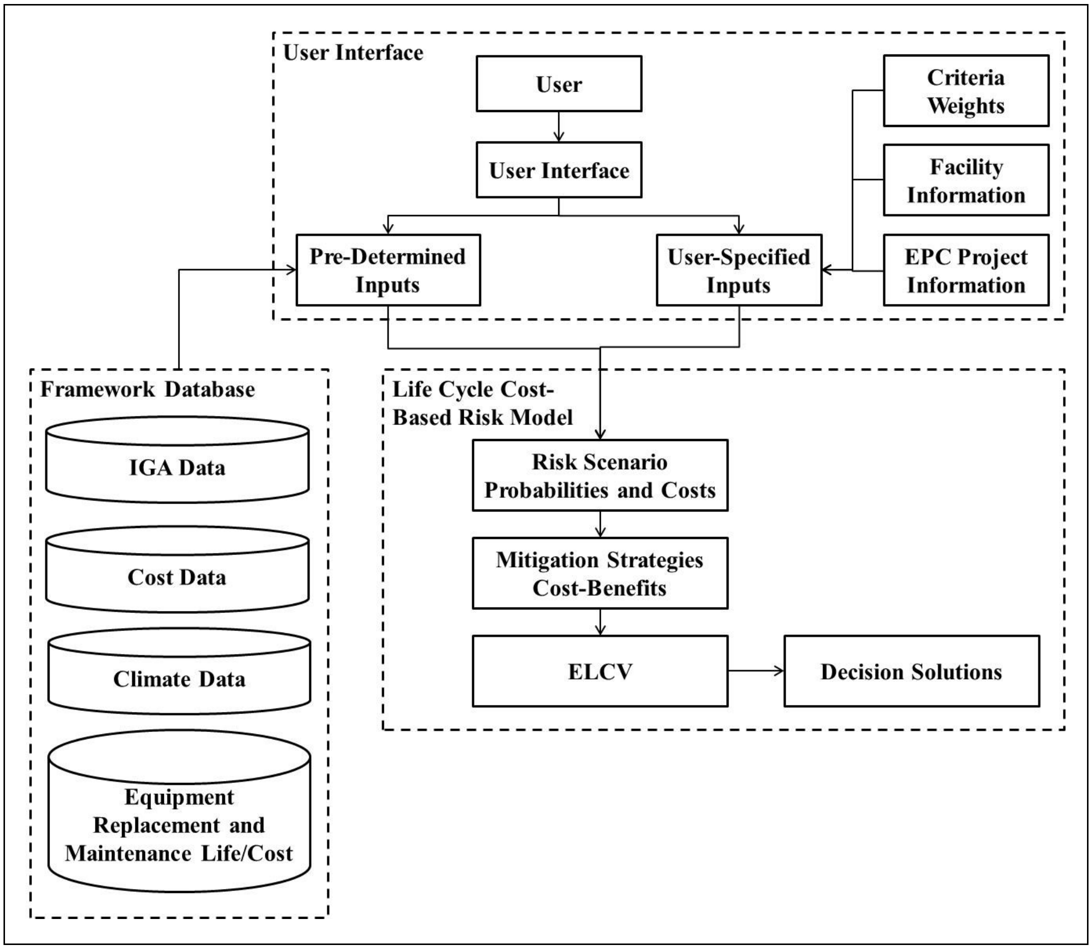


Figure 5-11. Risk Analysis and Evaluation Framework for EPC Retrofits

three primary components of the framework include the user interface, the database, and the life cycle cost-based risk model.

The risk model is the central component of the framework and incorporates elicited and constructed knowledge from ESCO experts, risk-specific information from the SFMEA panel described earlier in this chapter, and quantitative information from the framework database. The framework development steps were described in earlier sections and included knowledge from the a priori risk framework, the a posteriori risk framework, and the EPC retrofit process model.

5.4.1 Life Cycle Cost-Based Model

The life cycle cost-based model uses the information obtained from the SFMEA to represent decision maker expertise, risk preferences, and external information in examining the financial impacts of risk scenarios and their associated mitigation strategies. There are four elements of the model: (1) risk scenario probabilities and costs, (2) mitigation strategies cost-benefits, (3) ELCV, and (4) decision solutions.

5.4.1.1 Risk Scenario Probabilities and Costs

Calculation of Risk Probabilities: Based on the expertise elicited from SFMEA panelists, 77 risk scenarios are available for criticality analysis. Prior and posterior probabilities for each scenario are derived from one of the following sources:

- SFMEA panelist-assigned values;
- User inputs; or
- Project, facility, and external environment characteristic-driven values.

The latter option consists of specific project, facility, and external environment characteristics that were identified by SFMEA expert panelists as affecting the calculation of prior probabilities. The classifications used for these instances are shown in Table 5-12.

Project Factors: Prior probability values were generally obtained from SFMEA panelists; however, variables related to ECM service life-related costs were generated through a random number obtained from a probability density function (PDF). The PDF was generated based on

ECM-specific service life values in the ASHRAE Service Life and Maintenance Cost Database (ASHRAE 2014).

Table 5-12. Project-, Facility-, and External Environmental-Based Values for Probability of Cause

Factor	Related Risk Scenarios	Variable Levels	P_{cause}
Project Factors			
Prior corrections EPC experience	1D1-1D11	• No experience - 0 prior projects • Minimal experience - 1-2 prior projects • Moderate experience - 3-5 prior projects • Significant experience - 6+ prior projects	• 0.9 • 0.8 • 0.6 • 0.4
Frequency of client use of design-bid-build (DBB) procurement	2F1-2F3	Continuous values 0%-100%	0.0-1.0
Difficulty in demonstrating ECM results prior to installation[a]	2CD1-2CD3	Discrete values: • ECM is (Yes) difficult to demonstrate • ECM is not (No) difficult to demonstrate	 • 1.0 • 0.0
Difference between ECM service life and probabilistically-derived service life	2G2, 2G7, and 2G8	Continuous values - the probability of service life that is lower than the design parameter based on a probabilistically-derived random number	0.0-1.0
Facility Factors			
Facility age	1A1 and 1A2	• Built or renovated before 1985 • Built or renovated 1985-2000 • Built or renovated after 2000	• 1.00 • 0.75 • 0.25
Facility age[b]	1A3 and 1A4	• Built or renovated before 1980 • Built or renovated after 1980	• 1.0 • 0.0
Retrofit disturbance of fuel tanks and related piping	1A4 and 1A5	Discrete values: • Yes • No	 • 0.85 • 0.00
External Environment Factors			
Difference between annual normal heating degree days (HDD) and probabilistically-derived HDD	2G3 and 2G4	Continuous values - the probability of annual HDD differing from the design parameter based on a probabilistically-derived random number	0.0-1.0
Difference between annual normal cooling degree days (CDD) and probabilistically-derived CDD	2G3 and 2G4	Continuous values - the probability of annual CDD differing from the design parameter based on a probabilistically-derived random number	0.0-1.0

Facility Factors: Cause probabilities were developed through expertise elicited from SFMEA panelists. Renovation was defined as a major renovation activity that would have likely contacted the hazardous material of concern (e.g., previous steam line repairs resulted in removal of asbestos pipe wrap, previous door frame repair involved either lead-based paint removal or encapsulation). Panelists also indicated that they use a fixed prior probability of 0.85 for the likelihood of encountering fuel-related contamination during correctional facility retrofits; however, their primary decision making regarding this point is based on whether construction activities that are directly or indirectly involved with installing retrofit measures will disturb fuel tanks or associated piping.

External Environment Factors: Prior probability values were generated from a random number that was obtained from a PDF. The PDF was generated based on historical annual HDD and CDD values, which could then be compared to the design value of these parameters. In a nationwide study of energy consumption at U.S. Air Force bases, Griffin (2008) determined that HDD overall had 4.5 times the impact on energy consumption per square foot of building area as CDD. The risk model provides the ability to identify the climate zone of the project location. For climate zones 4 and above, the model utilizes HDD; CDD are utilized for climate zones 1 through 3.

Example Rules: The above relationships were developed in the model through conditional statements using IF- THEN-ELSE logic. This enabled the model to represent the knowledge elicited from the SFMEA panelists to calculate EC values for each affected scenario. As an example, the probability of encountering lead-based paint that requires remediation resulting from the facility's age would be represented as:

IF (# square feet) built or renovated before 1980 >0 THEN Pcause = 1.0 x SF ELSE

IF (# square feet) built or renovated after 1980 THEN Pcause = 0.0 x SF

Calculation of Risk Scenario Costs: As with the calculation of probabilities, costs for each scenario are derived from one of the following sources:

- SFMEA panelist-assigned values;
- User inputs; or
- Externally-derived data.

Scenario-based FMEA panelists were asked to assign relative costs as a proportion of the ESCO's margin for a given retrofit project. This reflected the fact that the most frequent end effect identified by SFMEA panelists was "savings shortfall/erosion of ESCO's margin" which was expected, given the focus of EPC retrofit projects on maintaining the margin in light of realized energy savings performance. Other end effects appearing in scenarios included "difficulty getting financing," "reduced project value for ESCO," and "legal impacts." Panelists agreed in all cases that these consequences could be adequately addressed in terms of the proportion of the ESCO's project margin that would potentially be at risk if these risk scenarios were left unmitigated.

The first two risk scenario maps had end effects of "Remove/Modify" or "Manage in Place" and "Modify Affected System(s)," respectively. In these cases, construction estimates were used whenever possible, since risk consequences could be directly assessed utilizing industry standard cost databases, such as those developed by RS Means (RS Means 2014). Such cost calculation methods were applied to risk scenarios 1A1 (asbestos abatement), 1A3 and 1A4 (lead-based paint abatement and management in-place, respectively), and 1A5 and 1A6 (fuel-related contaminants). Data for asbestos abatement costs per building square foot were derived from Azen et al. (1992) and Whitestone Research (2009), with costs converted to 2014 dollars through the use of consumer product indices for the base years when research was conducted and the current year. Data from RS Means (RS Means 2014) supported costs estimates for all variables in this section.

5.4.1.2 Mitigation Strategies Cost-Benefits

The second element of the model is focused on determining the costs and benefits of mitigation strategies for each risk scenario. Potential mitigation strategies were identified through two sources: (1) the refined risk framework presented in Chapter 4 and (2) risk mitigation review conducted by an ESCO industry professional. Mitigation can typically follow one of two management schemes; risks can be retained and managed or allocated to another party via contractual or technical means (Ahmed et al. 2007; Perera et al. 2009; Banaitiene and Banaitis 2012). For the purposes of this model, only retained risks are subject to mitigation activities, and mitigation is defined as an activity that enables potential risks to be detected and managed before the energy performance guarantee contract is signed, after which time the ESCO has limited opportunities for cost recovery due to unknown or unmitigated risks.

Mitigation strategies were organized by risk scenario map, and the model provided the opportunity to select appropriate strategies for each of the 12 groups of risk scenarios. Two measures are required of each mitigation strategy in order to effectively model them: (1) the efficacy of the strategy, and (2) the cost of the strategy. Since consensus was not achieved for these measures from an expert panel, the model required manual entry of these values by the analyst, except for those for which cost-estimating relationships were derived from industry standard databases (e.g., asbestos sampling costs).

Efficacy is the assessment of how effective the measure is at mitigating the original source of risk. For example, conducting an asbestos survey in a building may not adequately characterize 100% of the asbestos-containing materials, thereby leaving some residual amount of unmitigated risk; efficacy is, therefore, measured as the percent effectiveness of a given measure. There may be a relationship between efficacy and cost, where increased intensity of the mitigation strategy may result in greater efficacy at a higher cost. This cost-benefit relationship is the central component of interest for this part of the model. An important consideration is the ability to make decisions about risk control and mitigation strategies at given levels of cost.

5.4.1.3 Expected Life Cycle Value

The third element of the model is the calculation of the net effects of project risks and mitigation strategies using the ELCV metric. Values of unmitigated value at risk, mitigated value at risk, and ELCV are calculated and presented in terms of EC and percentage of the ESCO’s margin. To accomplish this, values of expected cost for each scenario are calculated from the earlier model element focused on risk probabilities and costs, mitigation costs and efficacies are carried forward from the previously-discussed model element. The remaining risk is then calculated for each scenario, as the portion of the EC remaining after mitigation, owing to the efficacy of each strategy. This results in the calculation of a cost-benefit relationship for each scenario, where values below one represent mitigation strategies that cost more to implement than the value they mitigate. This element of the model also examines the value of ELCV-related cost parameters throughout the project life cycle, by assigning to each scenario the project phase where end effects are realized.

5.4.1.4 Decision Solutions

The final element of the model is the use of ELCV-related data in providing advice about the risk management process. The model highlights instances of negative cost-benefit ratios and negative values of ELCV, which indicate that elected mitigation strategies cost more to implement than the value of the mitigated risk. The decision solutions element, therefore, supports the ability of the decision-maker to find optimal combinations of risk mitigation strategies to maximize the value of the ELCV. To support this process, the model also provides a graphical representation of the unmitigated value at risk, the mitigated value at risk, the ELCV, and the average cost-benefit value across each project phase.

5.4.2 Framework Database

The database providing facility-, probability-, and cost-related data utilizes data sources as described in the EPC retrofit process model. This is delivered through four primary sub-databases: (1) IGA data, (2) cost data, (3) climate data, and (4) equipment replacement and maintenance life/cost. Relevant IGA data is provided directly by the model user through the interface, described below. Relevant information from the IGA includes the following:

- Facility and project-specific information
    - Size and age of buildings undergoing retrofit activities;
    - The presence of fuel tanks and piping;
    - Design values for HDD and CDD; and
    - Utility rates and escalation factors.
- Energy guarantee-related information
    - Contract length;
    - Total and annual guaranteed energy savings; and
    - Total predicted savings.
- An ECM-by-ECM analysis of the following
    - Whether the ECM is difficult to demonstrate;
    - Design values for ECM service life;
    - Replacement cost; and
    - Design energy savings.

As described earlier in this section, cost data was derived from industry standard construction cost estimating databases, such as RS Means (RS Means 2014), and research that has been directed to defining asbestos remediation costs per square foot of building area (Azen et al. 1992; Whitestone Research 2009). Climate data consisted of annual normal HDD and CDD values as well as 62 years of CDD and HDD data. The latter dataset was used to generate the PDF by first identifying the data's distribution and using a random number generator seeded with the parameters of that distribution. Equipment service life data was obtained from the ASHRAE Service Life and Maintenance Cost Database. Probabilistic values for ECM service life costs were generated from that dataset, using cost data from the IGA, following the method as described for probabilistic HDD/CDD values. These values were then used to calculate probabilistic energy savings, using the results of the multivariate regression model developed by Griffin (2008), which found that for every one unit increase in HDD energy consumption per square foot increases by 0.032 KBTUs (or 0.00032 therms). A 1:0.007 relationship was observed for CDD.

5.4.3 User Interface

The user interface has the primary purpose of enabling the user, defined here as the decision maker seeking advice on risk management actions, to interact with the model. The interface enables two-way communication, whereby the user can provide information that is translated into the model, and where the model can provide information back to the user in a format that is understandable, in order to facilitate support of decision making.

5.5 CHAPTER SUMMARY

This chapter discussed development of the risk analysis and evaluation framework for ESCO risks when undertaking EPC retrofits, focused on correctional facilities. Using potential risk root cause and mitigation strategy information elicited from the Delphi panel, the framework used SFMEA to analyze and assess risks. A four member expert panel was convened to conduct a SFMEA analysis of 28 causes, which resulted in the analysis of 23 causes via the development of 77 different risk scenarios organized into 12 scenario maps.

The SFMEA panel analyzed risks using two measures of criticality – RPN and EC. This provided the opportunity for the research to empirically test the differences between the two methods and evaluate the findings of Kmenta and Ishii (2004). While relationships were detected between individual contributory parameters of both RPN and EC, the measures of criticality generally did not exhibit a one-to-one relationship with one another. The use of EC also provides a cardinal measure of risk criticality, enabling decision making on the basis of the difference in values. This was found to be a challenge with the use of the RPN score, where higher numbers do not necessarily indicate greater amounts of risk. Several scenarios were shown where EC varied greatly at the same value of RPN and vice versa, as well as the situation where RPN and EC scores yielded mixed priorities for decision making. At given median values of the RPN, the EC varied by an average of 68%, and in some instances was as high as 200%. As a result of this analysis, EC was demonstrated to be the more effective measure to support decision making.

The parameter values obtained via the SFMEA panel along with external sources of information, project-, facility-, and external environment-related factors, and decision maker heuristics were captured and represented via a life cycle cost-based risk model framework. This framework consists of a user interface, a database of external quantitative information, and the model which utilizes expert panel data, quantitative information, and expert knowledge to represent risk scenarios and associated mitigation costs over the project life cycle. A pilot-scale application of this model is conducted in the next chapter.

CHAPTER 6

PILOT APPLICATION OF LIFE CYCLE COST-BASED RISK MODEL

6.1 INTRODUCTION

Chapter 5 described the risk analysis and evaluation method used to complete the risk management process for energy service company (ESCO) risks when undertaking energy performance contracting (EPC) retrofit projects, with a focus on correctional facilities. Scenario-based failure mode and effects analysis (SFMEA) was selected as the analytical method for its ability to incorporate expert knowledge and determine risk criticality through a consensus-based process. The SFMEA panel identified and prioritized potential risk root causes from the refined risk framework (Chapter 4) and developed 77 risk scenarios that were analyzed using risk priority number (RPN) and expected cost (EC). The relationship between RPN and EC was analyzed following research conducted by Kmenta and Ishii (2004), and determined that EC is a preferred measure of risk criticality given its use of measures that support improved decision making.

The risk analysis and evaluation framework was then developed into a model through the inclusion of quantitative information from a database and the use of a user interface. The model enabled users to evaluate risk mitigation decisions based on facility and project characteristics, qualitative and quantitative data as described in the EPC retrofit process model (Chapter 4) and heuristics used by the SFMEA panelists and the user in approaching project level risks.

This chapter focuses on the pilot-scale implementation of the life cycle cost-based risk model for EPC retrofits in correctional facilities, to determine its applicability and usability to the types of risks faced in such projects and the suitability of such a model for effective decision making.

6.1.1 Glossary

Frequently used terms in this chapter are defined as below:

- EC: expected cost; a measure of risk that assesses the probability of the occurrence and missed detection of a fault, in terms of cost over the life cycle of the fault condition (Gilchrist 1993); calculated as EC= P_{cause} X P_{effect} X Cost;
- EC_{PV}: expected cost based on present value;
- ELCV: expected life cycle value; the amount of risk (expressed as expected cost) effectively mitigated at a given cost, over the project life cycle;
- $ELCV_{PV}$: expected life cycle value based on present value; the amount of future risk discounted to the present that is effectively mitigated at a given cost, over the project life cycle;
- Risk Scenario: A cause-effect chain describing a root cause, end effect, and potentially intermediate effects which lead to the calculation of an EC value;
- Risk Scenario Map: Multiple related scenarios organized together in a map to describe a particular system or function of interest;
- Scenario-Based FMEA: SFMEA; FMEA method that analyzes risk by constructing cause-effect chains to describe failures rather than defining a single cause-single failure mode relationship; and

- Single Present Value: SPV; calculates the present value of a future cash amount, for one-time amounts; SPV factor is calculated as $SPV = \frac{1}{(1+d)^t}$ where d is the discount rate and t is the year at which SPV is calculated.

6.1.2 Chapter Objectives

The model framework developed in Chapter 5 was concerned with the simultaneous use of several information sources to support decision making regarding risk management strategies over the project life cycle. Information sources included knowledge elicited from the SFMEA panel, direct user inputs, and quantitative information from external sources related to costs, climate, equipment replacement and maintenance, and investment grade audit- (IGA) related data. The goal of this chapter is to demonstrate the applicability and use of the risk model by ESCO professionals. The following objectives were established in order to accomplish this goal:

- Demonstrate the functioning of the life cycle cost-based risk model and test on a correctional facility; and
- Verify the function of the model based on the application to the case study and finalize the system, as needed.

6.2 DEMONSTRATION OF LIFE CYCLE COST-BASED RISK MODEL

As shown in Chapter 5, quantitative information and expert knowledge could be represented in a model framework to reflect the outcomes of decisions made regarding the management of EPC retrofit project risks. The core function of the model utilized risk relationships and data identified and developed from the following sources:

- Elicited expertise and constructed knowledge from the Delphi panel of 19 ESCO experts discussed in Chapter 4:
    - Risk identification, potential root cause identification, and a partial list of controls and mitigation strategies; and
    - Information sources and their use to support decision making under conditions of risk at each project phase.
- Elicited expertise from the SFMEA panel, described in Chapter 5:
    - Seventy-seven risk scenarios organized into 12 risk scenario maps;
    - Probabilities of cause, conditional end effect probabilities, and relative costs for each scenario; and
    - Facility-, project-, and external environmental-related factors that influence risks.
- Quantitative data related to construction costs estimates, probabilities of cause given factors listed above, climate data, equipment service life, and IGA-related information.

The next sections describe how the user interface was developed as well as supporting structures for variable development in the model system.

6.2.1 Development of User Interface

The purpose of the user interface is to allow the decision maker seeking risk management advice the ability to interact with the model in an organized manner that enhances system understanding. The user interface also provides communication to the user via risk management advice derived from the results of the model. This section explains each element of the user interface, its critical functions, how decision making is represented, and how connections to quantitative information are made.

6.2.1.1 User Interface Layout

The interface consists of five input screens and one combination input/output screen. The model was built in Microsoft Excel; each screen consists of a separate workbook. The screens consist of: (1) starting screen, (2) user preferences screen, (3) review scenarios screen, (4) risk data entry screen, (5) mitigation screen, and (6) an expected life cycle value (ELCV) results & decisions screen. These screens are selected using the Excel workbook tabs following a sequential numbering format for ease of use (Figure 6-1).

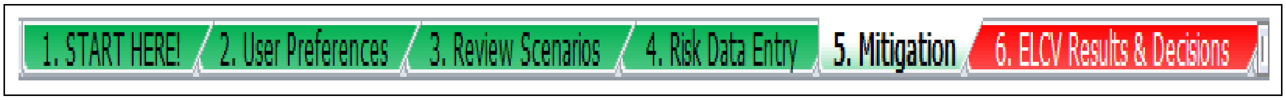
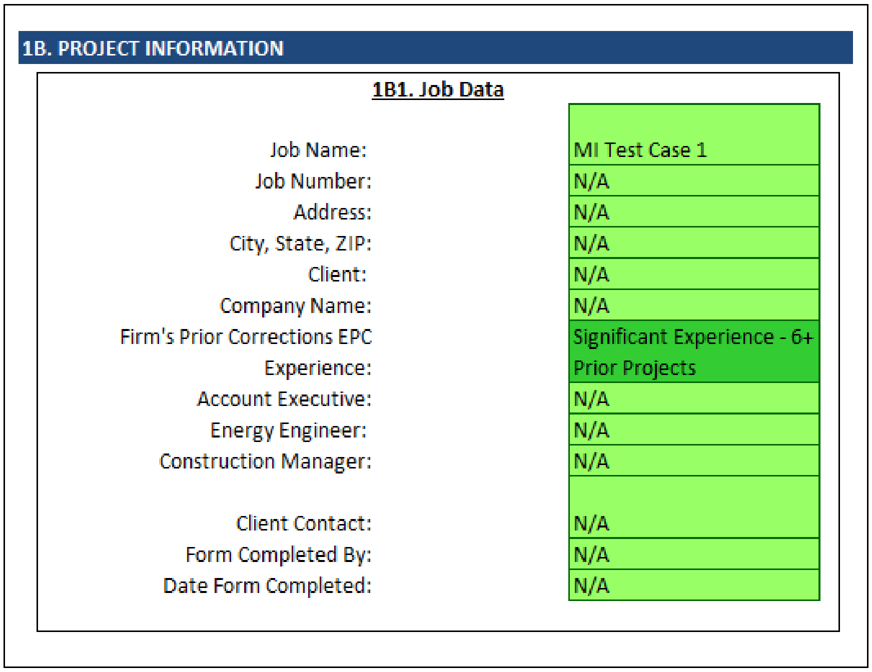


Figure 6-1. User Interface Screen Selection

6.2.1.2 Start Screen

The start screen allows the user to provide information about the retrofit project in four categories: (1) job data, (2) facility and project data, (3) energy guarantee information, and (4) energy conservation measures.

The **job data box** is used to capture information about the project team conducting the retrofit and is generally not used in model calculations. One exception is the data entry option for the firm’s level of previous corrections EPC experience. This was a significant issue raised numerous times by Delphi panelists and SFMEA participants; as a result, this information is captured here and values are assigned based on their experiences. Those values become the probability of cause for scenarios 1D1-1D11. The job data input screen is depicted in Figure 6-2.



1B. PROJECT INFORMATION

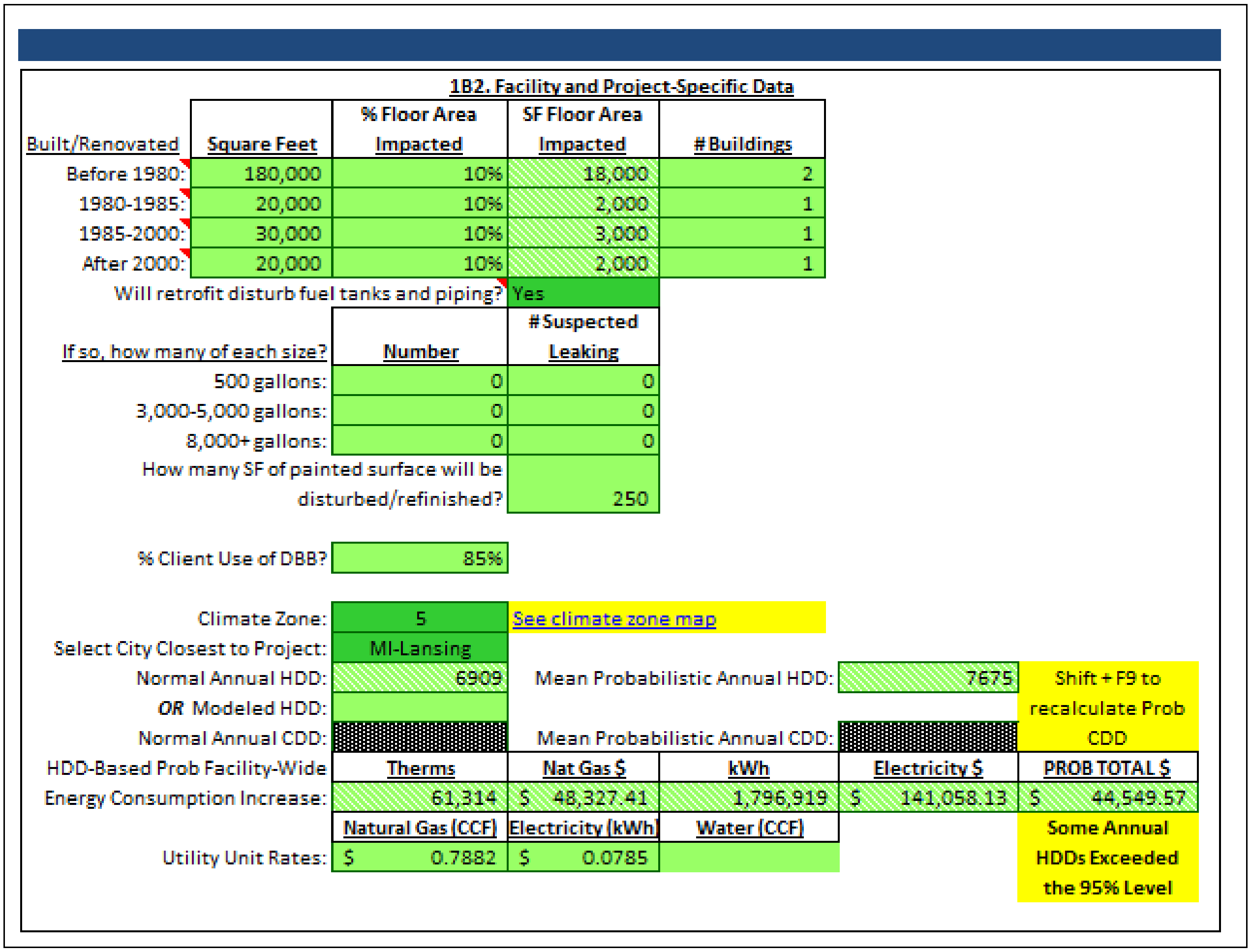
1B1. Job Data

Job Name:	MI Test Case 1
Job Number:	N/A
Address:	N/A
City, State, ZIP:	N/A
Client:	N/A
Company Name:	N/A
Firm's Prior Corrections EPC Experience:	Significant Experience - 6+ Prior Projects
Account Executive:	N/A
Energy Engineer:	N/A
Construction Manager:	N/A
Client Contact:	N/A
Form Completed By:	N/A
Date Form Completed:	N/A

Figure 6-2. Job Data Input Box

The **facility and project data box** allows the user to provide information about facility, project, and external factors which were initially developed by SFMEA panelists. As discussed in the previous chapter, these factors potentially have a significant impact on the calculation of a number of probabilities of risk cause and costs. A screen shot of the interface is provided in Figure 6-3.

Notable among these inputs is the ability to distinguish between manual data input requirements (solid green cells) and automatically-calculated values (diagonally-hatched cells). Instructions are highlighted in yellow, and non-applicable information based on previous inputs is shaded in black. These help ensure that users are entering data in the appropriate locations on the worksheet and also provides interactive guidance if error conditions are detected.



1B2. Facility and Project-Specific Data

Built/Renovated	Square Feet	% Floor Area Impacted	SF Floor Area Impacted	# Buildings
Before 1980:	180,000	10%	18,000	2
1980-1985:	20,000	10%	2,000	1
1985-2000:	30,000	10%	3,000	1
After 2000:	20,000	10%	2,000	1

Will retrofit disturb fuel tanks and piping? Yes

If so, how many of each size?	Number	# Suspected Leaking
500 gallons:	0	0
3,000-5,000 gallons:	0	0
8,000+ gallons:	0	0

How many SF of painted surface will be disturbed/refinished? 250

% Client Use of DBB? 85%

Climate Zone: 5 See climate zone map

Select City Closest to Project: MI-Lansing

Normal Annual HDD: 6909 Mean Probabilistic Annual HDD: 7675 Shift + F9 to recalculate Prob CDD

OR Modeled HDD:

Normal Annual CDD: Mean Probabilistic Annual CDD:

HDD-Based Prob Facility-Wide Energy Consumption Increase:	Therms	Nat Gas $	kWh	Electricity $	PROB TOTAL $
	61,314	$ 48,327.41	1,796,919	$ 141,058.13	$ 44,549.57

Utility Unit Rates:	Natural Gas (CCF)	Electricity (kWh)	Water (CCF)
	$ 0.7882	$ 0.0785	

Some Annual HDDs Exceeded the 95% Level

Figure 6-3. Facility and Project-Specific Data Input Box

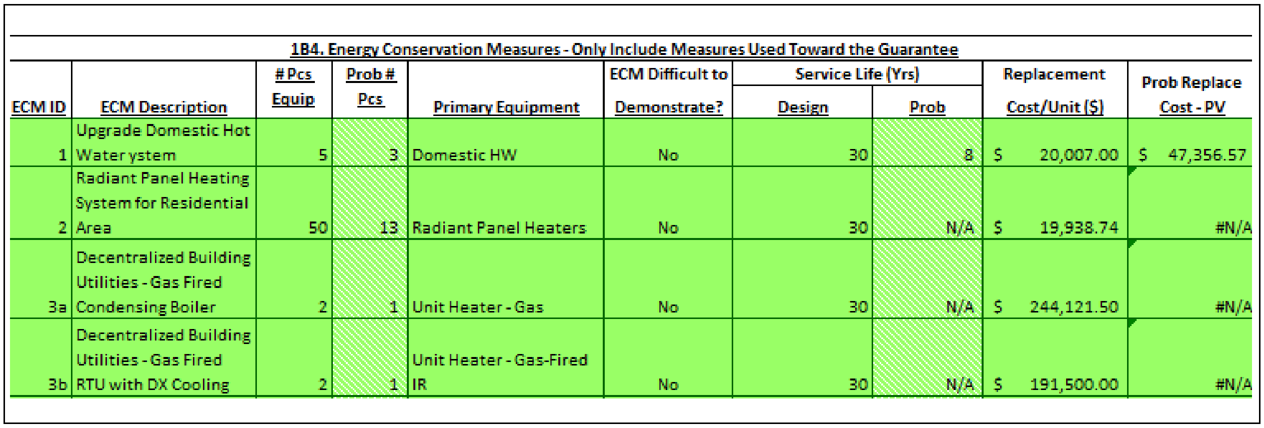
The lower portion of the screen provides mean probabilistic values for annual heating degree days (HDD) and cooling degree days (CDD). These values are called from a supporting worksheet which utilizes a random number generated from a probability function derived from over 60 years of HDD data. One probabilistic HDD value is recorded for each year of the contract, as provided in the job data input screen. Probabilistic facility-wide energy consumption estimates are then calculated based on changes between the normal annual or modeled HDD and the probabilistic annual HDD value for each contract year. The calculation of this impact relies on the linear relationship observed by Griffin (2008) between HDD and energy consumption per square foot of building area. Consumption was converted from thousand British Thermal Units

(KBTUs) to therms (natural gas consumption) and kilowatt hours (kWh) for electricity consumption. Probabilistic consumption values are then multiplied by the total facility square footage subject to retrofit activities, obtained previously on this screen, and the respective utility unit rates which were obtained directly from the IGA.

Utility rate escalation factors provided by the FEMP (Rushing et al. 2013) are applied to each year's resultant total energy cost increase or decrease to account for future conditions in energy markets. These factors are derived by fuel type (i.e., natural gas and electricity), by end-use (e.g., industrial vs. residential consumers), and by U.S. Census Region. Finally, each year's probabilistic HDD value is compared to the probability density function (PDF) for HDD; only values equal to or exceeding the $95^{\%}$ confidence level are passed to the cost field of the appropriate risk scenario (2G4). This was done to reflect SFMEA panelist experience with reduced energy performance that led to contractual disputes during severe climate conditions that deviated significantly from normal annual conditions.

The **energy guarantee box** captures data about baseline energy consumption, the contract length, total savings and annual guaranteed savings, as well as total energy savings and the ESCO's margin, also called the contractor's cash flow. This value automatically calculates and is important as it is used to parameterize relative costs in scenarios that do not use fixed or probabilistic costs when calculating the EC.

The **energy conservation measures (ECMs) box** of the start screen provides summary information about ECMs selected for the retrofit, as shown in Figure 6-4. The ECM description



1B4. Energy Conservation Measures - Only Include Measures Used Toward the Guarantee

ECM ID	ECM Description	# Pcs Equip	Prob # Pcs	Primary Equipment	ECM Difficult to Demonstrate?	Service Life (Yrs)		Replacement Cost/Unit ($)	Prob Replace Cost - PV
						Design	Prob		
1	Upgrade Domestic Hot Water ystem	5	3	Domestic HW	No	30	8	$ 20,007.00	$ 47,356.57
2	Radiant Panel Heating System for Residential Area	50	13	Radiant Panel Heaters	No	30	N/A	$ 19,938.74	#N/A
3a	Decentralized Building Utilities - Gas Fired Condensing Boiler	2	1	Unit Heater - Gas	No	30	N/A	$ 244,121.50	#N/A
3b	Decentralized Building Utilities - Gas Fired RTU with DX Cooling	2	1	Unit Heater - Gas-Fired IR	No	30	N/A	$ 191,500.00	#N/A

Figure 6-4. Energy Conservation Measures Input Box

mirrors data from the IGA, and the primary equipment field utilizes a drop-down menu from which the main type of equipment used for each ECM is selected. Each ECM may have multiple entries, as is seen with the ECM number 3, if that ECM utilizes more than one type of mechanical or other equipment. In that case, the original ECM numbers are supplemented by a lower case letter as an additional identifier, such as 3a. With ECM 3, the retrofit measures were separated into gas-fired condensing boilers and gas-fired rooftop units with direct expansion (DX) cooling.

An assessment is made by the user as to whether the ECM is difficult to demonstrate, which helps construct the probability of cause for risk scenarios 2CD1 through 2CD3. The design service life is then entered by the user, and a probabilistic service life is calculated by the model, utilizing the user input and ECM-by-ECM service life data provided by ASHRAE (2014). A random number is generated from the constructed probability distribution function, which results in the value entered in the “Prob” cell for service life. If that value is less than the design value, further assessment is made as to whether the service life is less than the contract length, as entered in the energy guarantee information data screen and as shown by ECM 1 in the figure. A separate random number is also generated to assess how many pieces of equipment may be affected by this shorter service life. For example, there are five domestic hot water heaters installed in ECM 1; the random number generator assigned three of these units as having a reduced service life of eight years. Since eight years is less than the length of the contract term (10 years in this case), the manually-entered replacement cost (derived from the IGA) in current dollars is discounted using the SPV, with the time variable entered as the early failure year; in the example case, the SPV was based on a time of eight years. The sum of the discounted replacement values for all mechanical ECMs is used to generate cost parameters for risk scenarios 2G7 and 2G8.

This screen includes entries for non-mechanical system ECMs; however, due to data limitations for the ASHRAE database (ASHRAE 2014), not all mechanical equipment can be listed and non-mechanical equipment (e.g., lighting, water conservation devices) is not evaluated.

6.2.1.3 User Preferences Screen

The user preferences screen permits the user to select their desired method for risk scoring. Options are to accept the expert panel data, derived from the SFMEA panel, or to manually enter values for each scenario. A link is provided to take the user directly to the risk data entry screen in order to facilitate a review of the panel data before deciding which method they wish to use. At the time of model development, a third option was explored – model-derived probability and relative cost values based on the user's background. This was to be based on the characteristics of the SFMEA panelists with regard to risk tolerance, professional tenure in ESCO projects, job level within the organization, and the project phases that the individual supports. Due to the small sample size of the SFMEA panel, establishing such quantitative relationships was impossible; further work that can be conducted in this regard is discussed in Chapter 7.

6.2.1.4 Review Scenarios Screen

The “Review Scenario” screen is required in order to review each risk scenario, both to ensure understanding of the relationship among various causes, intermediate effects, and end effects, as well as to decide which of the 77 scenarios will be included in the model. A comments field is provided to explain user decisions for selection or non-selection of scenarios. To facilitate ease of use and understanding, selection fields are color-coded to alert users to their selection; selected risks appear in green, non-selected risks are red, and risks with no data entered with regard to selection are in yellow.

6.2.1.5 Risk Data Entry Screen

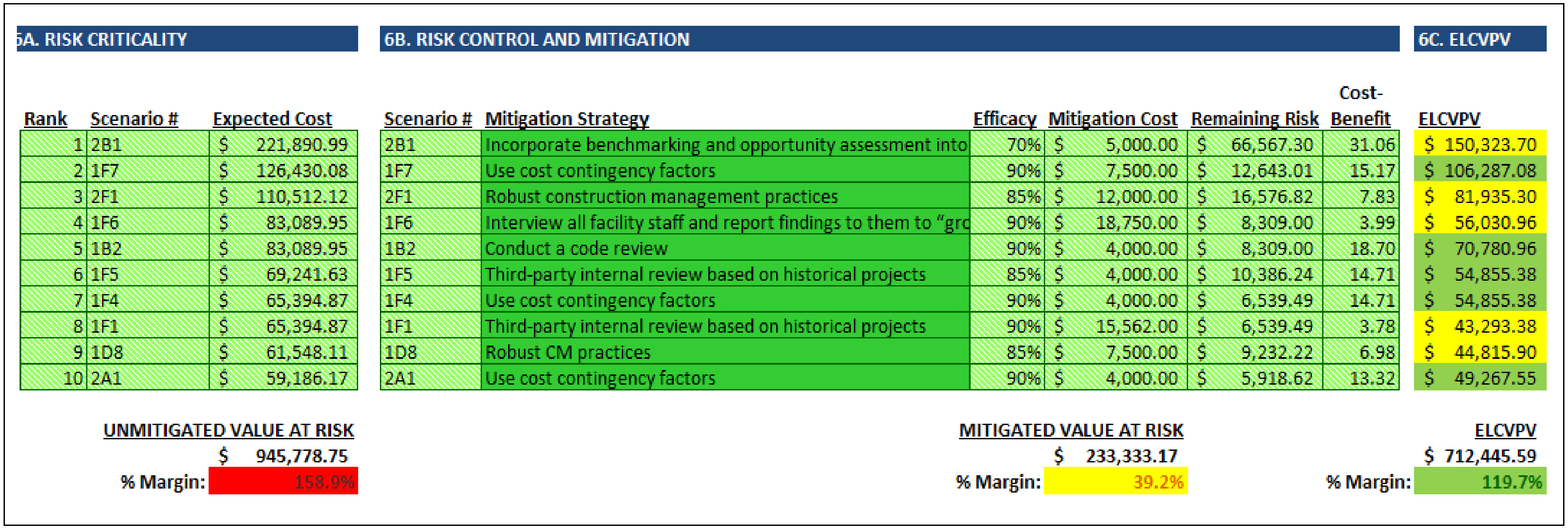
As stated earlier, the risk data entry screen is used to review probability and cost values for risk scenarios during the user preferences selection process. This screen also reflects the data that has been either brought forward from the expert SFMEA panel, or empty green cells appear indicating that the user has selected to manually enter data, which is also accomplished on this screen. Users also have the ability to enter a value for the year when each risk scenario is realized, which is used in the calculation of the EC_{PV}. Those risks not selected for further analysis are highlighted to allow the user to focus on just their selected risks.

6.2.1.6 Mitigation Screen

For the purposes of the model, risk mitigation is defined as activity that enables risk to be controlled before the energy savings guarantee is signed. It is generally accepted that the ESCO has limited ability to initiate change orders if they detect unmitigated risk conditions after that point. The mitigation screen provides a list of mitigation strategies associated with each scenario map. Users may accept these strategies for the project, or overwrite the "other" field with their own preferred strategy. An efficacy value must also be provided for each strategy. Efficacy is given as the amount of risk, expressed as a percentage that is effectively mitigated through each given strategy. Users must then enter a cost value for each mitigation strategy. The cost may be entered as a lump sum, or fields are available to enter labor cost, labor hours, material cost, and equipment cost associated with each mitigation measure. With the exception of strategies calculated using quantitative information provided elsewhere in the model, values must be manually entered for each strategy.

6.2.1.7 ELCV Results & Decisions Screen

This screen provides a hybrid of user inputs and outputs to assist the user in making effective decisions (Figure 6-5). Sections 6A through 6C are based on the ten most critical risks, as ranked by the value of the present value of the EC (EC_{PV}). Section 6A identifies those risk scenarios by



A. RISK CRITICALITY

Rank	Scenario #	Expected Cost
1	2B1	$ 221,890.99
2	1F7	$ 126,430.08
3	2F1	$ 110,512.12
4	1F6	$ 83,089.95
5	1B2	$ 83,089.95
6	1F5	$ 69,241.63
7	1F4	$ 65,394.87
8	1F1	$ 65,394.87
9	1D8	$ 61,548.11
10	2A1	$ 59,186.17

UNMITIGATED VALUE AT RISK
$ 945,778.75
% Margin: 158.9%

6B. RISK CONTROL AND MITIGATION

Scenario #	Mitigation Strategy	Efficacy	Mitigation Cost	Remaining Risk	Cost-Benefit
2B1	Incorporate benchmarking and opportunity assessment into	70%	$ 5,000.00	$ 66,567.30	31.06
1F7	Use cost contingency factors	90%	$ 7,500.00	$ 12,643.01	15.17
2F1	Robust construction management practices	85%	$ 12,000.00	$ 16,576.82	7.83
1F6	Interview all facility staff and report findings to them to “grc	90%	$ 18,750.00	$ 8,309.00	3.99
1B2	Conduct a code review	90%	$ 4,000.00	$ 8,309.00	18.70
1F5	Third-party internal review based on historical projects	85%	$ 4,000.00	$ 10,386.24	14.71
1F4	Use cost contingency factors	90%	$ 4,000.00	$ 6,539.49	14.71
1F1	Third-party internal review based on historical projects	90%	$ 15,562.00	$ 6,539.49	3.78
1D8	Robust CM practices	85%	$ 7,500.00	$ 9,232.22	6.98
2A1	Use cost contingency factors	90%	$ 4,000.00	$ 5,918.62	13.32

MITIGATED VALUE AT RISK
$ 233,333.17
% Margin: 39.2%

6C. ELCVPV

ELCVPV
$ 150,323.70
$ 106,287.08
$ 81,935.30
$ 56,030.96
$ 70,780.96
$ 54,855.38
$ 54,855.38
$ 43,293.38
$ 44,815.90
$ 49,267.55

ELCVPV
$ 712,445.59
% Margin: 119.7%

Figure 6-5. Data Inputs on the ELCV Results & Decisions Screen number along with their attendant EC_{PV} values. Section 6B provides the user with dropdown lists containing the risk mitigation strategies developed in the previous screen. In addition to the efficacy and mitigation costs carried forward from the mitigation screen, the model calculates the remaining risk and the cost-benefit relationship for each scenario. Remaining risk is calculated as:

$$(1\text{-Efficiacy}_{\text{mitigation}}) \text{ X } EC_{PV}$$

Cost-benefit is calculated as:

$$(\text{EC-Risk}_{\text{remaining}})/\text{Cost}_{\text{mitigation}}$$

The cost-benefit relationship provides the user with a rapid screening tool for assessing the financial performance of each selected mitigation strategy. Cost-benefit values below 1 indicate a mitigation measure that costs more to implement than it saves. The final value calculated by the model is the $ELCV_{PV}$, which was described in Chapter 5 as the ELCV discounted to the present. The $ELCV_{PV}$ is effectively the value of the mitigated risk, once mitigation costs and remaining risks have been subtracted. Like the cost- benefit ratio, optimal solutions of the model maximize the value of $ELCV_{PV}$ across the range of risk scenarios examined. A negative $ELCV_{PV}$ value indicates the same thing as a cost-benefit value below one. The model provides color coding to help the user quickly focus on the risk factors with the best and worst outcomes. Negative $ELCV_{PV}$s are highlighted in red; green highlighting is used for $ELCV_{PV}$s that represent effective mitigation of 75% or more of the EC for a given risk.

The rest of the $ELCV_{PV}$s are shaded yellow, indicating that further mitigation may be required for those risks.

Similar shading is used for the three summary values that connect the input portions of the screen with the output portions. The unmitigated value at risk is the sum of the EC_{PV} values for the ten most critical risks and reflects the percentage of the ESCO margin that is potentially at risk if those risk scenarios remain unmitigated. The mitigated value at risk is the portion of the original value that remains at risk after mitigation has been conducted. This includes the cost of mitigation which is borne by the ESCO, as well as the remaining risk. The $ELCV_{PV}$ can then be expressed as the difference between the unmitigated and mitigated values at risk, and reflects the financial value of successful risk mitigation activities. Unmitigated Value at Risk calculations that are greater than 40% of the ESCO's margin are flagged in red; those that are less than 20% are shaded green, and yellow cells denote cases that fall in between those values. The same shading is used for unmitigated value at risk calculations. The $ELCV_{PV}$ utilizes the reverse of those color scales – values greater than 40% of the margin are shaded green and lower values are in yellow and red boxes. This makes sense as the goal of the model is to maximize values of $ELCV_{PV}$ while minimizing mitigation costs.

Section 6D presents the value at risk, ELCV, and cost-benefit data in a more efficient format to aid decision making. First, each risk scenario's project life cycle assignment, as described in Chapter 5 and as noted on the risk data entry screen, is used to aggregate these values at each point in the project life cycle where they are realized (Figure 6-6). This provides the ability to determine the future value of risks avoided at the point in the project where the model is used.

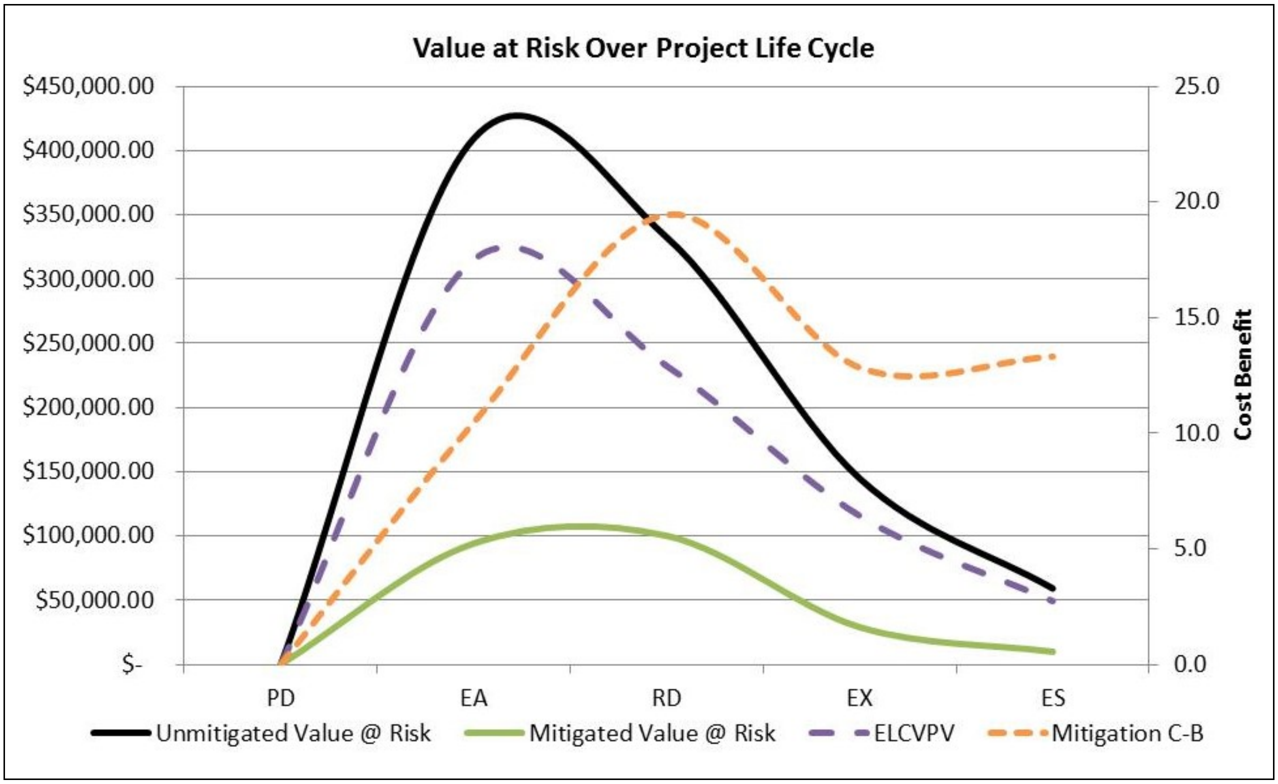


Figure 6-6. Project Life Cycle Value at Risk Plot

Project cash flow can also be overlaid on this time series plot to determine the appropriate project timing for making risk management investments, particularly those at lower cost-benefit values.

The model also facilitates the examination of value at risk for each of the ten most critical risks (Figure 6-7). Mitigation strategies that contribute the most (2B1) and least (1F6) to the overall project $ELCV_{PV}$ can quickly be detected. These relationships enable the user to determine which scenarios could be improved further through the pursuit of different mitigation strategies, additional effort to improve the efficacy of a given strategy at minimal additional cost, or

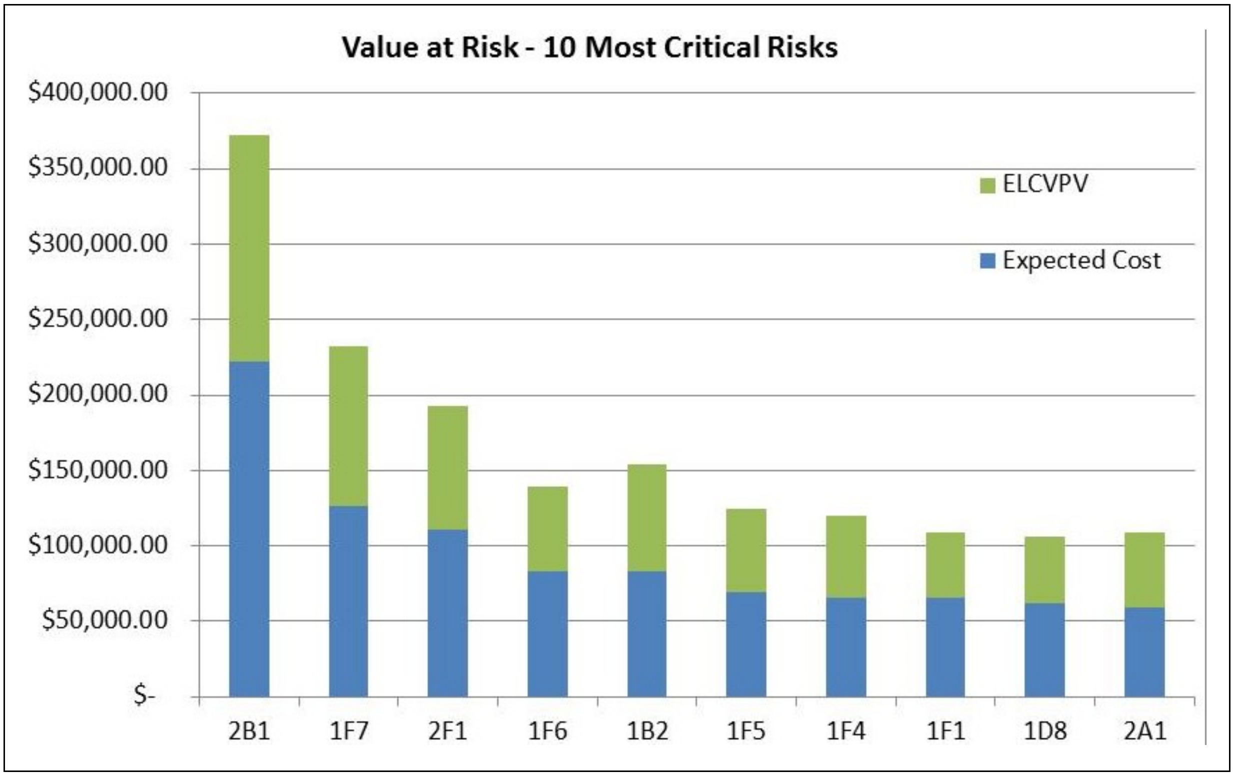


Figure 6-7. Most Critical Risks Value at Risk Plot

through the addition of multiple strategies to a single risk scenario if the additive effect would further enhance ELCV.

6.2.2 Supporting Structures for Variable Development

In addition to the user interface screens, the model contains several screens that support the development of variables. While the various user interface screens support the development of model variables through direct input and calculated values based on user inputs (e.g., the job data, facility and project-specific data, energy guarantee information, and energy conservation measures screens), several call functions and instances of IF-THEN-ELSE logic are used to further support enhanced variable development.

Five hidden screens (risk data, references, mitigation, probability data, and costs) contain readable and writable model data; however, to minimize errors, these screens are not available for end-user access. The risk data screen includes the values of P_{cause}, P_{effect}, and cost for the 77 scenarios. The default condition for these cells is storage of the SFMEA panelist consensus scores for each variable; however, values are automatically written for risk cause probabilities in the 1A scenario map, estimated costs for scenarios 1A1 through 1A6, and risk cause probabilities for scenarios 2G3-2G4 and 2G7-2G8 (Table 6-1).

Table 6-1. Variables Supported by the Risk Data Screen

Scenario	**Variable**	**Variable Calculation**
1A1	P_{cause}	Average of square footage per age category * P_{cause} given by panel
1A1	Cost	Asbestos abatement plan cost + \$5.88 SF floor area impacted by ECMs
1A2	P_{cause}	Average of square footage per age category * P_{cause} given by panel
1A2	Cost	Asbestos abatement plan cost + \$5.88 SF floor area impacted by ECMs
1A3	P_{cause}	Average of square footage per age category * P_{cause} given by panel
1A3	Cost	SF painted surface disturbed by ECMs * average lead paint abatement cost/SF
1A4	P_{cause}	Average of square footage per age category * P_{cause} given by panel
1A4	Cost	SF painted surface disturbed by ECMs * average lead paint encapsulation cost/SF
1A5	P_{cause}	IF tanks/piping will be disturbed THEN $P_{cause} = 0.85$ ELSE $P_{cause} = 0.0$
1A5	Cost	IF tanks/piping will be disturbed THEN number of tanks of each size * cleanup cost/tank, IF tanks are suspected leaking THEN number suspected leaking of each size * leaking cleanup cost/tank ELSE 0
1A6	P_{cause}	IF tanks/piping will be disturbed THEN $P_{cause} = 0.85$ ELSE $P_{cause} = 0.0$
1A6	Cost	IF tanks/piping will be disturbed THEN number of tanks of each size * cleanup cost/tank, IF tanks are suspected leaking THEN number suspected leaking of each size * leaking cleanup cost/tank ELSE 0
2CD1-3	P_{cause}	IF ECM data reveals an average number that are “difficult to demonstrate” >0 THEN P_{cause} =average number of such ECMs ELSE 0
2G3	P_{cause}	IF $HDD_{prob}>0$ THEN 1 ELSE 0
2G4	P_{cause}	
2G4	Cost	$\sum$ IF $HDD_{prob}>=HDD_{0.95}$ THEN Total Energy $Cost_{prob}$ X SPV factor ELSE use SFMEA panel value of relative cost

Table 6-1 (cont'd)

Scenario	**Variable**	**Variable Calculation**
2G7	P_{cause}	IF Service $Life_{prob}$ < contract length THEN ∑ECMs where Service $Life_{prob}$/number of ECMs ELSE use SFMEA panel value of P_{cause}
2G8	P_{cause}	
2G7	Cost	IF Service $Life_{prob}$ < contract length THEN Cost = $\sum Cost_{replacement}$ X SPV factor ELSE Cost = 0
2G8	Cost	

The references screen organizes the variable values that are presented to the user via dropdown boxes. These, in turn, serve as inputs elsewhere in the model. For example, the dropdown list for the experience with corrections retrofits variable is stored here, and connects descriptions of variable levels (e.g., "moderate experience – 3-5 prior projects") to their associated input values for P_{cause} (in this case, $P_{cause} = 0.60$).

The mitigation references screen serves a similar function as described for the references screen, in this case strictly supporting mitigation strategy-related variables.

The probability data screen contains the functions for all variables that are based wholly or partially on selecting a value from a probability density function. These include the base case and probabilistic case for calculation of scenarios involving HDD, CDD, and mechanical equipment service life. Distributions were selected that best fit the original data, and values from the resultant probability functions were selected from among these distributions.

The costs screen supports the development of scenario costs derived through construction estimation. This was applied to scenarios 1A1 and 1A2 (asbestos-related risks), 1A3 and 1A4 (lead-based paint-related risks), and 1A5 and 1A6 (fuel contaminant-related risks). In general these data were derived from RS Means construction cost estimating databases (RS Means 2014) and were used to calculate risk scenario costs directly through the use of facility factors described by SFMEA panelists. For example, as shown in Table 6-1, the calculation of lead-based paint costs utilizes the following relationship:

Average of square footage per age category x P_{cause}, as given by the panel

This utilized average square-foot costs for lead-based paint abatement in RS Means (RS Means 2014) to calculate the scenario cost.

Asbestos abatement costs were calculated somewhat differently. RS Means (RS Means 2014) contains significant amounts of data about asbestos abatement costs; however, there is a great deal of variability among unit costs due to several factors, to include the physical condition of the asbestos-containing material, the type of asbestos-containing material (e.g., pipe wrap, spray-on fireproofing, ceiling tiles), and the intensity level of the abatement activity. Research was sought that could provide a relationship between building characteristics, presence of asbestos, and unitary abatement costs. Research conducted by Azen et al. (1992) and Whitestone Research (2009) found similar square foot costs for asbestos abatement in public buildings, when adjusting for inflation between the research dates. This unit cost could then be applied to the estimate of an equivalent floor area square footage impacted by retrofit activities, provided via the user interface, to estimate the quantity of asbestos present and calculate a cost for relevant scenarios.

6.3 TEST CASE CHARACTERISTICS

The final part of demonstrating the function of the model was to test its use on a case study location. This section discusses the criteria for selection of the case study location, the data collected from the case study, as well as the model results when applied to risk management of the EPC retrofit process.

6.3.1 Case Study Selection

Purposive sampling was used to select the case study location. As opposed to probabilistic sampling, where the goal is to sample individuals from a population such that findings can be generalized to the population as a whole, purposive sampling seeks to focus on specific characteristics of interest within that population (Oliver 2006; Teddlie and Yu 2007; Tongco 2007). As was described in chapters 3 and 4, the Delphi panel was constructed via the same strategy, where the focus was on finding knowledgeable experts with specialized knowledge of the research subject, willingness to participate in the research, and the reliability of experts (Oliver 2006; Tongco 2007; Duah 2014).

As a result, the following characteristics were used when selecting the case study location:

- Capacity and willingness of ESCO and facility agency staff to participate in the study. This included the ability and willingness to share the IGA report, final retrofit design, performance guarantee documents, and contracts;
- Highly experienced key informants (ESCO and facility owner staff) with regard to correctional facility EPC retrofits; and
- Locations were sought that recently (i.e., within the past five years) entered the energy savings phase of an EPC project, such that data would be readily available and key informants would have recent knowledge of project characteristics.

Based on the case study location selection criteria, the steps for testing the life cycle cost-based risk model included:

1. Identify case study location;
2. Review the IGA report, final retrofit design, financial performance, and contract for case study;
3. Visit case study location and perform a visual inspection of building conditions and installed ECMs;
4. Researcher inputs data into risk model using project-, facility-, and external environment-related information from the case study:
    a. Variables and parameter values obtained from SFMEA panelists; and
    b. Probabilistically-generated values through the model;
5. Run risk model to obtain value at risk and ELCV;
6. Provide risk results and recommendations to ESCO and client representatives from the case study location; and
7. Asses system function and utility; finalize the system based on user inputs and recommended modification.

The researcher visited the case study location and had extensive interactions with both the ESCO project representative and the agency representative over an 18 month period. The researcher and the agency representative published a case study about three recent EPC retrofits in correctional facilities, and spent several months discussing the case study location and its suitability for this research. Both individuals were also members of the SFMEA panel, therefore their domain expertise related to risk management was elicited in a general sense, and then again with respect to the selected case study through telephone calls, face-to-face meetings, and site visits.

6.3.1.1 Case Study Location

The selected case study is a correctional facility located in the lower peninsula of Michigan that completed the pre-execution and execution phases of an EPC retrofit in 2011. It was selected because it was representative of a number of similar correctional facility EPC retrofit projects completed during the same time period. Complete case study location details are provided in Appendix E. An overview of the selected location is provided in Table 6-2.

Table 6-2. Case Study Location – Selected Characteristics

Project Characteristics			
ESCO Experience with Correctional Facility EPCs:	Significant experience – 6+ projects		
Facility Characteristics			
Building Vintages:	1925-2002	Building Area (SF):	905,220
Construction Types:	• Brick, pre-cast concrete block, steel, and glass • Weatherized pole barns with sealed concrete floors and plaster-board walls	Energy Conservation Measures:	• Lighting retrofit • Water efficiency • Decouple steam plant and condition independently • Controls
Security Level:	I – Minimum Sec.	Climate Zone:	5
Energy Performance Contract and Savings Guarantee Information			
Baseline Electricity (kWh):	9,442,290	Project Value:	$12,890,098
Baseline Natural Gas (therms):	560,016	Guaranteed Savings/Year:	$1,195,334
Baseline Steam (therms):	1,059,181	Payback Period:	10 yrs

Data was collected by the researcher after reviewing the IGA, energy savings guarantee, and contractual documents, followed by a field visit to the case study location and interactions with the agency representative. This individual had significant experience implementing EPC projects in a correctional setting (20 years) and was thus considered a knowledgeable informant for this research. This individual also participated in the SFMEA panel as member RP-03-E – relative expertise scores are available in Chapter 5.

Data was obtained from agency and ESCO reports, as well as the knowledgeable informant and a member of the ESCO staff who developed the EPC retrofit at the case study location (Table 6-3).

Table 6-3. Data Obtained for Case Study Location

Information Required by Model	Information Obtained
Project Information – Job Data	
Job Name:	Parnall Correctional Facility
Firm's Prior Corrections EPC Experience:	Significant Experience - 6+ Prior Projects
Project Information – Facility and Project-Specific Data	
Building Area Built/Renovated Before 1980:	602,600 SF[a,b]
Building Area Built/Renovated 1980-1985:	0 SF[a]
Building Area Built/Renovated 1985-2000:	14,260 SF[a,b]
Building Area Built/Renovated After 2000:	23,939 SF[a,b]
% SF Impacted by ECMs Built/Renovated Before 1980:	~35%
% SF Impacted by ECMs Built/Renovated 1980-1985:	~10%
% SF Impacted by ECMs Built/Renovated 1985-2000:	~100%
% SF Impacted by ECMs Built/Renovated After 2000:	~100%
Will retrofit activities disturb fuel tanks and piping?	No
Area of Painted Surfaces to be Disturbed:	~250 SF
Percent Client Uses DBB Procurement:	85%
Climate Zone:	5
Nearest City in Model DB:	Lansing, MI
Normal Annual HDD	6909
Natural Gas Unit Rate (CCF):	$0.7782
Electricity Unit Rate (kWh):	$.07850
Project Information – Energy Guarantee Information	
Baseline Annual Electricity Consumption (kWh):	9,442,290
Baseline Annual Natural Gas Consumption (therms):	560,016
Contract Length (Years):	10
Total Guaranteed Savings ($):	$12,890,098.00
Annual Guaranteed Savings ($):	$1,195,334.00
Total Predicted Savings ($):	$15,646,197.00
Financing Costs:	$2,161,000.00
Hedged Savings ($)/Cash Flow:	$545,931.00

Table 6-3 (cont'd)

Information Required by Model	Information Obtained
Energy Conservation Measures	
ECM #1:	Renegotiate Incinerator/Steam Contract
ECM #2:	New HVAC for CB9, CB10 - Hydronic Radiant Panel Heating System and Roof-Mounted Air Rotation Units
ECM #3:	Decentralized Building Utilities - Gas Fired Unit Heater; Gas Fired Infrared Heater; Gas Fired Condensing Boiler; Domestic Hot Water; Gas Fired Rooftop Unit with DX Cooling
ECM #4:	Campus Lighting Retrofit - Interiors
ECM #5:	Renegotiate Incinerator/Steam Contract
ECM #6:	Campus Water Conservation
ECM #7:	Decommission Former Textiles Building
ECM #8:	Minimize Heat in Bldg 31 and Minimize Heat in Cell Block 8 - Hydronic Unit Heater
ECM #9:	Replace Dishwasher

Notes:
a\ Risk scenarios addressing the presence of asbestos containing materials were not used in the pilot test; it is the State of Michigan's policy to separately address and pay for the abatement of any asbestos discovered during the construction process and not otherwise burden the contractor.
b\ Approximately 250,000 square feet of building area was subjected to retrofit activities.

Additional details about installed ECMs were obtained by reviewing the project schedule of values. Based on data availability and the model limitations of the model, several assumptions were made when compiling this data:

- For the purposes of the life cycle cost-based risk model, only the primary system components were of interest (e.g., rooftop units, boilers), as opposed to associated piping, electrical, and minor controls elements. Cost data provided in the IGA and schedule of values was rather coarse with regard to this level of detail. As a result, estimates of replacement cost may be higher than actual costs, as they can be expected to include system accessories. Estimated unitary costs were used, whenever possible, by isolating project overhead and profit from specific item costs.
- In some cases (e.g., ECM #8), the schedule of values did not isolate the cost of individual mechanical systems. As a result, costs were apportioned to individual systems in each

ECM based on estimates of the type of equipment being installed, and through an analysis of unitary costs provided in the IGA alongside the schedule of values.

- Non-mechanical ECMs (e.g., lighting, dishwasher replacement, water conservation measures) were excluded from the analysis. Probabilistic data regarding installed service life was only available for mechanical systems, as collected by ASHRAE (ASHRAE 2014). Even with a large, nationwide data set, some equipment types relevant to this research were missing from the ASHRAE database.
- Only ECMs used to achieve the energy savings guarantee were included; therefore, ECM #1 (incinerator steam cost savings) was not included in the analysis.

6.3.1.2 Probabilistic Scenarios for Test Case

Once the data described above was input through the user interface, probabilistic variable values were developed, as described in Table 6-4. These values were related to the random selection of annualized HDD from a probability distribution of over 60 years of such data from the project location and equipment service life data obtained from ASHRAE (2014).

6.3.2 Risk Analysis and Evaluation Results

The pilot model was run with 75 of the 77 identified risk scenarios. Scenarios 1A1 and 1A2 (asbestos abatement and management in-place, respectively) were not included due to the State of Michigan separately funding asbestos-related mitigation on such projects.

Based on the deterministic and probabilistic model inputs, including selection of the expert panel inputs for risk probabilities and costs (except where overridden formulaically, as discussed previously in this chapter), the following ten risk scenarios were assessed as being most critical (Table 6-5). A $138,800 difference was observed between the top-most ranked risk and the bottom-most risk.

Table 6-4. Probabilistic Variable Values

Probabilistic Variable	Prob. Value	Reference Value	Result on Model Parameters
HDD_{prob}	Mean HDD of 7730	6909	Did not increase probabilistic facility-wide annual energy costs because no single year HDD_{prob} exceeded the 95% level of the PDF. As a result the EC_{PV2G4}=$0 since $P_{cause}=0$.
Service $Life_{prob1}$	N/A	20	No change – prob service life >= 10 years
Service $Life_{prob2a}$	N/A	30	No change – prob service life not calculated – no similar equipment type found in ASHRAE 2014
Service $Life_{prob2b}$	10	30	No change – prob service life >= 10 years
Service $Life_{prob3a-3b}$	N/A	30	No change – prob service life not calculated – no similar equipment type found in ASHRAE 2014
Service $Life_{prob3c}$	10	30	No change – prob service life >= 10 years
Service $Life_{prob3d}$	18	30	No change – prob service life >= 10 years
Service $Life_{prob3e}$	26	30	No change – prob service life >= 10 years
Service $Life_{prob4}$	N/A	15	No change – prob service life not calculated
Service $Life_{prob5}$	N/A	15	No change – prob service life not calculated
Service $Life_{prob6}$	N/A	30	No change – prob service life not calculated
Service $Life_{prob7}$	N/A	30	No change – prob service life not calculated
Service $Life_{prob8a}$	N/A	30	No change – prob service life not calculated
Service $Life_{prob8b}$	18	30	No change – prob service life > 10 years
Service $Life_{prob9}$	N/A	20	No change – prob service life not calculated
Replacement $Cost_{prob1-9}$	N/A	Varies	No change – since no values of the probabilistic service life were shorter than the contract term, these costs are not calculated

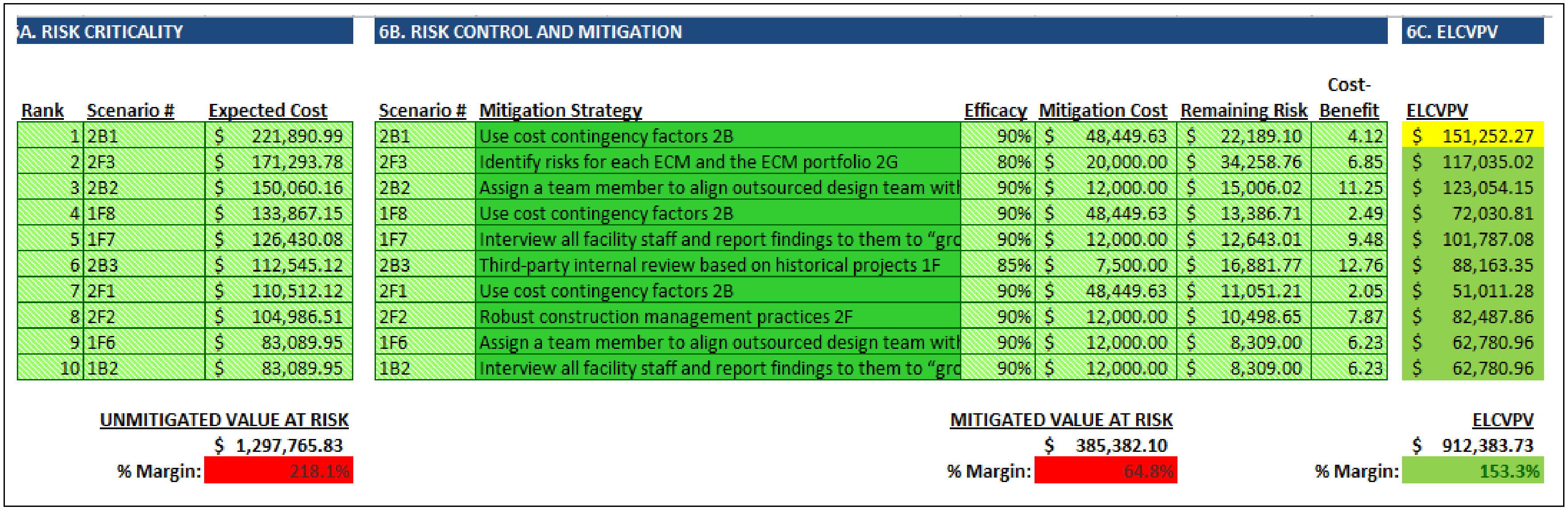
Table 6-5. Model Output – Ten Most Critical Risks

Rank	Risk Scenario	Expected Cost		Rank	Risk Scenario	Expected Cost
1	2B1	$221,890.99		6	2B3	$112,545.12
2	2F3	$171,293.78		7	2F1	$110,512.12
3	2B2	$150,060.16		8	2F2	$104,986.51
4	1F8	$133,867.15		9	1F6	$83,089.95
5	1F7	$126,430.08		10	1B2	$83,089.95

Notes:
a\ Shaded cells indicate risk scenarios that originated from the same risk scenario map

Figures 6-8 and 6-9 depict the results screen obtained through the pilot model run. Some observations of interest for decision makers immediately become clear from these results. First, the ten most critical risks were responsible for a potential erosion of 218.1% of the ESCO margin if left unmitigated. Seventy percent of the initial unmitigated risk was recovered over the project life cycle through the implementation of risk mitigation strategies, resulting in an $ELCV_{PV}$ of $912,383, or 153.3% of the ESCO margin. It is important to note that while 64.8% of the ESCO margin remains at risk, the improvement described above was after mitigating just the top 10 out of 75 possible risk scenarios in the model. Further mitigation efforts will improve the values of Mitigated Value at Risk and $ELCV_{PV}$.

In making recommendations, the first risks to examine are those with cost-benefit ratios of less than one, indicating that these risks cost more to mitigate than the value that was potentially recovered and those approaching a value of one, indicating an approximately break-even relationship. There is no such case present in the modeled results, as the lowest cost-benefit value among mitigation strategies is that for risk scenario 2F1 with a value of 2.05. This risk scenario is based on the root cause of a client preparing the EPC scope of work based on terms



A. RISK CRITICALITY			6B. RISK CONTROL AND MITIGATION						6C. ELCVPV
Rank	Scenario #	Expected Cost	Scenario #	Mitigation Strategy	Efficacy	Mitigation Cost	Remaining Risk	Cost-Benefit	ELCVPV
1	2B1	$ 221,890.99	2B1	Use cost contingency factors 2B	90%	$ 48,449.63	$ 22,189.10	4.12	$ 151,252.27
2	2F3	$ 171,293.78	2F3	Identify risks for each ECM and the ECM portfolio 2G	80%	$ 20,000.00	$ 34,258.76	6.85	$ 117,035.02
3	2B2	$ 150,060.16	2B2	Assign a team member to align outsourced design team witl	90%	$ 12,000.00	$ 15,006.02	11.25	$ 123,054.15
4	1F8	$ 133,867.15	1F8	Use cost contingency factors 2B	90%	$ 48,449.63	$ 13,386.71	2.49	$ 72,030.81
5	1F7	$ 126,430.08	1F7	Interview all facility staff and report findings to them to "grc	90%	$ 12,000.00	$ 12,643.01	9.48	$ 101,787.08
6	2B3	$ 112,545.12	2B3	Third-party internal review based on historical projects 1F	85%	$ 7,500.00	$ 16,881.77	12.76	$ 88,163.35
7	2F1	$ 110,512.12	2F1	Use cost contingency factors 2B	90%	$ 48,449.63	$ 11,051.21	2.05	$ 51,011.28
8	2F2	$ 104,986.51	2F2	Robust construction management practices 2F	90%	$ 12,000.00	$ 10,498.65	7.87	$ 82,487.86
9	1F6	$ 83,089.95	1F6	Assign a team member to align outsourced design team witl	90%	$ 12,000.00	$ 8,309.00	6.23	$ 62,780.96
10	1B2	$ 83,089.95	1B2	Interview all facility staff and report findings to them to "grc	90%	$ 12,000.00	$ 8,309.00	6.23	$ 62,780.96

UNMITIGATED VALUE AT RISK
$ 1,297,765.83
% Margin: 218.1%

MITIGATED VALUE AT RISK
$ 385,382.10
% Margin: 64.8%

ELCVPV
$ 912,383.73
% Margin: 153.3%

Figure 6-8. Pilot Model Run Results Screen

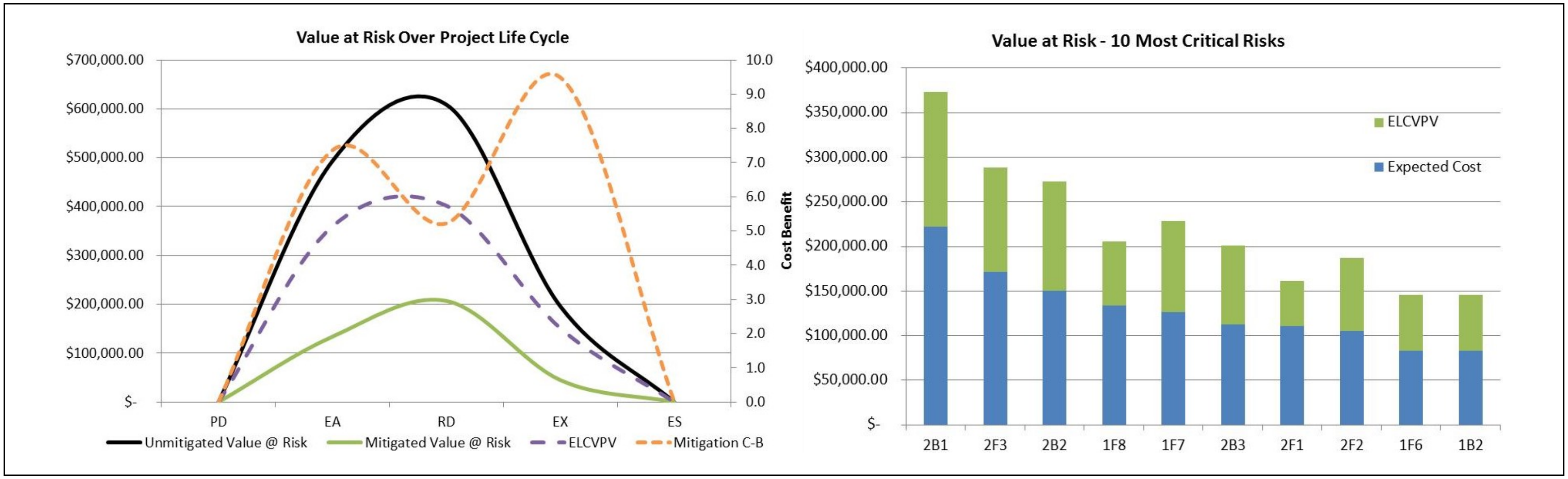


Figure 6-9. Pilot Model Run Results Screen Plots

and conditions found commonly in typical design-bid-build public procurement which requires overstated soft costs resulting from the use of standard, fixed overhead and profit rates. The $ELCV_{PV}$ results and decisions screen also provides insight into these relationships graphically, as shown in Figure 6-9.

The value at risk over the project life cycle plot (left side of Figure 6-9) shows that the ten most critical project risks are concentrated in the energy audit and retrofit design phases, so early decisions regarding risk management are critical. The value at risk – 10 most critical risks plot (right side of Figure 6-9) indicates that to further reduce the project's mitigated value at risk, relatively poorer performing mitigation strategies such as 1F8 and 2F1 can be targeted for more intensive activity, with the intent to increase efficacy or lower cost solutions to risk management and control.

As discussed in Chapter 4, the most important risks occurred during the earliest project phases; lower risk importance scores were assigned to risk categories occurring later in the project. Reasons for this included the inability to address risks contractually once the energy savings guarantee was signed, thereby requiring risks to be addressed early in the project life cycle. Because activities related to the IGA and ECM selection and installation have such a large impact on later project phases, these risk categories were scored as having among the highest risk importance scores. A review of all 75 risk scenarios included in the model yields expected results for the level of risk realized at each phase of the project life cycle (Figure 6-10). The upper graph depicts the project risk profile using the EC_{PV} while the lower graph used the EC. In general,

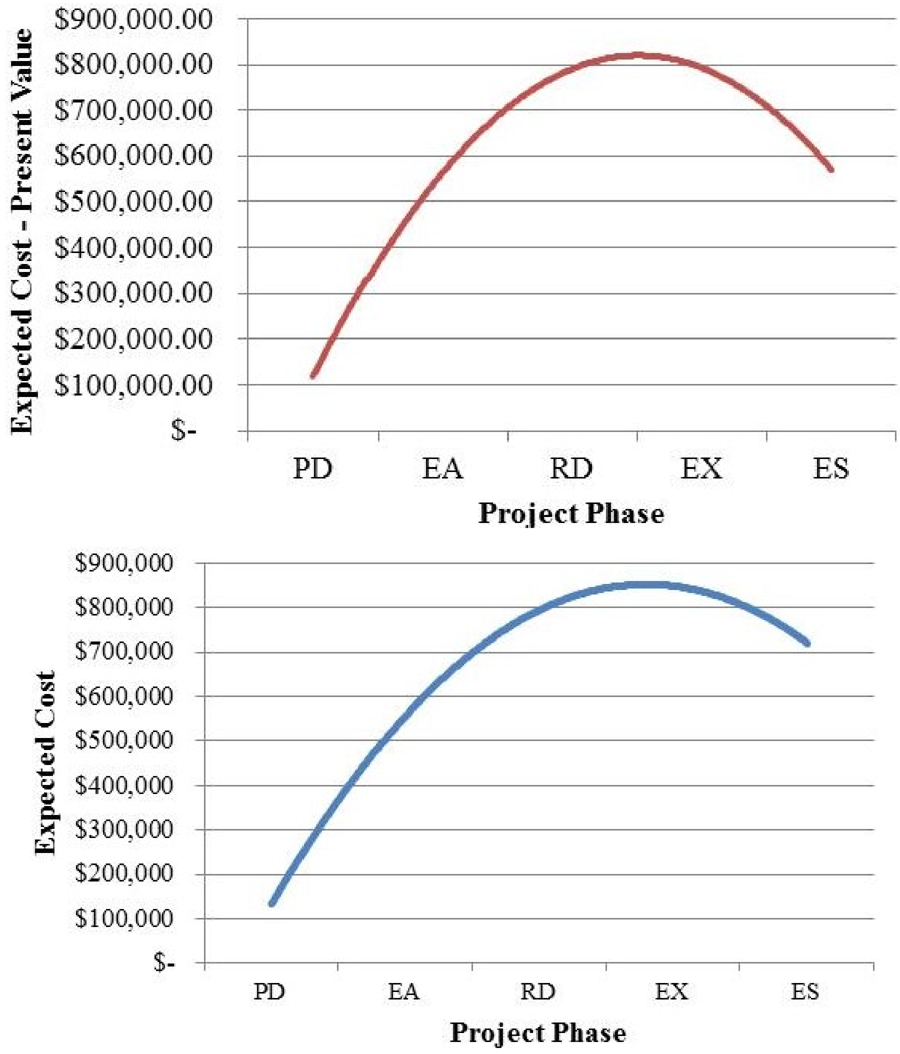


Figure 6-10. Model Risks by Project Phase

project risks increased toward the latter project phases, as expected based on the project decisions and costs model presented in Chapter 4 (Figure 4-8), underscoring the need to gain adequate control of project risks during the earliest phases. In the model output using ECPV, a more pronounced reduction in risk is noted during the energy savings phase. This is somewhat expected given that this is the longest phase, occupying nearly 8 years in the case study. As a result of the present value calculation, risks realized later in the project have lower present values, which are reflected in the Figure 6-10.

6.3.3 Sensitivity Analysis

Sensitivity analysis was conducted to determine the impact of inputs on the results of the life cycle cost-based risk model. Key areas of interest included the sensitivity of the model to changes in deterministic and probabilistic parameters. The use of probabilistic inputs in the model made it difficult to assess risk criticality in a single model run because the results changed with each iteration, so Monte Carlo analysis was used for this step.

ModelRisk by Vose Software (Vose Software 2014) was used to conduct the Monte Carlo analysis. In order to determine the distribution of possible model outcomes (ELCV), probabilistic parameters were included as described earlier in this chapter; deterministic parameters were calculated using the risk modeling function of ModelRisk. For each risk scenario, the minimum, maximum, and mean panelist values of P_{cause}, P_{effect}, and cost were recorded and used as inputs to a triangular distribution. Since each risk scenario only had four data points, the selection of a data distribution can be challenging. The main reason for selecting the triangular distribution is its use of either the mean or mode in its construction. With smaller sample sizes, distributions that emphasize central tendency can be more reliable than those that emphasize extreme values (U.S. Environmental Protection Agency 2001). Parameters that relied on probabilistic functions were populated with the appropriate distribution in lieu of the triangle distribution. The model was run 10,000 times during the Monte Carlo simulation, which resulted in a normal distribution of EC_{PV} values over those trials (Figure 6-11). Expected cost distribution values were:

- Minimum – $2,330,929
- Maximum – $3,976,759
- Mean - $3,075,946

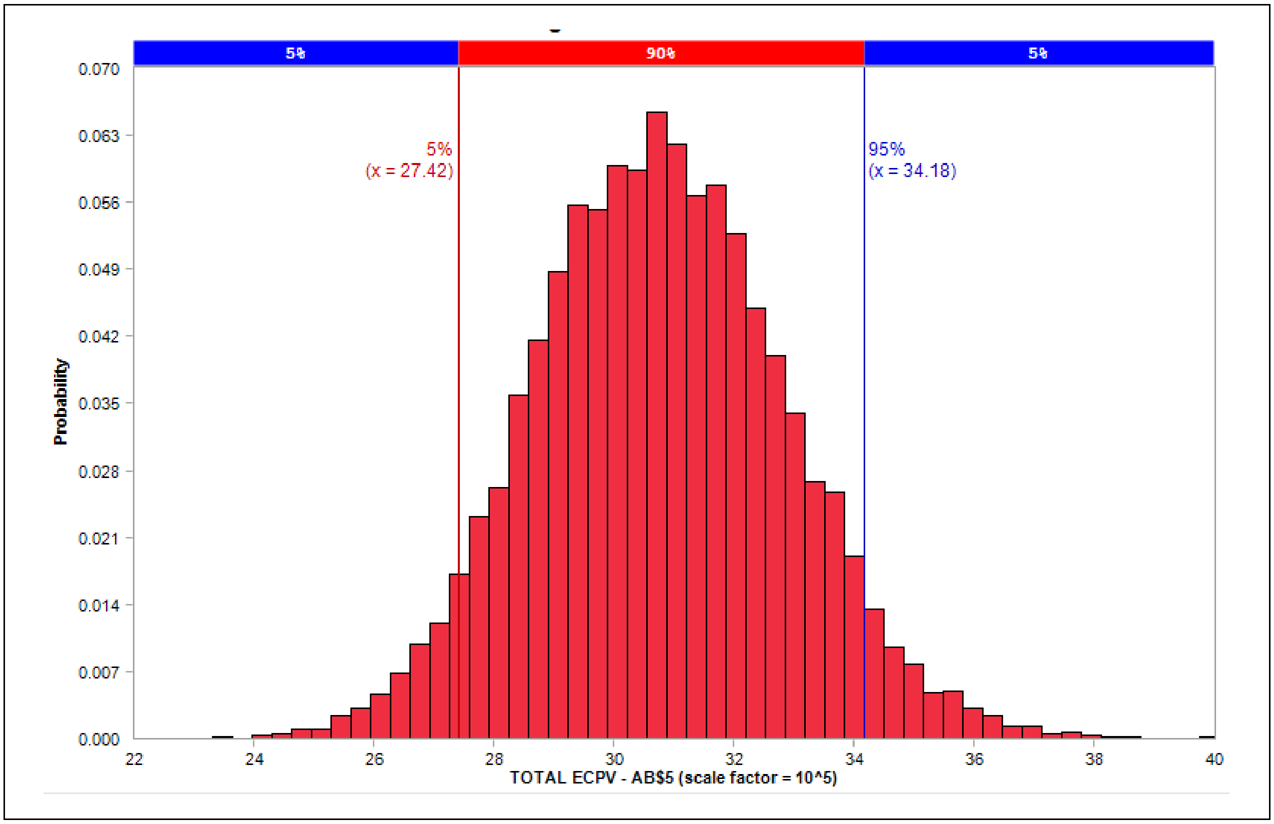


Figure 6-11. Monte Carlo Simulation Results – Distribution of EC Values

The Monte Carlo results were analyzed to determine which scenarios the model result is most sensitive to. This was done to compare the pilot application results, which resulted from a single model run, to the simulated range of possible values. The ten risks for which the model is most sensitive were determined for the Monte Carlo simulation by examining the contribution of each risk scenario to uncertainty of the conditional mean of EC at the 99th percentile of the output distribution. These risks are listed in Table 6-6. The delta value represents the difference between the lowest and highest values for each scenario that contribute to the output value.

Table 6-6. Ten Risks to Which the Model is Most Sensitive

Risk Scenario	**Delta**		**Risk Scenario**	**Delta**
2B3	$191,096.03		2B2	$157,455.18
1A7	$189,360.33		1F1	$136,499.67
2B1	$166,794.80		1E4	$131,124.63
2G4	$158,121.56		1F8	$127,283.17
1B7	$158,104.74		2CD1	$119,533.99

Sensitivity of the model to the probabilistic inputs was determined first. This was accomplished by turning off the distribution-based cause, effect, and cost parameters for the deterministic variables, as described above, and only using panelist-derived values. Probabilistic input values were allowed to vary within the bounds established by the model. Results of this sensitivity analysis are provided in Figure 6-12. As can be seen, the deterministic inputs have the greatest overall contribution to uncertainty of the model output, which may be the result of having just four probabilistically-derived risk scenarios (2G3, 2G4, 2G7, and 2G8) in the pilot model, compared to 71 deterministic scenarios..

Figure 6-12. Model Sensitivity to Deterministic and Probabilistic Parameters

Sensitivity of the model to the two probabilistic parameters (HDD and equipment service life) was also assessed. The distribution of the two input parameters is depicted in Figure 6-13. The distribution of probabilistic equipment service life-driven values of EC_{PV} is positively-skewed; equipment service life-related values of EC_{PV} appear to be uniformly distributed across a much smaller range of values than the HDD-driven values.

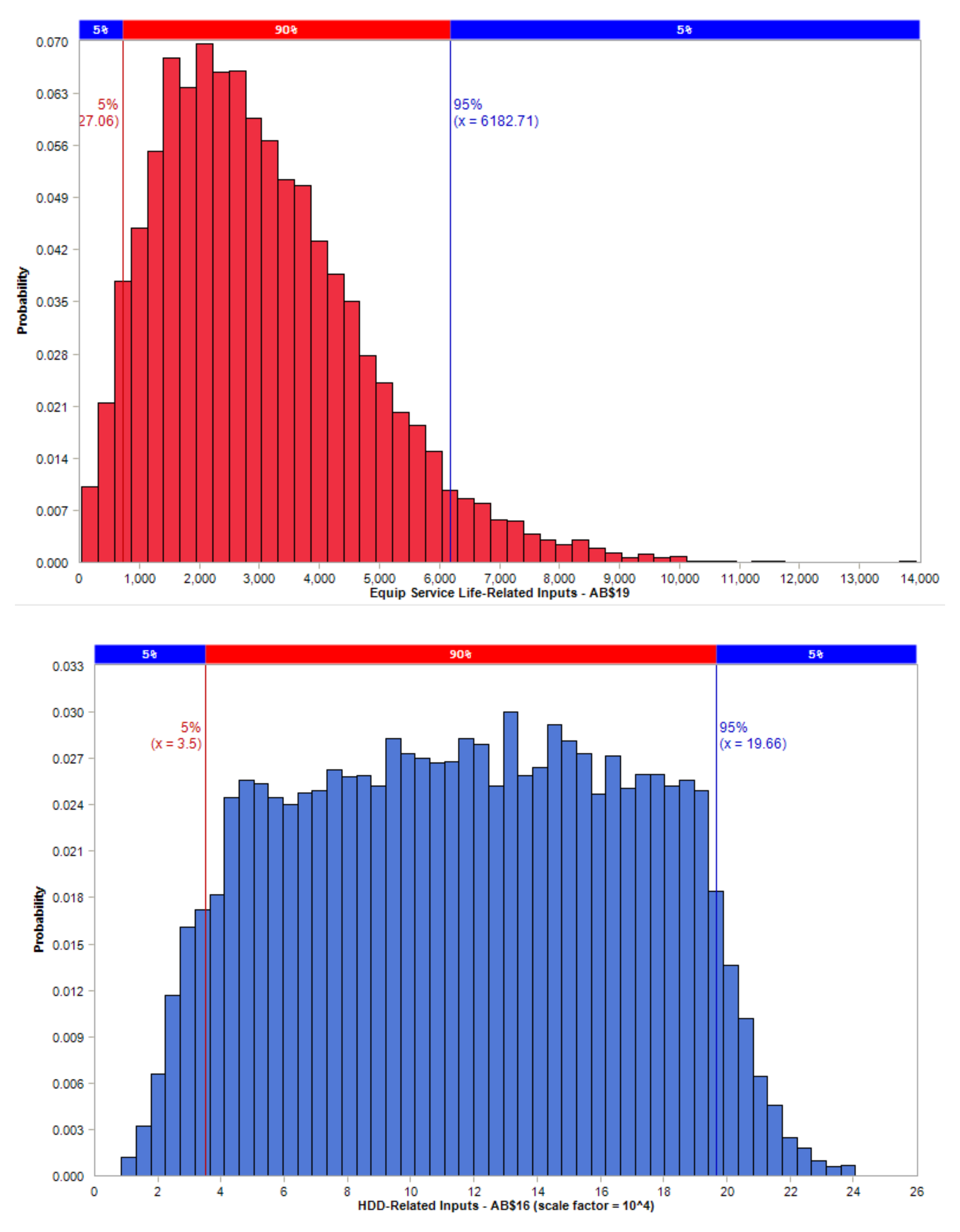


Figure 6-13. Probabilistic Input Parameter Distributions

Sensitivity of the model outputs to the probabilistic HDD- and equipment service life-related inputs is shown in Figure 6-14. The model showed more sensitivity to the distribution of HDD-

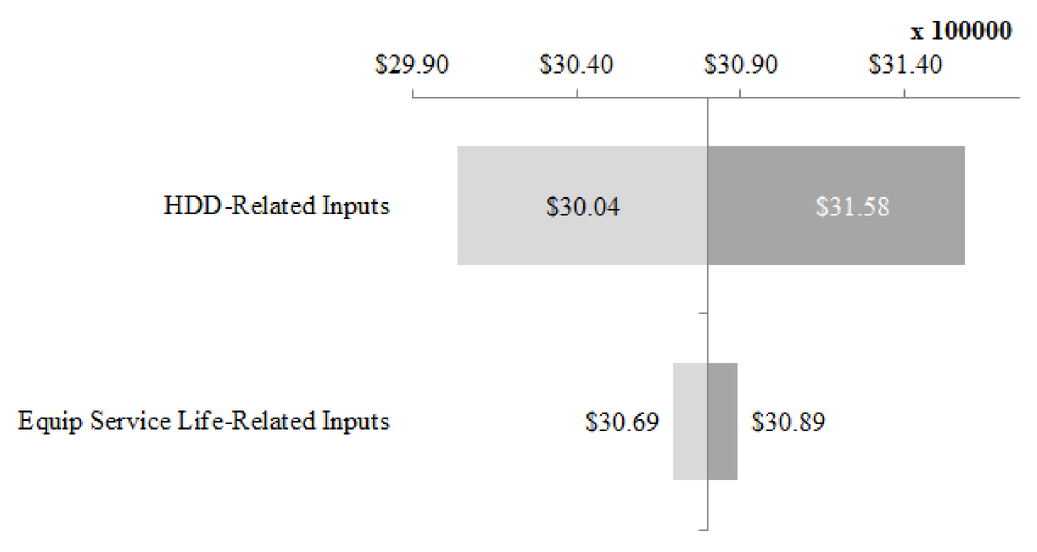


Figure 6-14. Model Sensitivity to Probabilistic Equipment Service Life Parameter Values

related input values. Whether the parameter values for equipment service life are from the high or low range of the distribution, there is little effect on the model outcome.

6.4 LIFE CYCLE COST-BASED MODEL FUNCTION AND REFINEMENT

The demonstration of the life cycle cost-based risk model received generally positive feedback from ESCO and agency client representatives. The model was particularly useful in providing a basis to illustrate the presence of latent risks that do no surface until later stages of projects. This was found to be helpful toward discovering and treating such risks early in the project process. Additionally, the ability to utilize panel data or override those parameters with values that reflect individual preferences toward risk was recognized as a strength of the system.

The agency client representative recognized the value of the probabilistic weather data and its use in creating increased energy consumption scenarios. Such a scenario was observed over the winter of 2013-2014, when temperatures were much colder than long term averages. As a result, one of their projects experienced some performance degradation as a result of sub-optimal ECM performance in extreme climatic conditions. The ability to continually “game” the model to derive high and low deviations in HDD values was regarded as a strength of the approach.

Both informants found the ability to generate scenarios by selecting different mitigation strategies and altering the efficacy and costs of such strategies, to be effective decision aids in evaluating different management approaches to long-term risk control and management. In both cases, participants indicated a desire to be able to select more than one mitigation strategy per risk scenario to better represent management approaches that employ multiple controls. Additionally, they believed that the results screen would be easier to navigate if there was a visual reference to remind the user of the construction of the risk scenarios under review, as the alphanumeric coding was difficult to recall.

One participant also indicated that the model would be strengthened through the ability to optimize retrofit design parameters along with their attendant project-level risks. Further refinement of this model could include additional research and development activities to enable this model to exchange information with an energy modeling platform, such as EnergyPlus or DOE2. Work in that regard would be focused on finding optimal solutions that balance energy performance, cash flow, and life cycle project risks.

6.5 CHAPTER SUMMARY

The risk analysis and evaluation framework developed in Chapter 5 sought to connect quantitative data with expertise to effectively create and manage risk scenarios. The framework was designed to help ESCO professionals make better-informed decisions about the long-term effects of project-level risks over the course of the project life cycle. The framework was developed into a model through the connection of the framework with a quantitative database and the connection to expert knowledge through a user interface.

This chapter focused on verification of the model function and its applicability to the types of decision problems under review. It provided the opportunity to demonstrate the suitability of a life cycle cost-focused risk management system in assessing risks on projects with long contractual terms. The applicability of the model was demonstrated by selecting a correctional facility case study that had recently undergone an EPC retrofit, and is currently in the energy savings phase. Personnel involved with this project, from both the ESCO and in the facilities management function of the correctional agency, were knowledgeable, engaged, and willing to participate in long-term research of EPC retrofit risks.

The applicability of the life cycle cost-based risk model was demonstrated using data from the case study. The advice provided to visualize and to manage life cycle risks during early project phases received positive feedback. Areas of concern among the professionals involved in framework review were the ability to include multiple mitigation strategies for each risk scenario and the ability to automatically generate optimal solutions that maximize ELCV without manually searching for and assigning mitigation strategies to each risk. Finally, a suggestion was made to enhance the tool's applicability by connecting it to standard energy modeling software, such that the risk tool can also be used as a design advisor. In that way, life cycle cost impacts of project risks can be incorporated into the project design prior to contract execution. This is recommended as an area for future research.

CHAPTER 7

SUMMARY AND FUTURE RESEARCH

7.1 INTRODUCTION

In this chapter, a summary of the research is presented, followed by a review of the research goal and the output of each objective in support of attaining that goal. The key contributions and conclusions of this research are presented next, and finally recommended areas for future research are proposed.

The main goal of this research is to understand risks related to the adoption of energy efficiency retrofit practices in the municipalities, universities, schools, and hospitals (MUSH) market. To achieve this goal, in-depth analysis and improved understanding was sought with regard to contractors' risks that are unique to energy performance contracts (EPC) performed in this market. This was supported through the development of a model that enabled the management of risks across the project life cycle. To help develop this model, a preliminary framework was developed, based on literature and a preliminary expert interview, to identify, describe, organize, and classify risks faced by energy service companies (ESCOs) when undertaking EPC retrofit projects.

The preliminary risk framework was refined through the extensive and comprehensive study of ESCO risks in MUSH market projects through a knowledge elicitation strategy. The preliminary framework revealed that construction and engineering professionals rely heavily on their expertise to identify and analyze risks. Concurrent with the development of the refined risk framework was the assessment of EPC project phases, the key decisions made during each phase, and the quantitative and expert sources of knowledge used to support the decision-making process in an EPC retrofit process model. A risk analysis and evaluation framework was proposed, using the refined risk framework and retrofit process model as inputs to identify key risks and assess their criticality based on values of expected cost. The expected cost data, combined with the information sources identified in the retrofit process model, was used to develop a life cycle cost-based risk model. The application of the risk model was then demonstrated through a pilot scale implementation on a correctional facility case study.

Chapter 1 provided the background, established the need and associated premises, outlined the goal and related objectives, outlined the methodology, and identified the scope, limitations, and projected outcomes of this research. The literature related to energy performance contracting, risk in construction, and project life cycle cost considerations was examined in Chapter 2. Chapter 3 detailed the research methods and data collection efforts to support the research goal and objectives. The first stage of the energy management process, risk identification, was pursued in Chapter 4 through a comprehensive expertise elicitation strategy, which was used to elicit and compile relevant domain knowledge related to project-level risks in EPC retrofits. Chapter 5 detailed the development of a risk analysis and evaluation framework which was parameterized as a life cycle cost-based risk model. The applicability and suitability of the model was demonstrated through a pilot scale implementation using a correctional facility retrofit case study in Chapter 6.

7.2 SUMMARY OF OUTPUTS BY OBJECTIVES

The main goal of this research, supporting increased adoption of MUSH market EPC retrofits through enhanced understanding of ESCO risks inherent in the process, was supported through the development of a life cycle cost-based risk model. The model enabled the incorporation of quantitative information and expertise and included probabilistic elements to capture some of the variation inherent in EPC retrofits. The purpose was to represent key decisions made and information used to support those decisions during the risk management process undertaken by industry professionals. This section evaluates the research output of each objective and their role in achieving the research goal.

Objective 1 - To perform an exploratory analysis of the energy performance contract retrofit process and identify key areas of performance risk requiring in-depth analysis: Buildings in the United States consume a great deal of energy. Correctional facilities are among the upper half of buildings for energy consumption. Despite their generally large size, historical exclusion from energy efficiency retrofits, and high energy intensities, these facilities lag behind the energy efficiency improvement of other public building types. Lack of capital to finance such projects has been cited as a reason for this efficiency gap. The use of EPC retrofits has been growing quickly, particularly in the MUSH market, in response to constrained public budgets and decades of deferred maintenance.

The use of EPC for delivering energy efficiency retrofits is particularly attractive for public sector clients, not only because its financing mechanism facilitates the development of projects, but because the performance guarantee effectively allocates performance risk from the client to the ESCO. The transfer of risk and lengthy contract terms inherent with EPC retrofits (12-15 years is not uncommon; some jurisdictions permit 20 year terms) create the need for ESCOs to better understand risk management processes and the financial impacts of risks over the long project life cycle. A review of risk management methods employed by the construction and engineering management (CEM) industry, as well as by researchers in the same domains indicates that expertise is heavily relied on for risk identification and qualitative risk analysis. A wide variety of more rigorous qualitative and quantitative methods have been used in CEM research and despite the analytical methods selected, a four step risk management process is commonly encountered throughout the discipline.

Using this process as a guide, risks borne by ESCOs during EPC retrofit projects were studied through the creation of an a priori risk framework. This framework utilized an extensive literature review and preliminary interview with an ESCO professional possessing 30+ years of experience. Ten risk categories were identified through this process; one category was subdivided into three, for a total of twelve categories. This a priori risk framework was an important first step in characterizing ESCO risks and was used as an input to the work steps conducted as part of Objective 2.

Objective 2 - To construct a framework describing the sources of, and mitigation strategies employed for assessing key risks in energy performance contract retrofits: The literature review, preliminary expert interview, and a priori risk framework highlighted the importance and use of expertise in making risk-based decisions in the CEM industry and domain-specific research. As a result, an expertise elicitation strategy was developed relative to the risk management process outlined in Objective 1. The elicitation strategy utilized comprehensive knowledge elicitor training, the Delphi technique, semi-structured interviews, and job shadowing. The use of Delphi, a well-documented consensus-building technique, encouraged participation via semi and total anonymity (as requested by individual panelists), enabled panelists' use of professional language and standards that were familiar to them when describing their knowledge, and reduced bias while maintaining acceptable levels of reliability and validity.

Based on the ESCO risk expertise elicitation strategy, 19 ESCO professionals participated in a two-round interview process, completed primarily via telephone during the first round, and through an online survey platform in the second round. Expertise was elicited and compiled with regard to risk identification, risk importance scoring, risk causes and control strategies, and methods for risk identification and evaluation used in the ESCO industry. Questions sought two types of knowledge: (1) constructed and (2) elicited. Achieving consensus was the goal of elicited knowledge, in order to best represent the collective expertise and decision-making criteria of the panelists, whereas the goal of constructed knowledge was to gain in-depth understanding of practices and techniques employed by ESCOs in the management of risks. No previous studies could be found where knowledge was elicited from ESCO professionals within the context of risk management; therefore, this strategy represented a new approach in this body of research.

The elicited knowledge was used to refine the a priori risk framework through the inclusion of measures of risk consideration frequency and risk importance, modification of risk categories and their associated risks, and the inclusion of risk causes and control strategies. Risk importance scoring by the Delphi panelists led to the selection of two risk factors for further analysis in Objective 3 – energy audit quality and ECM selection and installation. An EPC retrofit process model was developed concomitantly with the refined risk framework. This model examined key risk-based decisions made during each phase of the EPC retrofit project life cycle and connected sources of quantitative information and expert knowledge to the specific decisions and retrofit project activities that were based on them. These two outputs served as important inputs to the work steps completed in Objective 3.

Objective 3 - To develop a strategy for analyzing and evaluating risks for energy performance contract retrofits focused on managing expected costs throughout the project life cycle, and use data collected through this strategy to develop and parameterize a risk model: The risk management process was completed in Chapter 5, which focused on analyzing risks based on their criticality and evaluating possible mitigation strategies for their overall impact on project outcomes. In order to accomplish this, a method was sought that would capture the decision making process and expertise of knowledgeable professionals and express measures of risk dimensionally, in order to improve management outcomes.

Failure mode and effects analysis (FMEA) was selected as the central element of this strategy for its focus on events that contribute to systemic failure (i.e., the failure to achieve the energy performance guarantee due to risk events throughout the project life cycle), its ability to address the complete risk management process in a single method, and its widespread use and acceptance among the risk management community. While not often applied to project management in general and the management of energy efficiency retrofits, specifically, this method has been used to examine failure modes in the built environment and it has demonstrated its ability to utilize expertise in an organized and robust analytical process. Scenario-based FMEA (SFMEA), a methodological improvement over traditional FMEA, was selected for this research for its ability to construct variable length cause and effect chains, its use of expected cost (EC) to express levels of risk, and its focus on examining risk at various points in a system life cycle.

A four member expert panel was convened to complete the SFMEA process and they used the refined framework to identify potential risk causes from which the analysis began. An empirical evaluation of the differences between risk criticality measures used in traditional FMEA and SFMEA demonstrated the strength and robustness of the EC method. The panel identified 77 different risk scenarios related to two risk categories applied to the context of correctional facility EPC retrofits – energy audit quality and ECM selection and installation. Project-, facility, and external environment-factors influencing risks were identified by the panel and their individual decision-making was captured through independent and consensus-based scoring of risk probabilities and costs. An additional expert examined mitigation strategies.

The net result of these efforts was the representation of the risk analysis and evaluation process in a model framework. The goal of the model was to decompose the decision-making process relative to risk management in EPC retrofits by incorporating expertise, quantitative information, and uncertainty to assist with decision-making over lengthy project life cycles. Consensus risk scoring and external factors were developed as model parameters, along with probabilistic parameters related to variability of climate conditions and ECM service life. External data, as described by the EPC retrofit process model, was developed as a supporting database for the model and a user interface was constructed using Microsoft Excel. The interface supported the entry of data by both the user and through automated selection of SFMEA panel expert values, as well as communicated risk management results to the user by providing a measure of risk mitigation called the expected life cycle value (ELCV). The ELCV measures the amount of unmitigated risk, expressed as EC that has been effectively mitigated once efficacy and cost of risk mitigation efforts have been accounted for.

Objective 4 - To demonstrate the applicability of the developed life cost-based risk model through a pilot application to a case study site: The functional capacity and applicability of the modeled framework to improve the correctional facility EPC retrofit risk management was assessed through a pilot test with a case study site. The site was selected as it was recently the subject of an EPC retrofit and was presently in the energy savings phase, the ESCO and agency staff members involved in the project were engaged with the project and willing to share their knowledge and project documents, and the site was representative of several other such projects either recently completed or currently under contract.

Results of the pilot test verified its applicability to the domain and its suitability to study risk management problems inherent with such projects. Modeled case study results, which led to system refinement, indicated that there is strong potential to extend the use of this system more broadly.

7.3 RESEARCH CONTRIBUTIONS

Despite the generally wide adoption of energy efficiency practices, and despite having some of the greatest need to implement energy efficiency in existing buildings, MUSH market facilities have experienced difficulties in securing public funding to pay for this work. This research contributes to attaining the full market potential in MUSH market EPC retrofits, particularly in correctional facilities. These buildings have unique challenges for retrofit, and despite their above average need for improving energy efficiency, have exhibited slower than average improvements in this area. The following sections highlight and briefly discuss the contributions of this research.

7.3.1 Consensus-Based Assessment of ESCO Risk Management

Consensus was reached among a panel of ESCO industry experts with regard to risk management and the knowledge of project risks that is used in decision-making. The Delphi technique was used for this step, which is a consensus-based method that utilizes a questionnaire to collect data from pre-qualified, expert participants. The fact that consensus was achieved for the questions included in the study indicates that the elicited knowledge was acceptable to the panelists and applicable to the problem under review.

This method enhances the reliability and validity of the data. Reliability is enhanced through the anonymity of participants, which avoids group biases and groupthink. The use of group opinion helps to ensure validity and is preferred to individual opinions. Additionally, panelists were selected using purposive sampling, which helps ensure that only domain experts were included in the research, thereby pre-qualifying the sources of the elicited knowledge before data collection began.

This consensus-based approach and the data it provided is a contribution. In addition to the dearth of research related to EPC risks in general, the consensus-based approach, in particular, is an important contribution in that it ensures that early research directed on the subject is properly grounded in methods that are both reliable and valid.

7.3.2 Characterization of EPC Retrofit Risks Borne by ESCOs

Despite a robust literature pertaining to CEM risk management, there is a lack of research directed toward understanding risk management in EPC retrofits. This is particularly troublesome, since one of the central features of EPC projects is the complete transfer of performance risk from the client to the ESCO. As a result, while clients can view energy efficiency projects delivered in this way as a risk management strategy, ESCOs must actively manage their risks and ensure successful project outcomes. As a first step in managing the risks faced by ESCOs, they must be identified and understood to facilitate future research on those that are most critical.

The first related contribution in this section was the development of an a priori risk framework which was guided by the literature and a preliminary expert interview. This served to create a conceptual grounding for the remainder of the work and was used to develop the expertise elicitation strategy for this research. A refined framework was developed based on the elicited expertise of 19 ESCO professionals, and represents the second contribution in this section. In addition to the conceptual grounding offered by the preliminary framework, this effort better delineated and organized risk categories and assigned specific risks, assigned risk categories to the project life cycle phases where they are realized, included measures of risk importance and frequency of consideration of risks in MUSH projects, and the identification of potential risk causes and mitigation measures. These efforts represent a first-of-their kind comprehensive study of risks in EPC retrofit projects.

7.3.3 Empirical Evaluation of Improved FMEA Method

Risk analysis and evaluation was accomplished through the use of SFMEA. While this represented several methodological improvements over the traditional FMEA approach, little empirical evaluation of its use and comparison with traditional FMEA had been conducted. SFMEA was selected for this research due to its focus on risk scenario development and measurement of risk criticality using expected cost, as several Delphi panelists had underscored the importance of financial measures when assessing EPC project risks. During implementation, SFMEA panelists were asked to analyze risks using traditional means and the EC method inherent to SFMEA. Based on the data obtained from the panel, both methods were analyzed and their suitability for decision-making was evaluated. The empirical analysis of the criticality measures is in itself a contribution to the risk literature. The application of FMEA to energy efficient retrofit project risks, through the modified SFMEA technique, represents another contribution to the study of construction risks via a method that comes from the manufacturing and quality domain.

7.3.4 Development of Life Cycle Cost-Based Risk Model

The development of the life cycle cost-based risk model is an advancement over traditional risk management methods in that latent project risks, those that may not occur until many years into the project, can be examined during the early stages of the project life cycle. Furthermore, model development utilized a combination of expertise, quantitative information, and probabilistic functions to create and define model parameters.

The model is expected to help ESCOs make informed decisions about the approach they take towards risk management. By clearly demonstrating the financial implications of unmitigated risks, the cost and efficacy of selected mitigation strategies, and their net benefit on levels of risk by phase and to the overall project, risk management-related decisions should be improved. The ELCV, a metric to evaluate the cost-benefit relationship of risk mitigation strategies and their impact on the project was developed, and taken with the life cycle cost-based risk model, represents a significant contribution to energy efficiency, EPC, and risk management domains.

7.3.5 Expansion of Research Approach to Other Domains

Finally, the research approach employed in this study to identify, analyze, and evaluate risks based on their expected costs over the project life cycle can be replicated in other domains. The ability to incorporate expertise, quantitative information, and probabilistic inputs strengthens the ability to represent any system under review, regardless of domain, and leads to the creation of robust findings that are broadly applicable. While the frameworks used in this research relied strictly on knowledge elicited from domain experts, the approach can be expanded to elicit knowledge from end-users, stakeholders, and regulators for incorporation with the model.

7.4 RECOMMENDED AREAS OF FUTURE RESEARCH

This section proposes three additional areas which are recommended for future research.

7.4.1 Integration of Modeled Energy Performance with Project Risks

Decision support systems (DSS) have been widely used to assist with the design of energy efficient buildings and the selection of ECMs in energy efficient retrofits (Horsley et al. 2003; Juan et al. 2009; Kolokotsa et al. 2009; Chidiac et al. 2012; Ferreira et al. 2013). Typically these DSS optimize energy performance with environmental, social, and/or economic outcomes, as described by Ferreira et al. (2013). Far fewer efforts have focused on optimizing energy performance and project risks. Heo et al. (2012) used a Bayesian approach to calibrate energy models based on parameter uncertainty. Jackson (2010) used risk management tools to support the selection of energy efficiency investment options. None of this research examined the effect of project-level risks as part of the energy efficiency performance or ECM selection process.

Through the incorporation of energy modeling techniques and identification of critical project factors, a DSS can be developed that seeks an optimal solution based on objective functions that seek to minimize the life cycle costs of project risks while maximizing energy performance and minimizing project costs. The risk model that was developed for this research was focused on project-level factors that give rise to risks; however, many of these factors incorporated design features and conditions that could not be addressed without the incorporation of the energy analysis and modeling conducted as part of the retrofit design. Examples of this include:

- Risk Scenario 1E1 - differing stakeholder needs result in a savings shortfall or erosion of the ESCO’s margin due to user modification of ECMs and override of operating parameters: lack of knowledge of the ECM-by-ECM modeled energy performance and assumptions to include run times, set points, and operating schedules make these effects difficult to assess in the project risk model.

- Risk Scenario 2G3 – actual climate conditions occurring outside the range of design parameters result in a savings shortfall or erosion of the ESCO's margin due to uncertainty in modeled parameters and reduced equipment service life: comprehensive quantification of this risk scenario relies on understanding modeled energy and equipment service life/performance parameters, which cannot be assessed solely by project-level risks.

The expansion of the risk model from this research through integration with building energy models and a more detailed assessment of project-, facility-, and external environment-related factors would enable the creation of a multiple criteria design advisor. The goal of the tool would be to guide the retrofit design phase of EPC projects by minimizing life cycle project-level risks while maximizing energy performance.

7.4.2 Development as an Intelligent Decision Support System

Duah (2014) and Syal et al. (2014) demonstrated the applicability of an intelligent decision support system (IDSS) framework, to improving the energy efficient retrofit process in the residential buildings context. An IDSS is a decision support system that includes a knowledge management system that utilizes expertise to help users make decisions, and may be particularly applicable to unstructured and semi-structured problems. The components of an IDSS include a data management system, a knowledgebase management system, and a user interface. An inference engine is used to integrate quantitative information and expertise and infer new decision-making options based on stored expertise (Duah 2014).

The current research explored the use of quantitative information and expert knowledge in the EPC retrofit process, and developed a retrofit process model to represent those relationships, as well as the presence of risks and the timing of key decisions throughout the project life cycle. The life cycle cost-based risk model utilized a database that incorporated many of the quantitative sources from the model and applied expertise derived from the SFMEA panel, by enabling its use as a source for input values to existing risk scenarios. The small sample size of the SFMEA panel, while acceptable for the given method, was too small to draw inferences from with regard to individual decision-making and biases, thus limiting the use of expertise in the model.

Grounded by the refined risk framework and the risk analysis and evaluation process, expertise should be elicited from a larger sample of ESCO professionals that focuses on capturing their decision-making process with regard to risk identification, scenario construction, and determination of risk criticality. Determinants of potential decision-making bias should also be refined and captured from this larger group to develop predictive models of risk behavior and decision-making related to risk management. This predictive model can be used to develop the elements of knowledgebase management system. When combined with the data management system utilized in this research and a refined user interface, to include development of an inference engine, this research can thus be expanded to take the form of a robust, knowledge-based decision support system to assist users in making life cycle cost-based risk management decisions in EPC retrofit projects.

7.4.3 Critical Success Factors for EPC Retrofits in Complex Facilities

During data collection activities, many ESCO experts provided their thoughts about what makes some projects successful while others are less so. Many of the stated factors were not directly applicable to the current research, as they did not impact attainment of the energy guarantee. Rather, several identified factors related to the quality of the ESCO-client relationship, the political landscape of the client agency, client leadership and commitment to the EPC model, communication throughout the project, facility-specific operating parameters, and the development of mutually-acceptable measurement and verification strategies.

These examples far exceed the scope of the risk model and indicate the presence of many complex, interrelated factors that may govern successful outcomes of EPC retrofit projects. The empaneled experts for the current research reached consensus on the idea that correctional facility EPC retrofits have unique complexities and may indeed be riskier than other facility types; however, a subset of like buildings was noted, to include hospitals, continuously-operating facilities, and mission critical facilities. There is, therefore, an inherent hierarchy of building types, ordered by the complexity of EPC retrofits taking place within their walls.

Based on the foregoing, a comprehensive assessment and analysis of critical success factors in these complex building types can be undertaken. The perspective gained from both ESCOs and their clients will be used to enhance the management of such projects and improve outcomes. As a result, the use of EPC retrofits among these buildings will be increased and energy performance of their related market sectors will be improved.

7.5 CHAPTER SUMMARY

This chapter provided a summary of the research goal and objectives, and the outputs that led to developing a life cycle cost-based risk model for ESCOs undertaking EPC retrofit projects in MUSH market buildings, specifically correctional facilities. The research activities and outputs were summarized for each objective and contributions to the body of knowledge as well as conclusions of this research were highlighted. Recommendations for future research were proposed, focused on expansion of the work within this domain and further work in related domains.

The goal of this research was to use enhanced risk management understanding and modeling to better understand the risks to ESCOs that are inherent in EPC retrofits, particularly in building sub-markets that have a significant need to increase energy efficiency. Focus was given to MUSH market buildings and correctional facilities as a sub-market, owing to limitations on the availability of capital financing and decades of deferred maintenance. These factors have created a near-crisis level condition in correctional facility operating costs and reduced energy performance across the country. The researcher envisions that full implementation of the life cycle cost-based risk management model will further encourage the growth of the ESCO industry, and support focused retrofits in complex building types that typically can benefit the most from such work. Ultimately, this will reduce the energy consumption of public sector buildings to levels that are more fitting with the global principles of sustainability and responsible management of constrained resources.

APPENDICES

APPENDIX A.1

Preliminary Questionnaire for Risk Tolerance, Risk Identification, and Risk Management in Energy Performance Contracting

Phase I Interview Questions

1. Please provide a description of your role in energy performance contract projects performed in MUSH market buildings.
    a. How many such projects have you worked on?
    b. Which sub-markets have you worked in (provide standard definitions)?
    c. How many years have you been working on such projects?
    d. What is your educational/professional background (e.g., engineer, architect, construction manager, etc.)

2. These questions relate to previously identified risk categories for ESCOs engaged in performance contracts (see attached).
    a. Do you consider any of these risk categories when developing energy performance contract projects? If so, which ones?
    b. Are there any risk categories that you consider that are not included in this list?
    c. Do MUSH market energy performance contract projects have different risk categories than non-MUSH market projects? If so, please describe those differences.

3. What is your risk management process for energy performance contracts?
    a. How do you identify risks in these projects? Do you use formal or informal methods? *Follow up with questions about knowledge of/use of FMEA, tree analysis, Monte Carlo, risk-based LCCA, or other? - why/why not are these methods used?*
    b. What method or methods do you use for evaluating the impact of a risk on the project?
    c. At what stage of the project do you identify risks?
    d. What are the top 3 reasons (risk categories) you believe an energy performance contract would not meet the performance guarantee?

4. For each of the risk categories identified in the previous question, what are the effects on the ESCO if these risks are not prevented or corrected?
    a. For each item listed, what can cause these risks?
    b. For each item listed, are there controls implemented that either prevent these risks or detect negative impacts of these risks if they occur?
    c. Do combinations of these risks pose a greater threat than these risks individually?

5. How do you evaluate potential energy conservation measures individually and as a portfolio for inclusion in an energy performance contract?
    a. Do you use life cycle cost analysis? If so, how do you define parameters (discount rate, inflation rate, energy costs)? If not, why not? What performance periods are typically used?
    b. Do you consider future uncertainty of life cycle costs (discount rate, inflation rate, energy costs)? Uncertainty of project categories (cost growth, schedule growth)
    c. Are non-energy benefits included in this analysis? If so, please describe. If not, why not?

REFERENCE FOR QUESTION 1b

Definition of MUSH Market and Sub-Markets

1. Municipal agencies (state/local government)
2. Universities/colleges
3. K-12 schools
4. Hospitals

REFERENCE FOR QUESTION 3

List of Previously-Identified Risk Categories for ESCOs Engaged in Performance Contracting

1. Customer Pre-Qualification
    a. Financial factors
        i. Customer may go out of business before full contract payment
    b. Facility/technical factors
        i. Customer-preferred short performance periods limit technical approach
        ii. Changes in future occupancy and use
        iii. Unknown latent conditions
    c. People factors
        i. Human activity inconsistent with M&V plans
        ii. Improper O&M undertaken by customer
        iii. Interference with customer operations

2. Project Development
    a. Costs incurred from project start-up; long development phases can lead to difficult to recover costs.

3. Energy Audit Quality
    a. The investment grade audit must include a risk assessment for each proposed ECM
    b. Improperly-established or disputed baseline can impact calculations of energy savings and also give rise to disputes.

4. Equipment Selection and Installation
    a. Selected ECMs not aligned with findings of the IGA.
    b. ECM package feasibility, failure to perform as designed, uncertainty in factors used to predict performance.
    c. Reduced involvement of ESCO in ECM selection/installation, procurement through bidding, risk of improper installation if the ESCO is not involved during the construction phase.

5. Commissioning
    a. Failure to commission may lead to missed opportunities to verify ECM performance and better overall project performance.
    b. Failure to commission may miss opportunities to verify installed equipment performance, to ensure that calibration, operation, and maintenance procedures are well-understood, and that all system documentation is turned over.

6. Operations and Maintenance Practices
    a. Poorly understood responsibilities by each party if the O&M plan is unclear.
    b. The customer may not perform O&M work to specification.
    c. Customer self-performance or contracted O&M may reduce revenue for ESCO.

7. Measurement and Verification of Savings
    a. Poorly-developed M&V plans can create additional risk for the ESCO. Poorly-designed M&V sampling protocols may not accurately reflect the overall performance of the ECM package.
    b. M&V protocols that do not capture non-energy benefits of EPCs may understate overall system performance.
    c. Failure to include O&M in the M&V plan may lead to missed savings.

8. Project Management Over the Project Life-Cycle

9. Construction-Specific Concerns
    a. Schedule growth may cause unrecoverable costs for the ESCO.
    b. Cost growth may impact the financial analysis that the savings guarantee is premised on - cost overruns may result from schedule delays, latent site conditions, and field changes.

10. Volatility of Energy Prices
    a. Changing prices can reduce project value.

APPENDIX A.2

Delphi Round 1 Questionnaire for Risk Tolerance, Risk Identification, and Risk Management in Energy Performance Contracting

Phase II Interview Questions

QUESTIONNAIRE PART I – YOUR RISK BEHAVIOR AND TOLERANCE

Note: Please complete Part I prior to conducting Part II over the telephone or in-person.

The following questions are based on a well-known and vetted risk-based portfolio selection tool used by TIAA-CREF (source: https://ais4.tiaa-cref.org/asstallocguidance/nsjsp/dms.do). These questions are intended to measure your individual approach to risk, and will help with further analysis of the data collected in Part II. Your individual raw answers to these questions will not be released except as aggregate analysis of all respondents to the questionnaire, even if you consent to the release of your name and company affiliation.

Please read the background information before answering each corresponding question.

QUESTION 1 BACKGROUND INFORMATION: Inflation, the rise in prices over time, can erode your investment return. Long-term investors should be aware that, if portfolio returns are less than the inflation rate, their ability to purchase goods and services in the future might actually decline. However, portfolios with long-term returns that significantly exceed inflation are associated with a higher degree of risk.

1. Which of the following portfolios is most consistent with your investment philosophy?
Please mark your answer with an X in the box to the left of your selected option.

	a. Portfolio A will most likely exceed long-term inflation by a significant margin and has a high degree of risk.
	b. Portfolio B will most likely exceed long-term inflation by a moderate margin and has a high to moderate degree of risk.
	c. Portfolio C will most likely exceed long-term inflation by a small margin and has a moderate degree of risk.
	d. Portfolio D will most likely match long-term inflation and has a low degree of risk.

QUESTION 2 BACKGROUND INFORMATION: Portfolios with the highest average returns also tend to have the highest chance of short-term losses. The table at right provides the average dollar return of four hypothetical investments of $100,000 and the possibility of losing money (ending value of less than $100,000) over a one-year holding period.

2. Please select the portfolio with which you are most comfortable.
Please mark your answer with an X in the box to the left of your selected option.

Probabilities After 1 Year			
		Possible Average Value at the End of One Year	Chance of Losing Money at the End of One Year
	a. **Portfolio A**	$106,000	16%
	b. **Portfolio B**	$107,000	21%
	c. **Portfolio C**	$108,000	25%
	d. **Portfolio D**	$109,000	28%
Data supplied by Ibbotson Associates.			

QUESTION 3 BACKGROUND INFORMATION: Investing involves a trade-off between risk and return. Historically, investors who have received high long-term average returns have experienced greater fluctuations in the value of their portfolio and more frequent short-term losses than investors in more conservative investments have.

3. Which statement best describes your investment goals?
Please mark your answer with an X in the box to the left of your selected option.

	a. Protect the value of the account. In order to minimize the chance for loss, I am willing to accept the lower long-term returns provided by conservative investments.
	b. Keep risk to a minimum while trying to achieve slightly higher returns than the returns provided by investments that are more conservative.
	c. Balance moderate levels of risk with moderate levels of returns.
	d. Maximize long-term investment returns. I am willing to accept large and sometimes dramatic fluctuations in the value of my investments.

QUESTION 4 BACKGROUND INFORMATION: Historically, markets have experienced downturns, both short-term and prolonged, followed by market recoveries. Suppose you owned a well-diversified portfolio that fell by 20% (i.e. $1,000 initial investment would now be worth $800) over a short period, consistent with the overall market.

4. Assuming you still have 10 years until you begin withdrawals, how would you react?
Please mark your answer with an X in the box to the left of your selected option.

	a. I would not change my portfolio.
	b. I would wait at least one year before changing to options that are more conservative.
	c. I would wait at least three months before changing to options that are more conservative.
	d. I would immediately change to options that are more conservative.

QUESTION 5 BACKGROUND INFORMATION:

The graph at right (Figure A-1) shows the hypothetical results of four sample portfolios over a one-year holding period. The best potential and worst potential gains and losses are presented. Note that the portfolio with the best potential gain also has the largest potential loss.

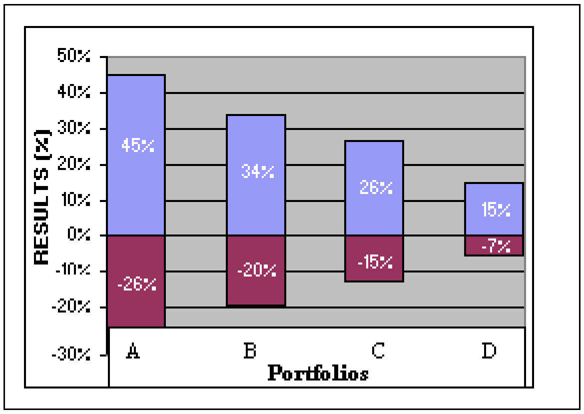


Figure A-1. TIAA-CREF Questionnaire Comparison Portfolios

5. Which of these portfolios would you prefer to hold?

Please mark your answer with an X in the box to the left of your selected option.

	a. Portfolio A
	b. Portfolio B
	c. Portfolio C
	d. Portfolio D

6. I am comfortable with investments that may frequently experience large declines in value if there is a potential for higher returns.

Please mark your answer with an X in the box to the left of your selected option.

	a. Agree
	b. Disagree
	c. Strongly Disagree

QUESTIONNAIRE PART II – UNCERTAINTY, RISK MANAGEMENT, AND LIFE CYCLE COSTING IN ENERGY PERFORMANCE CONTRACTING

Note: Please complete Part I prior to conducting Part II over the telephone or in-person. If possible, please complete Question 1 of Part II prior to conducting the rest of Part II over the telephone or in-person.

The following questions are based on your experiences in performing energy performance contract retrofit projects. All tables will be filled out by the researcher during the telephone or face-to-face interview. The tables and questions are provided here for your review; however, no action is needed on your part until the interview is conducted.

1. Please provide a description of your role in energy performance contract projects performed in MUSH (**M**unicipal agencies [state/local government] – includes correctional facilities, **U**niversities/colleges, K-12 **S**chools, and **H**ospitals) market buildings.

Sub-Question	**Your Answer**
1a. How many years have you been involved with EPC projects?	
1b. How many such projects have you worked on?	
1c. How many were MUSH market projects?	
1d. Which MUSH sub-markets have you worked in?	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	

2. These questions relate to previously identified risk categories for ESCOs engaged in performance contracts (see Table A-1 for questions 2a and 2b).
    a. Do you consider any of these risk categories when developing and executing energy performance contract projects? If so, which ones?
    b. Are there any risk categories that you consider that are not included in this list? If yes, we will add these to Table 1 and complete the questions about frequency and reasoning for consideration.

   c. What are the top 3 reasons (Risk Categories from Table A-1) you believe an energy performance contract would not meet the performance guarantee? Do you base this selection on one or more of the following?
      i. Probability of occurrence?
      ii. The seriousness of the end effect – measured through cost or another factor?
      iii. Difficulty in detecting the risk factor?
      iv. Ability to mitigate a risk factor once identified?

3. For each of the risk categories identified in the previous question, what are the effects on the ESCO if these risks are not prevented or corrected (Please refer to Table A-2)?
   a. For each of the three categories listed, what can cause these risks?
   b. For each item listed, are there controls implemented that either prevent these risks, detect negative impacts of these risks if they occur, and/or mitigate these risks? If so, what is done? Are formal methods used (e.g., status meetings, project risk response audits, risk response planning, earned value analysis, none, or other)?
   c. Do combinations of these risks pose a greater threat than these risks individually?

4. Do MUSH market energy performance contract projects have different risk categories than non-MUSH market projects? If so, please describe those differences.

5. What is your risk management process for energy performance contracts?
   a. How do you identify risks in these projects? Do you base this on experience, previous projects, client requirements, case based reasoning, contractual requirements? Do you use formal or informal methods? *Follow up with questions about knowledge of/use of documentation review, brainstorming, checklist analysis, root cause analysis, interviewing, SWOT analysis, assumption analysis, cause/effect diagramming, system/process flow chart, influence diagram, Delphi technique, none, other (Thaheem and DeMarco 2013) - why/why not are these methods used?*
   b. At what stage of the project do you identify risks?
   c. Who on the project team identifies these risks and performs these functions (e.g., sales lead, PM, engineer, attorney)?
   d. What method or methods do you use for evaluating the impact of a risk on the project? *Follow up with questions about knowledge of/use of FMEA, tree analysis, Monte Carlo, risk-based LCCA, none, or other? - Why/why not are these methods used?*

6. How do you evaluate potential energy conservation measures individually and as a portfolio for inclusion in an energy performance contract?
   a. Do you use life cycle cost analysis? If so, how do you define parameters (discount rate, inflation rate, energy costs)? If not, why not? What performance periods are typically used?

b. Do you consider future uncertainty of life cycle cost analysis model parameters (discount rate, inflation rate, energy costs)? Uncertainty of project factors (cost growth, schedule growth, identified risk categories)?
c. Do you build sunk costs (e.g., project management during M&V, inclusion of costs for security/escort staff, some NEB-related work) and loss leaders (e.g., additional no-fee services, some NEB-related work) into these analyses? On what basis do you include values for these elements?
d. Are non-energy benefits included in this analysis (e.g., water conservation, O&M savings, avoided capital costs, tradable emissions credits, improved health/well-being/productivity)? If so, please describe. If not, why not?

Table A-1. List of Previously-Identified Risk Categories for ESCOs Engaged in Performance Contracting (Accompanies Question 2)

		Do you consider any of these risk categories when developing and executing energy performance contract projects?							
Risk Category	**Non-Comprehensive Examples**	**Every Time**	**Usually (~90%)**	**Frequently (~70%)**	**Sometimes (~50%)**	**Occasionally (~30%)**	**Rarely (<10%)**	**Never**	**Why?**
1. Client Selection Factors									
1A. Financial factors	- Customer may go out of business before full contract payment								
1B. Facility/ technical factors	- Customer-preferred short performance periods limit technical approach - Changes in future occupancy and use - Unknown latent conditions								
1C. People factors	- Human activity inconsistent with M&V plans - Improper O&M undertaken by customer - Interference with customer operations								
2. Project Development	- Costs incurred from project start-up; long development phases can lead to difficult to recover costs.								
3. Energy Audit Quality	- The investment grade audit must include a risk assessment for each proposed ECM - Improperly-established or disputed baseline can impact calculations of energy savings and also give rise to disputes.								

Table A-1 (cont'd)

Risk Category	**Non-Comprehensive Examples**	**Do you consider any of these risk categories when developing and executing energy performance contract projects?**							
		Every Time	**Usually (~90%)**	**Frequently (~70%)**	**Sometimes (~50%)**	**Occasionally (~30%)**	**Rarely (<10%)**	**Never**	**Why?**
4. Equipment Selection and Installation	- Selected ECMs not aligned with findings of the IGA. - ECM package feasibility, failure to perform as designed, uncertainty in factors used to predict performance. - Reduced involvement of ESCO in ECM selection/installation, procurement through bidding, risk of improper installation if the ESCO is not involved during the construction phase.								
5. Commissioning	- Failure to commission may lead to missed opportunities to verify ECM performance and better overall project performance. - Failure to commission may miss opportunities to verify installed equipment performance, to ensure that calibration, operation, and maintenance procedures are well-understood, and that all system documentation is turned over.								

Table A-1 (cont'd)									
		Do you consider any of these risk categories when developing and executing energy performance contract projects?							
Risk Category	**Non-Comprehensive Examples**	**Every Time**	**Usually (~90%)**	**Frequently (~70%)**	**Sometimes (~50%)**	**Occasionally (~30%)**	**Rarely (<10%)**	**Never**	**Why?**
6. Operations and Maintenance Practices	- Poorly understood responsibilities by each party if the O&M plan is unclear. - The customer may not perform O&M work to specification. - Customer self-performance or contracted O&M may reduce revenue for ESCO.								
7. Measurement and Verification of Savings	- Poorly-developed M&V plans can create additional risk for the ESCO. - Poorly-designed M&V sampling protocols may not accurately reflect the overall performance of the ECM package. - M&V protocols that do not capture non-energy benefits of EPCs may understate overall system performance. - Failure to include O&M in the M&V plan may lead to missed savings.								
8. Project Management Over the Project Life-Cycle									

Table A-1 (cont'd)

Risk Category	Non-Comprehensive Examples	Do you consider any of these risk categories when developing and executing energy performance contract projects?							
		Every Time	Usually (~90%)	Frequently (~70%)	Sometimes (~50%)	Occasionally (~30%)	Rarely (<10%)	Never	Why?
9. Construction-Specific Concerns	- Schedule growth may cause unrecoverable costs for the ESCO. - Cost growth may impact the financial analysis that the savings guarantee is premised on - cost overruns may result from schedule delays, latent site conditions, and field changes.								
10. Volatility of Energy Prices	- Changing prices can reduce project value.								
11. Other (Please Specify)									
12. Other (Please Specify)									
13. Other (Please Specify)									
14. Other (Please Specify)									

Table A-2. Features of Top Three Identified Risk Categories
(Accompanies Question 4)

Identified Risk Category	**Potential Cause(s)**	**Controls Used**

APPENDIX A.3

Delphi Round 2 Questionnaire for Risk Identification and Risk Management in Energy Performance Contracting

1. Please enter your participant ID sent to you in the email that linked to this survey:

☐

2. Please select the EPC retrofit project phase or phases you most frequently support:

☐ Project Development
☐ Energy Audit
☐ Retrofit Design
☐ Project Execution (Construction and Commissioning)
☐ Energy Savings (O&M and M&V)
☐ Other (please specify)

3. In the first survey, 11 participants identified a total of 10 new risks that were added to matrix that you responded to. The number in parentheses indicates the number of panelists identifying each new risk. Please indicate below whether you concur with the addition of each risk. You may refer to the risk matrix in the document that was attached to the email you received to see all of the other risk categories and individual risks. A comment field is available if you wish to add your thoughts.

	Agree with Addition of this <u>Risk</u>	**Disagree with Addition of this <u>Risk</u>**
Political Risks - Client Selection Risks (4)	○	○
Productivity Losses in Corrections Projects (1)	○	○
Safety (1)	○	○
Changing Financial Incentives (1)	○	○
Cost of Doing Nothing or Self-Implementing (1)	○	○
Public Procedural Risks (1)	○	○
Time-Based Risk (1)	○	○
Timing (1)	○	○
Design Development (1)	○	○
Staff Turnover During Project (2)	○	○

4. Two participants identified a risk which did not fall under any existing risk category. The new risk category was identified as "Perception of the Performance Contracting Industry" and included two concerns:
    - Lack of knowledge regarding EPC enabling statutes by the ESCO limits some customers' understanding of how they can use EPC.
    - Unethical behavior negatively impacts the industry as a whole.

Please rank the frequency with which you consider this risk on your projects. As with the first interview, consideration means that you address these risks contractually, by project management, through technical means, or via financial assurance.

	Every Time	**(~90%) Usually**	**(~70%) Frequently**	**(~50%) Sometimes**	**(~30%) Occasionally**	**(<10%) Rarely**	**Never**
Perception of the Performance Contracting Industry							

5. 78% of panelists believe that MUSH market EPC retrofits have a higher level of project risk than commercial and industrial sector EPC retrofits. Panelists provided five MUSH market facility types that they believed had higher levels of risk than other buildings in the MUSH market. Which facility types do you believe have higher levels of project risk (select all that apply)?

☐ Correctional facilities
☐ Hospitals
☐ K-12 schools
☐ Continuously operated facilities (e.g., 24/7 operation) of all types, including hospitals, correctional facilities, etc.
☐ Mission-critical facilities
☐ EPC retrofits in MUSH market buildings do not inherently have any more risk than commercial and industrial EPC retrofits
☐ Other (please specify)

6. In the first survey, you were asked to identify the three most important risk categories you consider when developing and implementing MUSH market EPC retrofit projects. Based on your importance scoring, the top 6 risk categories are listed below. Importance scores are in parentheses next to each risk category. Please rank these from 1 to 6, with a score of 1 indicating the most important risk category to consider (as one panelist stated, "the things that keep me awake at night when I have a project underway") and a score of 6 indicating the least important among these 6.

	1	2	3	4	5	6
Energy Audit Quality (10)	○	○	○	○	○	○
ECM Selection and Installation (8)	○	○	○	○	○	○
Project Development Risks (8)	○	○	○	○	○	○
Construction-Specific Concerns (8)	○	○	○	○	○	○
Commissioning (7)	○	○	○	○	○	○
Measurement and Verification of Savings (5)	○	○	○	○	○	○

7. Please select which method or methods you use to identify risks during projects.

☐ Brainstorming
☐ Cause and Effect Diagram/Ishikawa Diagram
☐ Checklist
☐ Delphi
☐ Expertise/Expert Judgement
☐ Failure Mode and Effects Analysis (FMEA)
☐ Interviewing
☐ Monte Carlo Simulation
☐ Risk Mapping, Risk Matrix, Probability and Impact Matrix
☐ Root Cause Analysis
☐ Sensitivity Analysis
☐ Strengths, Weaknesses, Opportunities, and Threats (SWOT)
☐ None
☐ Other (please specify methods used)

8. Please select which method or methods you use to analyze risks during projects. Risk analysis is defined as determining the level of impact that a risk has on the project.

☐ Brainstorming
☐ Cause and Effect Diagram/Ishikawa Diagram
☐ Checklist
☐ Decision Tree Analysis
☐ Delphi
☐ Expected Monetary Value
☐ Expertise/Expert Judgement
☐ Failure Mode and Effects Analysis (FMEA)
☐ Interviewing
☐ Monte Carlo Simulation
☐ Risk Mapping, Risk Matrix, Probability and Impact Matrix
☐ Strengths, Weaknesses, Opportunities, and Threats (SWOT)
☐ None
☐ Other (please specify methods used)

APPENDIX B

Delphi Panel Description and Expert Determination

Use of Purposive Sampling

Participants were selected for this study using purposive sampling techniques (Barbour 2001; Oliver 2006; Tongco 2007), in order to focus on experts engaged in energy performance contracting (EPC) work with a variety of energy service companies (ESCOs). Rather than draw a large sample to be representative of all such ESCOs and types of EPC retrofits, this study necessitated participation from experts with significant experience in performing retrofits specifically in municipalities, universities, schools, and hospitals (MUSH) market buildings.

A number of purposive sampling methods have been identified in the literature. Teddlie and Yu 2007 identified a four-category typology for purposive sampling methods:

- Sampling to achieve representativeness or comparability
- Sampling special or unique cases
- Sequential sampling
- Sampling based on combinations of purposeful techniques

This study uses the latter strategy, a combination approach of expert sampling, snowball sampling, and critical case sampling to guide selection of individual participants, cases, and documents. The overarching goal of the sampling was to provide expertise from contractors possessing a high level of knowledge about MUSH market EPC retrofit projects. Expert sampling was, therefore, a cornerstone of the combination approach used; however, identifying and gaining access to such experts was difficult in many cases. As a result, a sequential sampling technique known as snowball sampling (also called chain sampling) was used, as it has been shown to assist in the recruitment of participants who are difficult to reach for a variety of reasons (Sadler et al. 2010). Through this technique, upon completion of the interview questionnaire, respondents were asked to provide referrals to other domain experts who would be likely to participate in this study and who met pre-determined expert selection criteria. This was particularly important with this group of practitioners, as unsolicited requests for participation led to relatively low participation rates (18.5%) and most ESCOs do not readily publish contact information for individuals who might qualify as domain experts. Experts were identified in connection with critical cases, which were defined based on key attributes that were central to the goal and objectives of this research, including:

- Individuals and projects were selected from the MUSH market;
- Individuals with experience in, and projects from the correctional facilities domain were particularly important; and
- Project documents, especially risk management checklists, were sought from firms with significant MUSH market retrofit experience and well-documented and widely-disseminated corporate risk management programs.

Delphi Panel – Determination of Expertise

Expertise was determined for each participant following a rubric based on Hallowell and Gambatese (2010) and Duah (2014), as described in Tables 3-1 (expertise selection guidelines) and Table 3-2 (expertise scoring rubric). Expertise was determined two ways:

1. A threshold number of expert selection categories were met (five out of nine qualifications met).
2. A goal of at least 4.5 points attained out of 8.5 available points obtained by following the scoring rubric.

Determinants of expertise are presented in Tables B-1 through B-19 for study participants.

Table B-1. Expertise Assessment for Participant ER-1-E

Company Type: Independent and Other ESCOs

Title: Corrections Market Business Development

Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	25 + yrs	1
1b. How many such projects have you worked on?	53 +	1
1c. How many were MUSH market projects?	All	1.5
1d. Which MUSH sub-markets have you worked in?	M - corrections	N/A
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	3-5	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	No	0
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	No	0
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes -14	0.5
TOTAL POINTS:	**5**	
TOTAL CATEGORIES:	**6**	

Table B-2. Expertise Assessment for Participant ER-2-E		
Company Type: Independent and Other ESCOs		
Title: Senior Business Development Manager		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	22	1
1b. How many such projects have you worked on?	50-60	1
1c. How many were MUSH market projects?	At least 90%	1.5
1d. Which MUSH sub-markets have you worked in?	All markets, primarily M and U	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	No	0
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	HVAC, mechanical, envelope, lighting, decentralization, co-gen, water, controls	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	No	0
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	No	0
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes – 10-12	0.5
TOTAL POINTS:	**4.5**	
TOTAL CATEGORIES:	**5**	

Table B-3. Expertise Assessment for Participant ER-3-U

Company Type: Utility Company ESCOs

Title: Senior Project Manager

Question	Response	Points
1a. How many years have you been involved with EPC projects?	9 years	1
1b. How many such projects have you worked on?	10	1
1c. How many were MUSH market projects?	8	1.5
1d. Which MUSH sub-markets have you worked in?	MUSH, Yes – corrections work	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	No	0
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	All listed plus controls, vending machine optimization, renewable	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	CEM	3
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	MS in Info Systems for Technology	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes – 2	0.5
TOTAL POINTS:	**9.5**	
TOTAL CATEGORIES:	**7**	

Table B-4. Expertise Assessment for Participant ER-4-M		
Company Type: Building Equipment Manufacturer ESCOs		
Title: Manager, Public Housing Innovation & Best Practices		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	19	1
1b. How many such projects have you worked on?	200	1
1c. How many were MUSH market projects?	200	1.5
1d. Which MUSH sub-markets have you worked in?	MUSH	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	5+	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	CEM	3
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	BS Mechanical Engineering and MBA	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes – 3-4/yr – about 30	0.5
TOTAL POINTS:	10	
TOTAL CATEGORIES:	8	

Table B-5. Expertise Assessment for Participant ER-5-M		
Company Type: Building Equipment Manufacturer ESCOs		
Title: Project Development Manager I		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	21 years	1
1b. How many such projects have you worked on?	100s - $300million in work	1
1c. How many were MUSH market projects?	100%	1.5
1d. Which MUSH sub-markets have you worked in?	M,U,S,H; No corrections	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes on rebates	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	Lighting, controls, water, mechanical upgrades, envelope, de-central	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	CEM	3
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	BS - EET	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	2/year	0.5
TOTAL POINTS:	10	
TOTAL CATEGORIES:	8	

Table B-6. Expertise Assessment for Participant ER-6-E

Company Type: Independent and Other ESCOs

Title: Vice President

Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	14	1
1b. How many such projects have you worked on?	50	1
1c. How many were MUSH market projects?	50	1.5
1d. Which MUSH sub-markets have you worked in?	M, U, S	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	6	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	No	0
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	BS Engineering, Masters in finance and business	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	1	0.5
TOTAL POINTS:	7	
TOTAL CATEGORIES:	7	

Table B-7. Expertise Assessment for Participant ER-7-M		
Company Type: Building Equipment Manufacturer ESCOs		
Title: Sales Team Leader, Northeast		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	14	1
1b. How many such projects have you worked on?	20 to 30	1
1c. How many were MUSH market projects?	All	1.5
1d. Which MUSH sub-markets have you worked in?	K12, Univ, State	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	8	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	CEM, PE	3
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	BS EET MBA - Finance	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	Yes, Part-Time	1
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes, ~40	0.5
TOTAL POINTS:	11	
TOTAL CATEGORIES:	9	

Table B-8. Expertise Assessment for Participant ER-8-M		
Company Type: Building Equipment Manufacturer ESCOs		
Title: Western Territory Team Project Developer		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	22	1
1b. How many such projects have you worked on?	30	1
1c. How many were MUSH market projects?	9-10	1.5
1d. Which MUSH sub-markets have you worked in?	Fed (M), U, S	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes – incentives and grants	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	Lighting, temp controls, HVAC modernization, few envelope,	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	CEM since 1992/93	3
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	BS Aerospace engineering-mechanical systems	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	A couple of times at Trane and a conference	0.5
TOTAL POINTS:	10	
TOTAL CATEGORIES:	8	

Table B-9. Expertise Assessment for Participant ER-9-M

Company Type: Building Equipment Manufacturer ESCOs

Title: Government Market Manager - Michigan

Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	33	1
1b. How many such projects have you worked on?	300	1
1c. How many were MUSH market projects?	99%	1.5
1d. Which MUSH sub-markets have you worked in?	MUSH – most M	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	8-10	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	No	0
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	No	0
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes – 10	0.5
TOTAL POINTS:	5	
TOTAL CATEGORIES:	6	

Table B-10. Expertise Assessment for Participant ER-10-E

Company Type: Independent and Other ESCOs

Title: Senior Sales Executive

Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	7	0
1b. How many such projects have you worked on?	~25	1
1c. How many were MUSH market projects?	16	1.5
1d. Which MUSH sub-markets have you worked in?	MUSH – correctional – counties with ESG	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	6+	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	No - Pursuing LEED AP; looking at CEM	0
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	BS in ME and AAS in electronics	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	3 articles published in trade journals for New Mexico	1
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes – 3+ times	0.5
TOTAL POINTS:	7	
TOTAL CATEGORIES:	7	

Table B-11. Expertise Assessment for Participant ER-11-E		
Company Type: Independent and Other ESCOs		
Title: Senior Account Executive		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	18	1
1b. How many such projects have you worked on?	80-100 - $30-40 million/yr	1
1c. How many were MUSH market projects?	98%	1.5
1d. Which MUSH sub-markets have you worked in?	MUSH - Corrections is largest customer segment	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	>5	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	No	0
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	No - BSBA	0
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	Articles – 3 or 4	1
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes – 5 or 6	0.5
TOTAL POINTS:	6	
TOTAL CATEGORIES:	7	

Table B-12. Expertise Assessment for Participant ER-12-M		
Company Type: Building Equipment Manufacturer ESCOs		
Title: Senior Contract Manager		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	14	1
1b. How many such projects have you worked on?	At least 100	1
1c. How many were MUSH market projects?	90%-95%	1.5
1d. Which MUSH sub-markets have you worked in?	MUSH	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	No	0
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	5+	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	No	0
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	JD – Directly related to function as contract manager	3
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	2	0.5
TOTAL POINTS:	7.5	
TOTAL CATEGORIES:	6	

Note: There is no entry for participant ER-13 due to the inability to complete an interview after participant identification numbers were created.

Table B-13. Expertise Assessment for Participant ER-14-E		
Company Type: Independent and Other ESCOs		
Title: Director of Construction Services		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	5	0
1b. How many such projects have you worked on?	100+	1
1c. How many were MUSH market projects?	95%	1.5
1d. Which MUSH sub-markets have you worked in?	All	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	3 to 6	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	No	0
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	Yes – BS in CM	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	No	0
TOTAL POINTS:	5.5	
TOTAL CATEGORIES:	5	

Table B-14. Expertise Assessment for Participant ER-15-M		
Company Type: Building Equipment Manufacturer ESCOs		
Title: Design-Build and ESPC Team Manager		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	7	0
1b. How many such projects have you worked on?	12	1
1c. How many were MUSH market projects?	100%	1.5
1d. Which MUSH sub-markets have you worked in?	M,S – Corrections through M	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	5+	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	EIT	0
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	BS Architectural Engineering	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes – 1 time	0.5
TOTAL POINTS:	6	
TOTAL CATEGORIES:	6	

Table B-15. Expertise Assessment for Participant ER-16-M

Company Type: Building Equipment Manufacturer ESCOs

Title: Account Executive

Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	29	1
1b. How many such projects have you worked on?	120	1
1c. How many were MUSH market projects?	90%	1.5
1d. Which MUSH sub-markets have you worked in?	MUSH; Yes corrections	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	Yes	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	CEM	3
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	BSIE; MS in Energy Systems Engineering I&CE	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	FT faculty @ BGSU – 2 years	1
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	Articles – 4	1
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes – 5+	0.5
TOTAL POINTS:	12	
TOTAL CATEGORIES:	10	

Table B-16. Expertise Assessment for Participant ER-17-U		
Company Type: Utility Company ESCOs		
Title: Associate Product Portfolio Manager		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	5	0
1b. How many such projects have you worked on?	~40	1
1c. How many were MUSH market projects?	95%	1.5
1d. Which MUSH sub-markets have you worked in?	MUS	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes – Incentives	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	3-4; Lighting and HVAC, some envelope,	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	No	0
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	No	0
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	Article – yes ACEEE whitepaper	1
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes – four times	0.5
TOTAL POINTS:	5	
TOTAL CATEGORIES:	6	

Table B-17. Expertise Assessment for Participant ER-18-E		
Company Type: Independent and Other ESCOs		
Title: Energy Engineer		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	10	1
1b. How many such projects have you worked on?	~30	1
1c. How many were MUSH market projects?	6 fed, rest MUSH	1.5
1d. Which MUSH sub-markets have you worked in?	MUSH	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes - rebates	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	3+	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	CEM and LEED AP	3
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	MS in Mechanical	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes – Numerous times	0.5
TOTAL POINTS:	10	
TOTAL CATEGORIES:	8	

Table B-18. Expertise Assessment for Participant ER-19-E		
Company Type: Independent and Other ESCOs		
Title: Energy Engineering Manager		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	14	1
1b. How many such projects have you worked on?	140+	1
1c. How many were MUSH market projects?	90%	1.5
1d. Which MUSH sub-markets have you worked in?	MUSH	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	3+	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	PE and CEM	3
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	BS ME minor in match	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	Associate Faculty at Cascadia Community College	1
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	Yes – at least 6	0.5
TOTAL POINTS:	11	
TOTAL CATEGORIES:	9	

Table B-19. Expertise Assessment for Participant ER-20-E		
Company Type: Independent and Other ESCOs		
Title: Engineering Manager		
Question	**Response**	**Points**
1a. How many years have you been involved with EPC projects?	16	1
1b. How many such projects have you worked on?	50+	1
1c. How many were MUSH market projects?	45	1.5
1d. Which MUSH sub-markets have you worked in?	MUSH	
1e. Did you have a role in securing financing and/or securing financial incentives on these projects?	Yes	0.5
1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?	5	0.5
1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?	CEM	3
1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?	MSME	2
1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?	No	0
1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?	No	0
1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?	6	0.5
TOTAL POINTS:	10	
TOTAL CATEGORIES:	8	

APPENDIX C.1

Detailed Analysis of Data Collected for Developing Life Cycle Cost-Based Risk Model in Delphi Round 1

PART I - RISK TOLERANCE QUESTIONS

KNOWLEDGE CATEGORY 1 – RISK TOLERANCE

The purpose of this question was to classify panelists based on their extant beliefs regarding risk. This is potentially important in the context of this research, as the literature has shown evidence of irrational risk behavior among contractors (McKim 1992) and a reliance on information and heuristics to address project risks (Raftery et al. 2001; Simu 2009) which can lead to cognitive biases in decision making. The six questions in this part of the survey utilized the TIAA-CREF Asset Allocation Evaluator (TIAA-CREF 2013), a well-vetted tool that provides insight into individual attitudes and tolerance toward risk (Cobb and Menas 2009). Table C-1 summarizes the risk tolerance of the panelists, organized in ascending order of risk tolerance.

Table C-1. Panelists' Risk Tolerance

Risk Tolerance	**N**[a]	**Percent (%)**
Conservative	3	16.7%
Moderately Conservative	2	11.1%
Moderate	5	27.8%
Moderately Aggressive	6	33.3%
Aggressive	2	11.1%

Notes:
a\ One panelist did not complete the risk profile tool

Risk tolerance was evaluated as a function of various characteristics of the panelists. Characteristics of interest were identified based on a study of construction managers' impacts on risk management (Simu 2009), and included education in a related field, the type of firm in which employed, years of energy performance contracting (EPC) experience, and project experience. Comparing proportions between these panelists' characteristics of interest and risk tolerance could be difficult due to the small sample size of panelists (n=19), the large number of outcomes for risk tolerance (5), and the corresponding relatively small number of outcomes for each characteristic of interest. As a result, risk tolerance outcomes were collapsed from five to three categories, as shown in Table C-2.

Table C-2. Modified Panelists' Risk Tolerance Categories

Risk Tolerance	**N**	**Percent (%)**
Conservative and Moderately Conservative	5	27.8%
Moderate	5	27.8%
Moderately Aggressive and Aggressive	8	44.4%

Restructuring the risk tolerance outcomes reveals that panelist attitudes toward risk place them along a conservative to moderate continuum (55.6%). The single largest category of panelists, however, was those who are considered moderately aggressive or aggressive. This gives rise to the question of which other characteristics may be related to specific risk tolerances.

PART II – PROFESSIONAL EXPERIENCE AND DETERMINATION OF EXPERTISE

KNOWLEDGE CATEGORY 2 – NUMBER OF YEARS IN EPC INDUSTRY

1a. How many years have you been involved with EPC projects?

This question sought to elicit the number of years each panel member has been involved with performing EPC retrofit projects. Consensus was not a goal of this question since the selected participants had varying amounts of work experience in this field. Additionally, this question was phrased such that a participant's cumulative work experience with EPC retrofits was elicited; this was particularly important in the case of experts who had varied work experience. For example, some participants conducted EPC retrofit-related work while working for utilities, engineering firms, or municipalities, universities, schools, and hospitals (MUSH) market building owners/managers prior to a career with an energy service company (ESCO). This question was phrased to capture the sum of a participant's experience in the delivery of EPC retrofit projects.

Responses were analyzed using equal categories beginning with 0-7 years (8 years or more EPC experience was one of the threshold criteria for expert identification). Table C-3 contains the number of years EPC experience held by the panel.

Table C-3. Number of Years in the EPC Retrofit Industry

Years	N	Percent (%)
0-7 Years	4	21%
8-15 Years	6	32%
16-23 Years	6	32%
24-31 Years	2	11%
32+ Years	1	5%

It can be seen that the majority of panel members (64%) have between 8 and 23 years' experience in conducting EPC retrofit projects. A small number of participants (16%) had greater than 24 years of experience. This is expected, since the United States ESCO industry developed in the 1980s (ICF and NAESCO 2007); participants were thus deemed to have a maximum possible tenure in this industry of between approximately 30 and 35 years. While 21% of participants had less than the threshold value for years of experience, 100% of these respondents had at least 5 years of experience.

KNOWLEDGE CATEGORY 3 – NUMBER OF EPC RETROFITS

1b. How many such projects have you worked on?

This question was intended to explore the relationship between an individual's tenure in the EPC retrofit industry and the number of projects they have worked on. This was included to explore the belief that the number of projects EPC experts work on annually may be a reflection of their role in the EPC retrofit process. Table C-4a shows the total number of projects worked on by the panel and Table C-4b shows the average number of projects work on annually by panel members.

Table C-4a. Number EPC Retrofits		
# of Projects	**N**	**Percent (%)**
0-25	4	21%
26-50	5	26%
51-75	2	11%
76-100	4	21%
100+	4	21%

Table C-4b. Number EPC Retrofits Per Year		
# of Projects/Year	**N**	**Percent (%)**
1-2	4	21%
2.1-3	3	16%
3.1-4	3	16%
4.1-5	3	16%
5.1+	6	32%

Analysis of Table C-4a reveals that the majority of panelists have completed between 51 and over 100 projects, with a maximum value of 300 projects. The number of projects panelists worked on annually centers on values between 2.1 and 5 (48% of panelists); however, 32% of participants worked on 5.1 or more projects per year, which was the largest single response category. Data in this category ranged from 7.1 to 20 projects worked annually. An analysis of this data reveals that the experts in the latter category generally held positions such as sales manager of an entire sector (e.g., public housing), state and regional market managers, and individuals with corporate-level responsibility (e.g., senior contract manager, director of construction services, and energy engineering manager).

The panelist working on the least number of EPC projects had 10 total projects (over 9 years). That same individual had the lowest number of projects per year at 1.11. This individual was a construction project manager, which is consistent with the relatively low number of projects per year, since the construction phase of EPC retrofits can take 6 to 18 months to complete. The panelist with the largest number of projects reported working on 300 EPC retrofits. The participant with the largest annual workload reported 20 EPC projects per year. The former panelist is a statewide market manager, and the latter panelist is a director of construction services.

KNOWLEDGE CATEGORY 4 – MUSH MARKET EPC RETROFIT EXPERIENCE

1c. How many were MUSH market projects?

In order to determine panelists' experience specifically with MUSH market EPC projects, participants were asked to identify the percentage of their total portfolio of work that was directed toward MUSH market buildings. Table C-5 shows the percentage of panelists' overall EPC retrofit work that took place in the MUSH market.

Table C-5. Percentage of EPC Retrofits in the MUSH Market		
Percentage of Projects	**N**	**Percent (%)**
<80%	2	11%
80-90%	5	26%
91%-95%	3	16%
96-99%	2	11%
100%	7	37%

An analysis of Table C-5 reveals that the majority of panelists' EPC retrofit project portfolios are dominated by MUSH market work; 64% of participants' portfolios are comprised of greater than 90% of such projects. This was not unexpected, given the large EPC market share given to MUSH market projects (Satchwell et al. 2010). The largest single response category indicated that 37% of panelists have worked exclusively in one or more MUSH sub-markets.

1d. Which MUSH sub-markets have you worked in?

In concert with the previous question, panelists were asked to identify which specific MUCH sub-markets they have worked in. Results are displayed in Table C-6a.

Table C-6a. Experience with MUSH Sub-Markets

Submarket(s)	N	Percent (%)
M Only	1	5%
MS Only	1	5%
MUS Only	4	21%
MUSH	13	68%

The vast majority of panelists (68%) have work experience in all four MUSH sub-markets (municipalities, universities, K-12 schools, and hospitals), further establishing their qualification to contribute their expertise to achieve the goal of this research.

Individuals were not asked specifically about their experience with correctional facility projects; however, 7 out of the 19 panelists offered this information when responding to question 1d. Those results are shown in Table C-6b.

Table C-6b. Experience with Corrections Facility EPC Retrofits

Response	N	Percent (%)
Yes	6	32%
No	1	5%
Unknown	12	63%

KNOWLEDGE CATEGORY 5 – FINANCIAL AID KNOWLEDGE

1e. Did you have a role in securing financing and/or securing financial incentives on these projects?

The purpose of this question was the assess panelists' experience with understanding the role that utility rebates, grants, and other financial incentives play in understanding the financial aspects of an EPC project and their contribution to the effective financing of an EPC retrofit. The importance of financial incentives was raised in the Phase 0 interview, which confirmed earlier case study findings that revealed the role of utility rebates in helping to finance a broader technical scope of work in EPC retrofits, particularly in non-energy areas, for three prisons in Michigan (Berghorn and Vallad 2013). The importance of financial incentives has also been emphasized in the literature (Hopper et al. 2007; Satchwell et al. 2010; IFC 2011; Stuart et al. 2013). Table C-7 shows panelists' responses to whether they have experience with financing and financial incentives for EPC retrofits.

As can be seen, the majority (84%) of participants have such experience. Four respondents indicated that their experience is only with rebates, grants, and/or incentives, and one respondent indicated that they have experience in this area on approximately 10% of their projects.

Table C-7. Experience with Project Financing and Financial Incentives

Response	N	Percent (%)
Yes	16	84%
No	3	16%

KNOWLEDGE CATEGORY 6 – RETROFIT MEASURES KNOWLEDGE

1f. On average, how many building systems were impacted on each project you worked on (e.g., envelope, lighting, central plant decentralization, water, mechanical upgrade, etc.)?
The purpose of this question was to elicit knowledge from panelists about their experience with specific retrofit measures included in the design and execution of EPC projects. The average number of measures deployed in MUSH market EPC retrofits increased to approximately 5.8 by 2008, with non K-12 school MUSH market projects averaging approximately 5 measures per project by that same time (Larsen, Goldman, and Satchwell 2012). Retrofit measures and their frequency of use in "public sector" projects (as defined, analogous to MUSH market) were identified by Larsen et al. (2012), as shown in Table C-8.

Table C-8. Retrofit Strategies Frequency of Occurrence in MUSH Market Projects

	Percent (%)			% Change
Retrofit Measure	1990-1997	1998-2004	2005-2008	1990-2008
Major HVAC	50%	54%	46%	-8%
Lighting Only	25%	9%	3%	-88%
Minor HVAC	12%	17%	13%	8%
Onsite Generation	5%	8%	11%	120%
Other	5%	4%	3%	-40%
Non-Energy	3%	8%	24%	700%

In order to facilitate comparisons across multiple projects and over 150 unique retrofit measures contained in the NAESCO database, the study used the following definitions of retrofit measures, which were developed and discussed in previous papers (Goldman et al. 2002; Hopper et al. 2005):

- Lighting-Only: Various lighting efficiency measures, controls, and strategies.
- Major HVAC: Major HVAC equipment replacement (e.g., boilers, chillers, cooling towers, HVAC dist. improvements) and may include other HVAC control, high-efficiency lighting, and motors measures.
- Minor HVAC: Less-capital intensive HVAC measures and controls (and exclude major HVAC equipment replacements), and may include lighting and other measures.
- Onsite generation: Installation of onsite generation equipment and may include other energy efficiency measures (e.g., lighting, HVAC equipment and controls, motor efficiency measures).

- Non-energy: Roof or ceiling replacement, asbestos abatement (i.e., measures that are not installed primarily for their energy savings), and may include other efficiency measures (e.g., lighting or HVAC upgrades).
- Other: All other measures including domestic hot water (DHW), water conservation, and installation of energy efficient equipment such as vending machines, laundry or office equipment, high-efficiency refrigeration, industrial process improvements, and strategies such as staff training or utility tariff negotiation. These individual measures may also be included in other retrofit strategies (except lighting-only); projects categorized as ‘‘other’’ retrofit strategy only installed these types of measures.

Analysis of previous information highlights the need for domain experts to possess broad knowledge of a variety of retrofit measures, and have experience with projects that deployed a wide variety of retrofit measures. The number of retrofit measures deployed on panelists' projects is given in Table C-9a.

Table C-9a. Number of Retrofit Measures Deployed on Projects

# of Retrofit Measures	N	Percent (%)
3-4	5	26%
5-7	9	47%
8-10	4	21%
10+	1	5%

While specific measures were not required as part of this question, several respondents provided information about ECMs that they typically encounter on EPC retrofits, which is summarized in table C-9b.

Table C-9b. Retrofit Strategies Deployed by Panelists – Response Rate for Each Measure

Retrofit Measure	N	Percent (%)
HVAC/Mechanical	5	100%
Lighting	5	100%
Envelope	5	100%
Controls	4	80%
Water	3	60%
Plant Decentralization	3	60%
Vending Machine Optimization	1	20%
Onsite Generation	1	20%
Cogeneration	1	20%

Analysis of the data in table C-9b indicates that panelists have broad expertise and experience with a number of high- and low-utilization retrofit measures, as described in Table C-8. Furthermore, this indicated the need to modify the expert-assessment rubric, such that at least five building systems were impacted on an average project. The selection rubric initially required experience with an average of three retrofit measures per project.

KNOWLEDGE CATEGORY 7 – RELATED CERTIFICATION AND EDUCATION

1g. Do you hold professional registration as a CEM, CxA, PE, NCARB/AIA, or LEED AP? If yes, which one(s)?

The purpose of this question was to elicit information for the purposes of determining expertise, following the rubric developed in Chapter 3. A review was conducted of relevant professional certifications, licensure, and registration that are relevant to the sustainable built environment, by examining membership rosters for various state chapters of the Energy Services Coalition, as well as reviewing the Association of Energy Engineers for available relevant certifications. Question options were structured from this review; however, participants were able to add additional credentials that they possessed if they deemed them relevant. A summary of panelist credentials is presented in Table C-10.

Table C-10. Energy-Related Credentials Held by Panelists

Credential	N	Percent (%)
Engineer in Training (EIT)	1	5%
LEED Accredited Professional (LEED AP®)	1	5%
Professional Engineer (PE)	2	9%
Certified Energy Manager (CEM)	9	41%
None	9	41%

An analysis of the data in Table C-10 reveals that several panelists hold more than one credential (N=3) and the most commonly-held professional credential is the CEM (41% of panelists). An equal number of panelists do not hold relevant credentials. Of those, one panelist holds a credential relevant to their primary job function (Bar Association certification for the panelist that serves as a senior contract manager), despite the credential not being specifically energy-related. Of the remaining eight, seven panelists are in sales and business development functions and one is a corporate vice president.

1h. Do you hold an advanced degree (BS or higher) in engineering or a related field to building construction, operations, design, or energy? If yes, what is your highest relevant degree?

This question further explored the credentials held by panelists in an effort to determine their expertise. Data related to the highest relevant degree held by panelists is shown in Table C-11.

Table C-11. Highest Relevant Degree Held by Panelists

Degree	N	Percent (%)
BS - Construction Management	1	5%
BS - Engineering Technology	2	11%
BS – Engineering	6	32%
MS – Technology	1	5%
MS – Engineering	3	16%
Juris Doctor	1	5%
No Related Degree	5	26%

The most commonly held highest degrees by panelists were a bachelor’s degree in engineering (mechanical, aerospace, and architectural) and a master’s degree in engineering (mechanical and energy systems). It should be noted that three panelists with bachelor's degrees in engineering also held an MBA. Of the panelists without a related degree, one entered this field through a trades background obtained first in the U.S. Navy, and over 30 years of experience as a mechanical tradesperson and supervisor. Of the nine panelists who do not hold a related professional credential, four hold a related advanced degree.

KNOWLEDGE CATEGORY 8 – PROFESSIONAL SERVICE AND OUTREACH

1i. Have you ever served as a faculty member in an energy engineering or management program at an accredited college or university?

The purpose of this question was to determine expertise through qualification and experience as a college or university faculty member, which represents acknowledgement of domain-level expertise by institutions of higher education that are generally independent and subject to rigorous accreditation standards. Additionally, this question also has the potential to demonstrate outreach through the sharing of knowledge by EPC professionals who are serving as an adjunct faculty member. Results for this question are shown in Table C-12.

Table C-12. Experience as a College or University Faculty Member

Response	N	Percent (%)
Yes	3	16%
No	16	84%

Of the three panelists with faculty experience, two have served as adjunct faculty in energy-related programs at community colleges and one served as a full-time faculty member at a doctoral degree-granting institution.

1j. Have you published at least two peer-reviewed publications or one book or book chapter related to EPC? If yes, how many of each type?

This question provides additional insight into third-party recognition of domain-level expertise through acceptance of publications. Table C-13 summarizes panelists' related publications.

Table C-13. Publications Related to EPC

Response	N	Percent (%)
Yes - Article	4	21%
No	15	79%

While a relatively small number of panelists have published related works, one indicated that they authored a white paper for the American Council for an Energy-Efficient Economy, a national non-profit think tank that has produced a sizable body of work related to EPC via whitepapers and conference papers.

1k. Have you ever been an invited conference presenter on a related subject? If yes, how many times?

Similarly to the previous question, this one seeks to elicit third-party recognition of domain expertise through invitations to present on a subject related to EPC. Table C-14 shows panelists' experience with delivering invited conference presentations.

As can be seen from the data, all but one panelist has given invited presentations. That individual has a lengthy background in construction management; however, they are a more recent entrant to the EPC domain. The majority of panelists have been invited presenters between one and five times (42%), with 16% of panelists having given greater than 15 invited presentations.

Table C-14. Invited Presentations on a Related Subject

# of Presentations	N	Percent (%)
0	1	5%
1-5	8	42%
6-10	5	26%
11-15	2	11%
15+	3	16%

PART III – RISK MANAGEMENT PROCESS

KNOWLEDGE CATEGORY 9 – RISK IDENTIFICATION

2a. Do you consider any of these risk categories (Table 1) when developing and executing energy performance contract projects? If so, which ones?

This question and question 2b were intended to elicit expert knowledge in the identification of risks that are encountered in EPC retrofit projects. This question provided a series of twelve risk categories and non-exclusive examples of specific risks associated with each risk category. These risk categories and example risks were identified through a preliminary interview with an EPC expert, through a review of the literature on EPC risks, and during the Phase 0 interview. The literature review and preliminary expert interview led to subdividing the first risk category (Client Selection categories) into three. These are summarized in Table 2-2. This question, therefore, gave panelists the ability to respond to pre-identified risk categories and elicited their expertise about specific example risks and the categories that give rise to the realization of these risks in EPC retrofits. Question 2b elicited panelists' expertise in an open-ended format by providing them the opportunity to identify additional risk categories that were not included in the initial list.

Consensus was sought among panelists as to whether they consider individual risk categories. Panelists were asked to rank their frequency of considering each risk category using a seven-category scale; any response greater than "never" (0% consideration) was logged as an affirmation that this risk category is identified and considered on EPC projects. That information is shown in Table C-15.

In explaining the intent of the question to several panelists, consideration of a risk category was defined as a risk that is identified by the project team, that is mitigated through contractual or other means, and/or that requires a specific plan of action for its assessment and management. A summary of the major themes that emerged through the elicitation of knowledge from the panelists related to each risk category is presented below.

Table C-15. Consideration of Individual Risk Categories

Risk Category	**N**	**Percent (%)**
1. Client Selection Factors	16	84%
1A. Financial factors	16	84%
1B. Facility/technical factors	18	95%
1C. People factors	18	95%
2. Project Development	18	95%
3. Energy Audit Quality	19	100%
4. Equipment Selection and Installation	19	100%
5. Commissioning	18	95%
6. Operations and Maintenance Practices	19	100%
7. Measurement and Verification of Savings	14	74%
8. Project Management Over the Project Life-Cycle	18	95%
9. Construction-Specific Concerns	17	89%
10. Volatility of Energy Prices	16	84%

2b. Are there any risk categories that you consider that are not included in this list?
The purpose of this question was to elicit expertise in an open-ended fashion; that is, rather than get reactions to already identified risks; panelists were given the opportunity to add additional risk categories and individual risks. Responses to this question generally fell into two categories: 1) risks that could be classified under an existing risk category and 2) truly unique risks and risk categories that had not been previously identified. Many risks falling into the former category were immediately moved to the appropriate risk category; however, several required further review before deciding how to most appropriately handle them. These risks have been discussed with the appropriate risk category in the section above. Risks in the latter category will be discussed in this section. Risks identified as part of this question that were not obviously part of one of the first twelve risk categories and their ultimate disposition are provided in Table C-16.

Obtaining consensus among panelists was a goal of this question. Since these were open-ended responses, and previous panelists were not re-interviewed after a new risk category or risk was added, consensus was not obtained during Delphi Round 1. Consensus on the identification of these risks and the newly-identified risk category will be sought during the second round of the Delphi technique. Despite the inability to seek consensus in the first round of interviews, it is worth noting that 4 panelists (21%) independently identified political risks as something to be identified and considered in MUSH market projects.

Perception of the Performance Contracting Industry

Two panelists raised their concern that negative perception of the performance contracting industry could harm project performance. One panelist stated their belief that about 20% of the ESCOs operating currently are staffed with knowledgeable professionals and are sincere in delivering a value solution, while the other 80% are prospecting for business because they think there are large profits to be had.

Three examples were provided:

1. Companies that “subterfuge” the guarantee if performance is not on track, to ensure they are not writing a check back to the client. This is often based on disputed changes in

occupancy, plug loads, etc. This harms the project directly as well as long-term client relationships.

Table C-16. Additional Risks Identified by Panelists

Risk	**Disposition**	**N**	**Percent (%)**
Political Risks	Moved to individual risk under "Client Selection Risks - People Factors"	4	21%
Productivity Losses in Corrections Projects	Moved to individual risk under "Construction Phase Risks"	1	5%
Safety	Moved to individual risk under "Construction Phase Risks"	1	5%
Changing Financial Incentives	Moved to individual risk under "Development Phase Risks"	1	5%
Cost of Doing Nothing or Self-Implementing	Moved to individual risk under "Development Phase Risks"	1	5%
Public Procedural Risks	Moved to individual risk under "Development Phase Risks"	1	5%
Time-Based Risk	Moved to individual risk under "Development Phase Risks"	2	11%
Timing	Moved to individual risk under "Development Phase Risks"	1	5%
Design Development	Moved to individual risk under "Energy Audit Quality"	1	5%
Staff Turnover During Project Lifecycle	Moved into individual risk under "Project Management Over the Project Lifecycle"	1	5%
Perception of the Performance Contracting Industry	Create New Risk Category	2	11%

2. Some companies move the project very quickly through development when they know they have a “less sophisticated” client, resulting in a low-yield project, which could have resulted in much larger benefits for the client if the ESCO invested more time up front. For the ESCO, this limits project scope and creates projects with lower overall value.
3. Lack of understanding of enabling statutes limits the ability for some ESCOs to deliver projects that best-meet the client’s needs. For example, a client was concerned about being able to undertake an EPC retrofit because they were at their debt cap. Several ESCOs told them that they could not execute a project until they cleared their debt-cap, meanwhile, state legislation allowed publicly funded entities to finance performance contracting without counting against the debt cap utilization. This creates the potential for generally negative views of the industry as a whole.

KNOWLEDGE CATEGORY 10 – MUSH MARKET-SPECIFIC RISKS

2c. Do MUSH market energy performance contract projects have different risk categories than non-MUSH market projects? If so, please describe those differences.

This question sought to elicit expertise from panelists to assess whether MUSH market EPC retrofit projects have specific risks that are different or unique from non-MUSH projects (e.g., private sector). Larsen et al. (2012) defined private sector projects as consisting of commercial, office, industrial, retail, hotel/hospitality, residential, and other building types; that definition was used to clarify the question if respondents needed additional information. Table C-17a provides panelist responses as to whether MUSH market EPC projects have different risks from other EPC project types.

As can be seen from Table C-17a, the majority of respondents (82%) believed that MUSH market EPC projects have different risk categories than private sector projects, and therefore, achieved consensus on this issue. Going deeper, information was elicited from panelists as to which market is riskier, and whether any specific sub-markets are riskier than others. Table C-17b and Table C-17c show the information provided by panelists in this regard. Follow up questions will be posed in round 2 to further clarify these responses.

Table C-17a. Do MUSH Market EPC Projects Have Different Risks from non-MUSH Projects?

Response	N	Percent (%)
Yes	14	82%
No	3	18%

Table C-17b. Riskier Market Sectors Identified by Panelists Perceiving a Different Risks in MUSH Market Projects

Riskier Market(s)	N	Percent (%)
MUSH	9	64%
Non-MUSH	3	21%
Non-MUSH, Hospitals, and Corrections	1	7%
Non-MUSH and Corrections	1	7%

Table C-17c. Segments with Greater Risk Identified by Panelists Identifying MUSH Market as the Riskier Market

Riskier Segment(s)	N	Percent (%)
Corrections	8	89%
Hospitals	3	33%
K-12 Schools	2	22%
24/7 Facilities	1	11%
Industrial	1	11%
Data Centers/High Security/Mission Critical	1	11%

KNOWLEDGE CATEGORY 11 – RISK IDENTIFICATION - METHODS

3a. How do you identify risks in these projects? Do you base this on experience, previous projects, client requirements, case based reasoning, contractual requirements? Do you use formal or informal methods?

The purpose of this question was to gain insight into the methods typically employed for risk identification. This assists in determining ESCO's overall level of organizational maturity, per Grimaldi et al. (2012). Panelists were asked to provide information about the risk identification methods they employ on their projects. All panelists reported that they rely on experience to some degree; however, the way experience is used varied significantly. Twenty percent of respondents reported utilizing company databases that contain information from previous projects that can be used to help identify risks by examining similar building types, locations, and ECMs. Five respondents from three different ESCOs reported the use of a formal corporate risk tool, or guidance document that is essentially a checklist constructed from the totality of experience with performing EPC retrofits. Two respondents reported specific risk identification objectives during a multi-stage risk management process. The first panelist indicated a risk identification process that examines risks related to energy savings calculations and M&V, design-related risk, and risks arising from cost and constructability concerns. The second panelist reported a process that begins by identifying risks associated with specific project milestones then utilizes the collective experience of the project team. Since many of these responses were open-ended, this question will be asked again in round 2 using methods found in Grimaldi et al. (2012) and Thaheem and DeMarco (2013).

KNOWLEDGE CATEGORY 12 – RISK IDENTIFICATION - TIMING

3b. At what stage of the project do you identify risks?

100% of respondents indicated that the risk identification process begins early in the project; 60% indicated that the process is iterative and takes place at designated points in time during the project.

KNOWLEDGE CATEGORY 13 – RISK IDENTIFICATION - RESPONSIBILITY

3c. Who on the project team identifies these risks and performs these functions (e.g., sales lead, PM, engineer, attorney)?

All panelists indicated that their organizations have designated individuals to manage the risk process; however, the job functions of these individuals varied. Seventy percent of respondents indicated that a team approach was used, which in the majority of the cases meant that the team member tasked with overall responsibility for activities occurring during a given project phase managed the risk identification process specific to that phase of the work. Generally speaking, these risk review teams were multi-disciplinary and included the project developer, energy engineers, the design engineer, the construction manager, assurance engineers (for M&V concerns), and in some cases, finance and legal staff members. Senior project review (vice president or above) was indicated by 30% of the panelists, and one panelist mentioned the use of in-house project inspectors who make random site visits to review risk, among other items.

KNOWLEDGE CATEGORY 14 – RISK EVALUATION METHODS

3d. What method or methods do you use for evaluating the impact of a risk on the project?

As a companion to question 3a, this question also sought to determine the level of organizational maturity with regard to risk for ESCOs in this study. The general sense from the panel was that ESCOs do not engage in formal methods of risk evaluation. Sixty percent of the panelists reported using informal methods or experience-based methods – one member reported relying on experience as codified in a project database. One panelist reported some use of probabilistic methods for risk evaluation to include Monte Carlo simulation (via Crystal Ball) and the use of PERT inputs for schedule-related risks. That individual reported that the greatest barrier to more widespread use of such methods is the inability to specify probabilistic input ranges for energy models, which limits the use of such methods. Another panelist reported use of an internally-developed tool that evaluates risks as having either “low” or “high” impacts relative to associated costs. The “high risk” cost value is then used as an input to the project’s contingency if the project team is unable to identify a feasible mitigation strategy. That panelist went as far as to say that they believed that process is “ineffective;” however, no changes to the risk evaluation method have been planned. Since many of these responses were open-ended, this question will be asked again in round 2 using methods found in Grimaldi et al. (2012) and Thaheem and DeMarco (2013).

KNOWLEDGE CATEGORY 15 – IDENTIFICATION OF MOST IMPORTANT RISK CATEGORIES

3e. What are the top 3 reasons (Risk Categories from Table 1) you believe an energy performance contract would not meet the performance guarantee?

The purpose of this question was twofold. First, expertise was elicited from panelists about those risks that they believe have a significant contribution to not meeting guaranteed performance. This provided the opportunity to more deeply examine the sources of and controls used to manage these risks (as elicited by the next two questions). Second, this question was used to determine which risk categories were deemed by panelists as being most important in EPC retrofits. These categories would in turn be subjected to further analysis in this research.

Two measures of risk importance were used: (1) quartile analysis of the frequency with which a risk category was identified in this question and (2) the frequency with which risk categories were considered by each panelist. Using those two measures yielded the results shown in Table C-18.

Table C-18. Phase I Delphi Panel Risk Importance Rankings

Risk Category	Pareto/Quartile[a]	Consideration Frequency[a,b]
Energy audit quality	1 (10)	4/1 (95%/100%)
ECM selection and installation	2 (8)	1/1 (100%/100%)
Construction-specific concerns	2 (8)	4/1 (95%/100%)
Commissioning	4 (7)	1/1 (100%/100%)
Project development	5 (5)	4/1 (95%/100%)
M&V	5 (5)	1/1 (100%/100%)

Notes:

a\ Numbers in parentheses are the raw values (e.g., non-ranked) for each variable.

b\ Values are ranks with outliers retained (left of slash) and with outliers removed (right of slash).

While the quartile analysis and consideration frequency generally yielded results within the same range, outlier removal from the data set resulted in every one of the risk categories in the upper two quartiles for risk importance score being tied for the number one ranking. Further clarification was sought in round 2.

4a. For each of the risk categories identified in the previous question, what can cause these risks?

The focus of this research was on the evaluation of the most important risk categories, as determined by question 3e. As a result, risk causes and controls are published herein just for those risk categories. The complete list for all 12 risk categories is available by contacting the author at gberghorn@gmail.com. Risk causes and controls for the two risk categories selected for further analysis (IGA quality and ECM selection and installation) are provided in Table C-18.

4b. For each item listed, are there controls implemented that either prevent these risks, detect negative impacts of these risks if they occur, and/or mitigate these risks? If so, what is done? Are formal methods used (e.g., status meetings, project risk response audits, risk response planning, earned value analysis, none, or other)?

The focus of this research was on the evaluation of the most important risk categories, as determined by question 3e. As a result, risk causes and controls are published herein just for those risk categories. The complete list for all 12 risk categories is available by contacting the author at gberghorn@gmail.com. See Table C-19 for risk causes and controls for the two risk categories selected for further analysis (IGA quality and ECM selection and installation).

Table C-19. Risk Causes and Control Measures for Top Risk Categories

Risk Category	**Risk Causes**	**Risk Control Measures**
Energy Audit Quality	Existing Conditions • Facility age – code update • Misunderstanding existing conditions, such as possible presence of asbestos Facility Stakeholder Concerns • Differing stakeholder needs Inexperience • Failure to understand facility operations and EPC goal – lack of EPC experience Information and Analysis • Calculation errors • Conducting the IGA too quickly • Energy model calibration error • Inaccurate/incorrect or disputed baseline • Information availability and accuracy • Missing information • Missing risk assessment for each ECM Project Complexity and Guaranteed Savings • Establishment of the guarantee amount - difficult balance between providing a large-enough project to generate client excitement and ESCO value and hedging on savings • Overstatement of issues leading to mismatch with technical needs; understatement of issues leading to reduced project value	Existing Conditions • Complete set of facility drawings • Conduct a code review Information and Analysis • Complete set of facility drawings • Contingency factors • Identify risks for each ECM being evaluated and the entire ECM portfolio • Include potential but unverified concerns in the IGA • Interview all facility staff and back-brief them on the findings to "ground truth" the audit results and uncover any missing information • Third-party internal review based on historical projects Project Complexity and Guaranteed Savings • Contingency factors • Third-party external reviews • Use stipulation and IPMVP Option A wherever appropriate

Table C-19 (cont'd)

Risk Category	Risk Causes	Risk Control Measures
ECM Selection and Installation	Contractual Concerns • Owners and/or project designers and engineers are used to design-bid-build in the public sector and are not used to designing based on fixed budgets and do not understand EPC cost structures • Disconnect between the design and audit intent – improper efficiency target; different operating schedule implemented than what was planned; different control system installed • Subcontractor quality and reliability • Unqualified and unsafe contractors create additional risks ECM-Specific Issues • Cheapest equipment sometimes selected – leads to sub-optimal O&M savings • ECM package constructability and feasibility • ECMs are not aligned with the IGA findings • Failure to perform as designed • Uncertainty in factors used to predict performance Facility Factors • Installation location Occupant Concerns • Comfort complaints can add extra work after construction is complete • Lighting is difficult to demonstrate before installation; owner and occupants can be unhappy with light quality after a retrofit Project Complexity and Guaranteed Savings • "Low-hanging fruit has been picked" – increasing complexity of ECMs • Lowest-cost solutions may create value concerns during O&M Security Concerns (Correctional Facilities) • Accessibility to inmates/physical security	• Information – equipment-specific Contractual Concerns • Assign a team member to align outsourced design team with internal energy auditing team • Coordinate phase handoffs between project developer and energy engineer • Designate a team member to coordinate contractor and ESCO team members. • Pre-qualify subcontractors • Robust CM practices • Use ESCO's own forces for complex aspects of system design, whenever possible • Use EMR ratings to assess subcontractor safety ECM-Specific Issues • Identify risks for each ECM being evaluated and the entire ECM portfolio • In-house design teams for specialty ECMs (e.g., lighting) that can have complex design and performance issues Project Complexity and Guaranteed Savings • In-house design teams for specialty ECMs that can have complex design and performance issues

PART IV– LIFE CYCLE COST ANALYSIS

KNOWLEDGE CATEGORY 16 – USE OF LIFE CYCLE COST ANALYSIS

5a. How do you evaluate potential energy conservation measures individually and as a portfolio for inclusion in an energy performance contract? Do you use life cycle cost analysis? If so, how do you define parameters (discount rate, inflation rate, energy costs)? If not, why not? What performance periods are typically used?

Generally all panelists reported using life cycle cost analysis (LCCA) to achieve various project objectives during retrofit design. Reasons for including LCCA included the ESCO providing operations and maintenance (O&M) service during the life of the contract, the fact that some projects require repair and replacement costs to be included, and as a tool to educate clients about the impact that required reinvested costs (e.g., maintenance) have on overall project performance. One panelist reported using LCCA in only approximately 20% of projects, which are owned by the State of Washington, which requires the use of life cycle costing for energy projects. Other panelists reported using LCCA to analyze the impact of deferred maintenance related to the installation of new equipment, typically involving stipulated escalation rates, which must be mutually agreed upon by parties before the contract is signed. One panelist, an equipment manufacturer ESCO, reported that in addition to the traditional LCCA, an internally-focused analysis is conducted which focuses on the project's selling price, the project markup, the use of their own branded equipment, ongoing services to be provided during the project performance period, whether or not continuous commissioning will be used, and the amount and duration of measurement and verification (M&V) to be included.

Two panelists specifically reported limited use of LCCA during their projects' design. The panelists who reported using LCCA on 20% of projects, those owned by the State of Washington, stated that the other 80% of clients prefer the use of simple payback period (SPP). Since the ESCO generally does not install ECMs with less than a five year service life, the panelist reported a degree of comfort relying on the SPP. The second panelist reported that their firm does not use LCCA since they work for public agencies that are not making decisions based on net present value or return on investment. This participant reported that he considers the inflation of energy costs and matches it with the lease purchase payment in order to analyze project cash flow, and since equipment replacement horizons are typically longer than project performance periods, life cycle costs are less relevant and less of a concern. This was an anomalous response, and similar information was not elicited from any other experts.

Panelists reached consensus on typical contractual lengths of between 10 and 20 years, with 12-15 years being the most common. One panelist echoed information elicited from other participants earlier in the questionnaire, stating that shorter payback periods tend to result in projects with higher risks, because public owners typically want to maximize the scope of work for their retrofits, which means the ESCO typically needs a longer payback period over which to extend ECM costs.

KNOWLEDGE CATEGORY 17 – UNCERTAINTY IN LIFE CYCLE COST ANALYSIS

5b. Do you consider future uncertainty of life cycle cost analysis model parameters (discount rate, inflation rate, energy costs)? Uncertainty of project factors (cost growth, schedule growth, identified risk categories)?

Uncertainty was cited as an important factor to consider by several panelists. From an equipment perspective, future degradation must be considered and ESCOs must predict this "as best as possible." Equipment life cycle performance tables developed by ASHRAE and manufacturers' product data are typically used to help assess the likelihood of equipment failure and degraded performance. This reduced performance can also lead to degraded energy savings if not detected and mitigated in an appropriate amount of time. One panelist reported using Monte Carlo analysis to assist in developing a "hedge" value against cumulative project risks; however, he did not report the use of probabilistic functions in other aspects of the LCCA. Based on expertise elicited from panelists, the selected risk evaluation strategy must:

- Include probabilistic functions; and

- Incorporate uncertainty in other aspects of the analysis to help provide greater insight into potential project risks.

KNOWLEDGE CATEGORY 18 – INDIRECT COSTS IN LIFE CYCLE COST ANALYSIS

5c. Do you build sunk costs (e.g., project management during M&V, inclusion of costs for security/escort staff, some NEB-related work) and loss leaders (e.g., additional no-fee services, some NEB-related work) into these analyses? On what basis do you include values for these elements?

Indirect costs identified by panelists included project management costs, overhead costs, and unrecoverable costs related to the procurement and sales process. Panelists agreed that these costs are generally included in their financial analysis of projects, and typically results in their distribution over the total project cost. Typically in the MUSH market, these costs must be factored up-front because they cannot be addressed after the contract has been signed (i.e., no opportunity for change orders on EPC projects). Many of these costs can also be negotiated during the development phase.

KNOWLEDGE CATEGORY 19 – NON-ENERGY BENEFITS IN LIFE CYCLE COST ANALYSIS

5d. Are non-energy benefits included in this analysis (e.g., water conservation, O&M savings, avoided capital costs, tradable emissions credits, improved health/well-being/productivity)? If so, please describe. If not, why not?

Panelists reported a great deal of interest in non-energy benefits (NEBs), both from clients and as part of their business process. A significant driver of NEB inclusion is enabling legislation that can determine whether they can be used, and if so, what options are authorized. The majority of panelists include water conservation measures in their projects; however, they agreed that because this is based on a measurable utility, these retrofit measures are generally treated as an energy-related ECM. Other commonly-referenced NEBs included O&M savings, operational savings, capital cost avoidance, waste management savings, daylighting controls, and building renovations. Improved indoor air quality resulting from mechanical system upgrades in under-ventilated buildings was recognized as an NEB used on projects by one panelist; however, the participant indicated that this can actually result in increased energy consumption over the baseline, due to air change rate and airflow volume enhancements.

Panelists generally agreed that savings resulting from NEBs would only be included if they could be stipulated, based on an agreement between the ESCO and client. This was connected to the level of risk incurred by the ESCO, with one respondent stating they were “not going to have any risk associated with building it [the retrofit project]."

APPENDIX C.2

Detailed Analysis of Data Collected for Developing Life Cycle Cost-Based Risk Model in Delphi Round 2

PART II – PROFESSIONAL EXPERIENCE AND DETERMINATION OF EXPERTISE

KNOWLEDGE CATEGORY 2b – EPC PROJECT PHASES

2. Please select the EPC retrofit project phase or phases you most frequently support:
This question was asked in order to provide additional panelist background information. This was used to detect any potential relationships between panelist background characteristics and risk identification responses. Results are provided in Table CC-1. Panelist experience was heavily concentrated in earlier project phases (e.g., pre-execution).

Table CC-1. Project Phases Most Frequently Supported

Project Phase	**Responses**[a]
Project Development	13 (86.7%)
Energy Audit	8 (53.3%)
Retrofit Design	7 (46.7%)
Project Execution (Construction and Commissioning)	3 (20.0%)
Energy Savings (O&M and M&V)	5 (33.3%)
Other (please specify)[b]	4 (26.7%)

Notes:
a\ Panelists could select multiple phases to adequately describe which project elements they routinely worked on. As a result, the sum of responses was greater than the number of individual respondents.
b\ Responses of “other” included:

- Sales qualification
- Contract execution – negotiation and contract development
- Utility rebate program support
- Project selling and negotiating

PART III – RISK MANAGEMENT PROCESS

KNOWLEDGE CATEGORY 9 – RISK IDENTIFICATION

3. In the first survey, 11 participants identified a total of 10 new risks that were added to matrix that you responded to. The number in parentheses indicates the number of panelists identifying each new risk. Please indicate below whether you concur with the addition of each risk. You may refer to the risk matrix in the document that was attached to the email you received to see all of the other risk categories and individual risks. A comment field is available if you wish to add your thoughts.

Since consensus was not achieved for this question in the first Delphi round, panelists were provided with a list of the newly identified risks and asked whether or not they agreed with its inclusion – results are shown in Table CC-2.

Table CC-2. Additional Risks Identified by Panelists

		Delphi Consensus Status			
		1st Round		**2nd Round**	
Risk	**Disposition**	**N**	**%**	**%**	**Consensus**
Political Risks	Moved to individual risk under "Client Selection Risks - People Factors"	4	21%	100%	Achieved
Productivity Losses in Corrections Projects	Moved to individual risk under "Construction Phase Risks"	1	5%	87%	Achieved
Safety		1	5%	60%	Not Achieved
Changing Financial Incentives	Moved to individual risk under "Development Phase Risks"	1	5%	80%	Achieved
Cost of Doing Nothing or Self-Implementing		1	5%	80%	Achieved
Public Procedural Risks		1	5%	73%	Achieved
Time-Based Risk		2	11%	73%	Achieved
Timing		1	5%	73%	Achieved
Design Development	Moved to individual risk under "Energy Audit Quality"	1	5%	67%	Not Achieved
Staff Turnover During Project Lifecycle	Moved into individual risk under "Project Management Over the Project Life Cycle"	1	5%	80%	Achieved
Perception of the Performance Contracting Industry	Create New Risk Category	2	11%	100%	Achieved

Consensus was achieved for all but two risks, thus excluding them from further analysis.

4. Two participants identified a risk which did not fall under any existing risk category. The new risk category was identified as "Perception of the Performance Contracting Industry" and included two concerns:

- **Lack of knowledge regarding EPC enabling statutes by the ESCO limits some customers' understanding of how they can use EPC.**
- **Unethical behavior negatively impacts the industry as a whole.**

Please rank the frequency with which you consider this risk on your projects. As with the first interview, consideration means that you address these risks contractually, by project management, through technical means, or via financial assurance.
100% of panelists agreed with the inclusion of this as a new risk category.

KNOWLEDGE CATEGORY 10 – MUSH MARKET-SPECIFIC RISKS

5. 78% of panelists believe that MUSH market EPC retrofits have a higher level of project risk than commercial and industrial sector EPC retrofits. Panelists provided five MUSH market facility types that they believed had higher levels of risk than other buildings in the MUSH market. Which facility types do you believe have higher levels of project risk (select all that apply)?

As a result of the open-ended responses obtained from several participants during the first round, in the second Delphi round panelists were asked to identify which MUSH market facility types had the greatest project risk profiles. Facility types included correctional facilities, hospitals, K-12 schools, mission-critical facilities, and continuously operated facilities; the latter facility type was inclusive of correctional facilities and hospitals, which operate continuously by definition. The percentage of responses for each facility type was 67%, 47%, 13%, 53%, and 47%, respectively. When accounting for respondents who did not identify correctional facilities, but did identify the inclusive category of continuously operated facilities, the response frequency increased from 67% to 87%. As a result, it is reasonable to conclude that MUSH market EPC retrofits in general, and correctional facility projects specifically, have a higher project risk profile than other markets and building and types.

KNOWLEDGE CATEGORY 15 – IDENTIFICATION OF MOST IMPORTANT RISK CATEGORIES

6. In the first survey, you were asked to identify the three most important risk categories you consider when developing and implementing MUSH market EPC retrofit projects. Based on your importance scoring, the top 6 risk categories are listed below. Importance scores are in parentheses next to each risk category. Please rank these from 1 to 6, with a score of 1 indicating the most important risk category to consider (as one panelist stated, "the things that keep me awake at night when I have a project underway") and a score of 6 indicating the least important among these 6.

A third data column was added to Table C-18, representing the Delphi round 2 responses to this question, and is presented below as Table CC-3. Rank order agreement across two or more categories was deemed as consensus that a risk category received an equivalent risk importance score. As a result of this, four risk categories achieved consensus (energy audit quality, ECM selection and installation, commissioning, and M&V), while two did not (construction specific concerns and project development).

Table CC-3. Risk Importance Ranking – Round 1 and Round 2 Delphi Panel Data

Risk Category	Pareto/Quartile	Consideration Frequency[b]	Delphi Round 2
Energy audit quality	1 (10)	4/1 (95%/100%)	1 (2.4)
ECM selection and installation	2 (8)	1/1 (100%/100%)	2 (3.0)
Construction-specific concerns	2 (8)	4/1 (95%/100%)	6 (3.9)
Commissioning	4 (7)	1/1 (100%/100%)	4 (3.6)
Project development	5 (5)	4/1 (95%/100%)	3 (3.1)
M&V	5 (5)	1/1 (100%/100%)	5 (3.7)

Notes:
a\ Numbers in parentheses are the raw values (e.g., non-ranked) for each variable.
b\ Ranks with outliers retained - left of the slash; ranks with outliers removed - right of the slash.

KNOWLEDGE CATEGORY 11 – RISK IDENTIFICATION - METHODS

7. Please select which method or methods you use to identify risks during projects.

This question was follow-up from open-ended responses in round 1 of the Delphi survey. Participants were provided with a list of risk identification measures described by Grimaldi et al. (2012) and Thaheem and DeMarco (2013) in order to provide better-defined response categories. The most frequently cited risk identification methods were expertise/expert judgement; brainstorming; checklist; and risk mapping, risk matrix, probability and impact matrix (Table CC-4). This placed the majority of respondent firms as being in either the “novice,” “normalized,” or “natural” categories of corporate maturity toward risk management (Grimaldi et al. 2012). A natural level of maturity is described as having integration between project management and risk management.

Table CC-4. Risk Identification Methods Used by Delphi Panelists

Risk Identification Method	**Responses**
Brainstorming	11
Cause and Effect Diagram/Ishikawa Diagram	1
Checklist	11
Delphi	0
Expertise/Expert Judgement	12
Failure Mode and Effects Analysis (FMEA)	2
Interviewing	6
Monte Carlo Simulation	0
Risk Mapping, Risk Matrix, Probability and Impact Matrix	7
Root Cause Analysis	1
Sensitivity Analysis	4
Strengths, Weaknesses, Opportunities, and Threats (SWOT)	4
None	2
Internal Tool	1

KNOWLEDGE CATEGORY 14 – RISK EVALUATION - METHODS

8. Please select which method or methods you use to analyze risks during projects. Risk analysis is defined as determining the level of impact that a risk has on the project.

This question was follow-up from open-ended responses in round 1 of the Delphi survey. Participants were provided with a list of risk analysis and evaluation measures described by Grimaldi et al. (2012) and Thaheem and DeMarco (2013) in order to provide better-defined response categories. The most frequently cited risk analysis and evaluation methods were expertise/expert judgement; brainstorming; checklist; and risk mapping, risk matrix, probability and impact matrix, which was identical to responses for risk identification (Table CC-5). Since firms undertaking risk analysis and evaluation are not considered to be “novice” with regard to risk management, the majority of respondent firms were classified as either “normalized” or natural (Grimaldi et al. 2012).

Table CC-5. Risk Evaluation Methods Used by Delphi Panelists	
Risk Evaluation Method	**Responses**
Brainstorming	9
Cause and Effect Diagram/Ishikawa Diagram	1
Checklist	8
Decision Tree Analysis	3
Delphi	0
Expected Monetary Value	6
Expertise/Expert Judgement	9
Failure Mode and Effects Analysis (FMEA)	2
Interviewing	5
Monte Carlo Simulation	1
Risk Mapping, Risk Matrix, Probability and Impact Matrix	8
Strengths, Weaknesses, Opportunities, and Threats (SWOT)	4
None	2
Internal Tool	1

As a result of the expertise elicited from ESCO professionals, the risk evaluation method selected for this research must meet the following objectives:

- Include expertise;
- Incorporate costs related to project risks as a consistent framework for evaluation; and
- Utilize probabilistic functions, where possible.

APPENDIX D

SFMEA Panel Results

Occurrence, Severity, and Detection Rank Tables

Table D-1. Failure Mode Occurrence Rank Table

Likelihood of Failure	Criteria: Occurrence of Causes	Rank
Very High	90+ in 100 projects	10
High	80 in 100 projects	9
	70 in 100 projects	8
	60 in 100 projects	7
Moderate	50 in100 projects	6
	40 in 100 projects	5
	30 in 100 projects	4
Low	20 in 100 projects	3
	10 in 100 projects	2
Very Low	<1 in 100 projects	1

Table D-2. Failure Mode Severity Rank Table

Effect	Criteria: Severity of Effect on Project	Rank
Failure to Meet Safety or Regulatory Requirements	May endanger lives of personnel.	10
Major Project Impact	May singularly lead to failure to achieve performance guarantee or endanger safety of personnel.	9
	Requires changes to the scope of work based on client requirements and project goals; may endanger future working relationship.	8
	Requires recalculation of energy guarantee.	7
Moderate Project Impact	Requires recalculation of key IGA elements/findings or similar.	6
	Inconvenience to ESCO staff and client staff time or after execution phase.	5
	Inconvenience to ESCO staff time in or after execution phase.	4
Minor Project Impact	Slight inconvenience to ESCO staff and client staff time in earliest project phases.	3
	Slight inconvenience to ESCO staff time in earliest project phases.	2
No effect	No effect.	1

Table D-3. Failure Mode Likelihood Rank Table

Detection Likelihood and Early Project Phase Timing	**Criteria: Likelihood and Timing of Detection**	**Rank**
Almost impossible to detect until execution phase commences	Cannot detect until after energy guarantee and price guarantee have been fixed by ESCO.	10
Very remote chance of detection before execution phase	Slight chance of detection before energy guarantee and price guarantee have been fixed by ESCO, but only through significant additional scope completed by ESCO.	9
Remote	Failure mode *may be* detected before entering execution through past project experience.	8
Very low	Failure mode *may be* detected before entering execution through modeled results.	7
Low	Failure mode *may be* detected before entering execution through a combination of visual inspection, laboratory testing, or direct measurement/observation.	6
Moderate	Failure mode *is* detected before entering execution through past project experience.	5
Moderately high	Failure mode *is* detected before entering execution through modeled results.	4
High	Failure mode *is* detected before entering execution through a combination of visual inspection, laboratory testing, or direct measurement/observation.	3
Very high	Design solutions have been highly correlated with early detection ability in previous projects of a similar type.	2
Almost certain	Failure mode cannot occur because it is addressed fully through design solutions.	1

SFMEA Worksheets

Table D-4. Panelist Consensus SFMEA Worksheet

	Cause	**%Likelihood Cause**	**Occurrence**	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**	**Severity**	**Detection**	**RPN**	**% Likelihood End Effect**	**Cost**
1A1	Misunderstanding Existing Conditions	1.0	10	Presence of Asbestos-Containing Materials (ACM)			Remove/ Modify	7	7	490	1	1
1A2	Misunderstanding Existing Conditions	1.0	9	Presence of Asbestos-Containing Materials (ACM)			Manage in Place	9	5	405	0.0	0.0
1A3	Misunderstanding Existing Conditions	1.0	10	Presence of Lead-Based Paint			Remove/ Modify	7	4	280	0.3	0.3
1A4	Misunderstanding Existing Conditions	1.0	9	Presence of Lead-Based Paint			Manage in Place	9	5	405	0.7	0.7
1A5	Misunderstanding Existing Conditions	0.8	9	Presence of Fuel-Related Contaminants			Remove/ Modify	8	3	216	1	1
1A6	Misunderstanding Existing Conditions	0.8	10	Presence of Fuel-Related Contaminants			Manage in Place	7	5	350	0.0	0.0
1A7	Misunderstanding Existing Conditions	0.8	9	Presence of Buried Infrastructure			Remove/ Modify	8	3	216	0.4	0.4
1A8	Misunderstanding Existing Conditions	0.8	10	Presence of Buried Infrastructure			Manage in Place	7	3	210	0.6	0.6

Table D-4 (cont’d)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1B1	Facility Age and Current Code Requirements	0.73	9	Fire Suppression and Alarm System Upgrades			Modify Affected System(s)	8	3	216	0.75	0.75
1B2	Facility Age and Current Code Requirements	0.9	9	Electrical System Upgrades			Modify Affected System(s)	7	5	315	0.9	0.9
1B3	Facility Age and Current Code Requirements	0.8	9	Plumbing System Upgrades			Modify Affected System(s)	7	3	189	1	1
1B4	Facility Age and Current Code Requirements	0.78	9	Mechanical System Upgrades			Modify Affected System(s)	7	5	315	0.73	0.73
1B5	Facility Age and Current Code Requirements	0.2	9	Universal Access (ADA) Upgrades			Modify Affected System(s)	9	7	567	0.1	0.1
1B6	Facility Age and Current Code Requirements	1.0	8	OSHA-Related Upgrades			Modify Affected System(s)	8	4	256	0.55	0.55
1B7	Facility Age and Current Code Requirements	0.95	8	Specialty-Standard Upgrades			Modify Affected System(s)	7	4	224	0.33	0.33
1C1	Overstatement of Issues	0.28	9	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	7	5	315	0.8	0.8
1C2	Overstatement of Issues	0.28	8	Improper Equipment Repurposing			Difficulty Getting Financing	7	5	280	0.28	0.28

Table D-4 (cont’d)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1C3	Overstatement of Issues	0.28	9	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	7	4	252	0.23	0.23
1C4	Overstatement of Issues	0.28	9	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	7	4	252	0.55	0.55
1C5	Understatement of Issues	0.53	7	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	8	6	336	0.5	0.5
1C6	Understatement of Issues	0.53	9	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	7	6	378	0.25	0.25
1C7	Understatement of Issues	0.53	9	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	7	4	252	0.55	0.55
1C8	Understatement of Issues	0.53	7	Missed Opportunities	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	8	4	224	0.6	0.6

Table D-4 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1D1	ESCO Lack of Experience with Facility Type	0.6	8	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M		Missed Opportunity for O&M Contract	9	5	360	0.4	0.4
1D2	ESCO Lack of Experience with Facility Type	0.6	8	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Reduced Project Value for ESCO	7	4	224	0.45	0.45
1D3	ESCO Lack of Experience with Facility Type	0.6	8	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Savings Shortfall/ Erosion of ESCO's Margin	8	6	384	0.23	0.23
1D4	ESCO Lack of Experience with Facility Type	0.6	9	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Baseline	Savings Shortfall/ Erosion of ESCO's Margin	8	6	432	0.33	0.33
1D5	ESCO Lack of Experience with Facility Type	0.6	7	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Retrofit Design	Savings Shortfall/ Erosion of ESCO's Margin	7	5	245	0.45	0.45
1D6	ESCO Lack of Experience with Facility Type	0.6	7	Failure to Understand Facility Operations and Client Goals	Improper Construction Timing and Phasing	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	7	5	245	0.6	0.6

Table D-4 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1D7	ESCO Lack of Experience with Facility Type	0.6	5	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	9	5	225	0.6	0.6
1D8	ESCO Lack of Experience with Facility Type	0.6	4	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin	8	7	224	0.75	0.75
1D9	ESCO Lack of Experience with Facility Type	0.6	5	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	8	7	280	0.48	0.48
1D10	ESCO Lack of Experience with Facility Type	0.6	6	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin	9	8	432	0.45	0.45
1D11	ESCO Lack of Experience with Facility Type	0.6	6	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Occupant Use of Equipment for Other Purposes	Legal Impacts	8	7	336	0.16	0.16

Table D-4 (cont'd)

	Cause	**%Likelihood Cause**	**Occurrence**	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**	**Severity**	**Detection**	**RPN**	**% Likelihood End Effect**	**Cost**
1E1	Differing Stakeholder Needs	0.52	8	Inconsistent Information About Facility Operating Parameters (e.g., too hot, too cold, too much airflow, not enough airflow)	Retrofit Design Does Not Satisfy All Stakeholders	User Modification of ECMs/Override Operating Parameters	Savings Shortfall/ Erosion of ESCO's Margin	7	4	224	0.65	0.65
1E2	Differing Stakeholder Needs	0.52	6	Codes and Standards Upgrades	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin	8	6	288	0.4	0.4
1E3	Differing Stakeholder Needs	0.52	7	Codes and Standards Upgrades	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity	Savings Shortfall/ Erosion of ESCO's Margin	7	4	196	0.4	0.4
1E4	Differing Stakeholder Needs	0.52	7	Increased Project Complexity	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin	6	3	126	0.65	0.65
1E5	Differing Stakeholder Needs	0.52	7	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity		Savings Shortfall/ Erosion of ESCO's Margin	7	8	392	0.6	0.6

Table D-4 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1F1	IGA Conducted Too Quickly	0.53	9	Miss Critical Functions and Savings Opportunities			Savings Shortfall/ Erosion of ESCO's Margin	5	5	225	0.85	0.85
1F2	IGA Conducted Too Quickly	0.53	8	Miscount Existing Equipment (e.g., Lights)			Savings Shortfall/ Erosion of ESCO's Margin	8	4	256	0.6	0.6
1F3	IGA Conducted Too Quickly	0.53	6	Miscount Existing Equipment (e.g., Lights)	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	6	6	216	0.75	0.75
1F4	IGA Conducted Too Quickly	0.53	5	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	8	4	160	0.85	0.85
1F5	IGA Conducted Too Quickly	0.53	9	Missing Facility Information	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	8	8	576	0.9	0.9
1F6	IGA Conducted Too Quickly	0.53	6	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin	5	5	150	0.9	0.9

Table D-4 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1F7	Facility Information Unavailable/ Inaccurate	0.73	9	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	8	8	576	0.7	0.7
1F8	Facility Information Unavailable/ Inaccurate	0.73	6	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin	5	5	150	0.7	0.7
2A1	Security Concerns	0.8	4	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment	Rework	Savings Shortfall/ Erosion of ESCO's Margin	7	6	168	0.7	0.7
2A2	Security Concerns	0.8	7	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment		Savings Shortfall/ Erosion of ESCO's Margin	5	6	210	0.7	0.7
2A3	Security Concerns	0.8	6	Technology Breakage/ Damage Possibility by Occupants	Equipment Impacts	Total Costs of Operation	Savings Shortfall/ Erosion of ESCO's Margin	7	6	252	0.48	0.48
2A4	Security Concerns	0.8	7	Technology Breakage/ Damage Possibility by Occupants	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	7	6	294	0.15	0.15
2A5	Security Concerns	0.8	7	Occupant Use of Equipment for Other Purposes			Legal Impacts	8	6	336	0.1	0.1

Table D-4 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2B1	Reduced Availability of "Low Hanging Fruit"	0.8	7	Increase in Project Complexity	Limited/Less Attractive Scope	Increased Opportunity for Diminished Savings	Savings Shortfall/ Erosion of ESCO's Margin	5	4	140	0.8	0.8
2B2	Reduced Availability of "Low Hanging Fruit"	0.8	7	Increase in Project Costs	IGA Scope Increase (No Additional Fee)		Savings Shortfall/ Erosion of ESCO's Margin	5	4	140	0.8	0.8
2B3	Reduced Availability of "Low Hanging Fruit"	0.8	8	Less Opportunity for Non-Energy Benefits (NEBs)	Project Schedule Impacted		Savings Shortfall/ Erosion of ESCO's Margin	5	7	280	0.8	0.8
2CD1	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.85	3	Failure to Meet Owner Project Requirements	Rework		Savings Shortfall/ Erosion of ESCO's Margin	6	8	144	0.68	0.68
2CD2	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.85	7	Failure to Meet Owner Project Requirements	Comfort Complaints		Savings Shortfall/ Erosion of ESCO's Margin	6	5	210	0.55	0.55
2CD3	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.85	6	Failure to Meet Owner Project Requirements			Savings Shortfall/ Erosion of ESCO's Margin	5	5	150	0.68	0.68

Table D-4 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2CD4	Operational Concerns	0.55	7	Failure to Meet Owner Project Requirements	Reduce Project Scope		Savings Shortfall/ Erosion of ESCO's Margin	6	7	294	0.45	0.45
2CD5	Safety Concerns	0.35	5	Failure to Meet Owner Project Requirements	Safety Incident		Legal Impacts	5	5	125	0.15	0.15
2E1	Unqualified Subcontractors	0.4	4	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	6	4	96	0.65	0.65
2E2	Unqualified Subcontractors	0.4	4	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin	7	6	168	0.25	0.25
2E3	Unqualified Subcontractors	0.4	7	Unsafe Working Conditions/Injuries	Safety Incident		Legal Impacts	7	5	245	0.15	0.15
2E4	Unreliable Subcontractors	0.3	8	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	6	6	288	0.4	0.4
2E5	Unreliable Subcontractors	0.25	4	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin	6	4	96	0.15	0.15

Table D-4 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2E6	Unreliable Subcontractors	0.3	3	Project Schedule Impacted			Savings Shortfall/ Erosion of ESCO's Margin	6	5	90	0.5	0.5
2F1	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.75	3	Require ESCO to use Fixed Overhead & Profit Rates	Overstate Project Soft Costs		Savings Shortfall/ Erosion of ESCO's Margin	6	4	72	0.75	0.75
2F2	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.75	4	Divide Procurement into Separate Phases	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin	4	5	80	0.48	0.48
2F3	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.75	3	Incorrect Vendor Selection	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin	4	5	60	0.78	0.78
2G1	Select Cheapest Available Equipment to Meet Specifications	0.5	6	Increased O&M Cost			Savings Shortfall/ Erosion of ESCO's Margin	7	5	210	0.5	0.5
2G2	Select Cheapest Available Equipment to Meet Specifications	0.5	5	Reduced Equipment Service Life			Savings Shortfall/ Erosion of ESCO's Margin	2	8	80	0.33	0.33

Table D-4 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2G3	Actual Climate Conditions Outside Range of Planned Conditions	0.28	6	Uncertainty in Factors Used to Predict Performance	Reduced Equipment Service Life		Savings Shortfall/ Erosion of ESCO's Margin	6	4	144	0.18	0.18
2G4	Actual Climate Conditions Outside Range of Planned Conditions	0.28	3	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin	5	3	45	0.48	0.48
2G5	ECM Constructability & Feasibility Issues	0.45	3	Uncertainty in Factors Used to Predict Performance	Reduced Energy Performance		Savings Shortfall/ Erosion of ESCO's Margin	3	4	36	0.45	0.45
2G6	ECM Constructability & Feasibility Issues	0.45	2	Rework			Savings Shortfall/ Erosion of ESCO's Margin	2	3	12	0.2	0.2
2G7	ECM Failure to Perform as Designed	0.24	10	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin	5	6	300	0.48	0.48
2G8	ECM Failure to Perform as Designed	0.24	9	Rework			Savings Shortfall/ Erosion of ESCO's Margin	4	4	144	0.2	0.2

Table D-5. Panelist RP-01-E SFMEA Worksheet

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1A1	Misunderstanding Existing Conditions	1	10	Presence of Asbestos-Containing Materials (ACM)			Remove/ Modify	9	4	360	1.0	0.20
1A2	Misunderstanding Existing Conditions	1	10	Presence of Asbestos-Containing Materials (ACM)			Manage in Place	10	9	900	0.0	0.10
1A3	Misunderstanding Existing Conditions	1	10	Presence of Lead-Based Paint			Remove/ Modify	4	10	400	0.5	0.05
1A4	Misunderstanding Existing Conditions	1	10	Presence of Lead-Based Paint			Manage in Place	10	10	1000	0.5	0.025
1A5	Misunderstanding Existing Conditions	0.8	9	Presence of Fuel-Related Contaminants			Remove/ Modify	10	5	450	1.0	0.10
1A6	Misunderstanding Existing Conditions	0.8	9	Presence of Fuel-Related Contaminants			Manage in Place	5	5	225	0.0	0.025
1A7	Misunderstanding Existing Conditions	0.9	10	Presence of Buried Infrastructure			Remove/ Modify	5	5	250	0.5	0.05
1A8	Misunderstanding Existing Conditions	0.9	10	Presence of Buried Infrastructure			Manage in Place	5	5	250	0.5	0.25
1B1	Facility Age and Current Code Requirements	0.7	8	Fire Suppression and Alarm System Upgrades			Modify Affected System(s)	8	1	64	1	0.1
1B2	Facility Age and Current Code Requirements	1	10	Electrical System Upgrades			Modify Affected System(s)	7	2	140	1	0.15

Table D-5 (cont'd)

	Cause	**%Likelihood Cause**	**Occurrence**	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**	**Severity**	**Detection**	**RPN**	**% Likelihood End Effect**	**Cost**
1B3	Facility Age and Current Code Requirements	1	10	Plumbing System Upgrades			Modify Affected System(s)	6	6	360	1	0.2
1B4	Facility Age and Current Code Requirements	0.8	9	Mechanical System Upgrades			Modify Affected System(s)	5	4	180	1	0.05
1B5	Facility Age and Current Code Requirements	0.1	2	Universal Access (ADA) Upgrades			Modify Affected System(s)	2	8	32	0.25	0.05
1B6	Facility Age and Current Code Requirements	1	10	OSHA-Related Upgrades			Modify Affected System(s)	6	3	180	1	0.05
1B7	Facility Age and Current Code Requirements	0.9	10	Specialty-Standard Upgrades			Modify Affected System(s)	2	9	180	0.5	0.1
1C1	Overstatement of Issues	0.8	9	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	7	4	252	0.05	0.025
1C2	Overstatement of Issues	0.8	9	Improper Equipment Repurposing			Difficulty Getting Financing	2	8	144	0.01	0.01
1C3	Overstatement of Issues	0.8	9	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	8	5	360	0.05	0.1

Table D-5 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1C4	Overstatement of Issues	0.8	9	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	5	6	270	0.025	0.025
1C5	Understatement of Issues	0.8	9	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	8	3	216	0.25	0.1
1C6	Understatement of Issues	0.8	9	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	6	3	162	0.25	0.1
1C7	Understatement of Issues	0.8	9	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	8	2	144	0.3	0.25
1C8	Understatement of Issues	0.8	9	Missed Opportunities	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	9	2	162	0.1	0.05
1D1	ESCO Lack of Experience with Facility Type	0.7	8	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M		Missed Opportunity for O&M Contract	7	3	168	0.5	0.05
1D2	ESCO Lack of Experience with Facility Type	0.7	8	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Reduced Project Value for ESCO	8	6	384	0.4	0.05

Table D-5 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1D3	ESCO Lack of Experience with Facility Type	0.7	8	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Savings Shortfall/ Erosion of ESCO's Margin	8	6	384	0.1	0.075
1D4	ESCO Lack of Experience with Facility Type	0.7	8	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Baseline	Savings Shortfall/ Erosion of ESCO's Margin	9	6	432	0.4	0.25
1D5	ESCO Lack of Experience with Facility Type	0.7	8	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Retrofit Design	Savings Shortfall/ Erosion of ESCO's Margin	7	4	224	0.15	0.10
1D6	ESCO Lack of Experience with Facility Type	0.7	8	Failure to Understand Facility Operations and Client Goals	Improper Construction Timing and Phasing	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	7	3	168	0.5	0.10
1D7	ESCO Lack of Experience with Facility Type	0.7	8	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	8	2	128	0.5	0.33
1D8	ESCO Lack of Experience with Facility Type	0.7	8	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin	8	3	192	0.75	0.40

Table D-5 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1D9	ESCO Lack of Experience with Facility Type	0.7	8	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	7	6	336	0.25	0.50
1D10	ESCO Lack of Experience with Facility Type	0.7	8	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin	6	5	240	0.2	0.50
1D11	ESCO Lack of Experience with Facility Type	0.7	8	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Occupant Use of Equipment for Other Purposes	Legal Impacts	5	5	200	0.2	0.25
1E1	Differing Stakeholder Needs	0.7	8	Inconsistent Information About Facility Operating Parameters (e.g., too hot, too cold, too much airflow, not enough airflow)	Retrofit Design Does Not Satisfy All Stakeholders	User Modification of ECMs/Override Operating Parameters	Savings Shortfall/ Erosion of ESCO's Margin	8	2	128	0.5	0.5
1E2	Differing Stakeholder Needs	0.7	8	Codes and Standards Upgrades	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin	8	3	192	0.5	0.4
1E3	Differing Stakeholder Needs	0.7	8	Codes and Standards Upgrades	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity	Savings Shortfall/ Erosion of ESCO's Margin	7	4	224	0.4	0.4

Table D-5 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1E4	Differing Stakeholder Needs	0.7	8	Increased Project Complexity	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin	8	3	192	0.6	0.3
1E5	Differing Stakeholder Needs	0.7	8	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity		Savings Shortfall/ Erosion of ESCO's Margin	8	3	192	0.6	0.2
1F1	IGA Conducted Too Quickly	0.8	9	Miss Critical Functions and Savings Opportunities			Savings Shortfall/ Erosion of ESCO's Margin	9	2	162	0.8	0.2
1F2	IGA Conducted Too Quickly	0.8	9	Miscount Existing Equipment (e.g., Lights)			Savings Shortfall/ Erosion of ESCO's Margin	9	2	162	0.8	0.2
1F3	IGA Conducted Too Quickly	0.8	9	Miscount Existing Equipment (e.g., Lights)	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	9	3	243	0.8	0.3
1F4	IGA Conducted Too Quickly	0.8	9	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	8	3	216	0.8	0.3

Table D-5 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1F5	IGA Conducted Too Quickly	0.8	9	Missing Facility Information	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	8	3	216	0.9	0.3
1F6	IGA Conducted Too Quickly	0.8	9	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin	8	3	216	0.9	0.3
1F7	Facility Information Unavailable/ Inaccurate	0.8	9	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	7	2	126	0.5	0.5
1F8	Facility Information Unavailable/ Inaccurate	0.8	9	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin	7	2	126	0.5	0.5
2A1	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment	Rework	Savings Shortfall/ Erosion of ESCO's Margin	7	4	252	0.7	0.25
2A2	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment		Savings Shortfall/ Erosion of ESCO's Margin	6	8	432	0.7	0.25

Table D-5 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2A3	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Equipment Impacts	Total Costs of Operation	Savings Shortfall/ Erosion of ESCO's Margin	5	3	135	0.2	0.1
2A4	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	3	7	189	0.1	0.1
2A5	Security Concerns	0.8	9	Occupant Use of Equipment for Other Purposes			Legal Impacts	2	4	72	0.1	0.1
2B1	Reduced Availability of “Low Hanging Fruit”	0.90	10	Increase in Project Complexity	Limited/Less Attractive Scope	Increased Opportunity for Diminished Savings	Savings Shortfall/ Erosion of ESCO's Margin	9	5	450	0.8	0.8
2B2	Reduced Availability of “Low Hanging Fruit”	0.90	10	Increase in Project Costs	IGA Scope Increase (No Additional Fee)		Savings Shortfall/ Erosion of ESCO's Margin	6	5	300	0.8	0.75
2B3	Reduced Availability of “Low Hanging Fruit”	0.90	10	Less Opportunity for Non-Energy Benefits (NEBs)	Project Schedule Impacted		Savings Shortfall/ Erosion of ESCO's Margin	4	7	280	0.8	0.9
2CD1	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.90	10	Failure to Meet Owner Project Requirements	Rework		Savings Shortfall/ Erosion of ESCO's Margin	6	6	360	0.75	0.2

Table D-5 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2CD2	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.90	10	Failure to Meet Owner Project Requirements	Comfort Complaints		Savings Shortfall/ Erosion of ESCO's Margin	7	8	560	0.2	0.25
2CD3	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.90	10	Failure to Meet Owner Project Requirements			Savings Shortfall/ Erosion of ESCO's Margin	8	6	480	0.75	0.2
2CD4	Operational Concerns	0.70	8	Failure to Meet Owner Project Requirements	Reduce Project Scope		Savings Shortfall/ Erosion of ESCO's Margin	4	4	128	0.1	0.2
2CD5	Safety Concerns	0.70	8	Failure to Meet Owner Project Requirements	Safety Incident		Legal Impacts	3	4	96	0.2	0.1
2E1	Unqualified Subcontractors	0.8	9	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	8	3	216	0.8	0.2
2E2	Unqualified Subcontractors	0.8	9	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin	6	4	216	0.5	0.1
2E3	Unqualified Subcontractors	0.8	9	Unsafe Working Conditions/Injuries	Safety Incident		Legal Impacts	3	2	54	0.1	0.1

Table D-5 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2E4	Unreliable Subcontractors	0.15	2	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	7	8	112	0.4	0.2
2E5	Unreliable Subcontractors	0.15	2	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin	2	2	8	0.1	0.1
2E6	Unreliable Subcontractors	0.15	2	Project Schedule Impacted			Savings Shortfall/ Erosion of ESCO's Margin	3	2	12	0.1	0.1
2F1	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.8	9	Require ESCO to use Fixed Overhead & Profit Rates	Overstate Project Soft Costs		Savings Shortfall/ Erosion of ESCO's Margin	7	5	315	0.75	0.2
2F2	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.8	9	Divide Procurement into Separate Phases	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin	9	2	162	0.8	0.5
2F3	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.8	9	Incorrect Vendor Selection	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin	9	3	243	0.8	0.5

Table D-5 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2G1	Select Cheapest Available Equipment to Meet Specifications	0.5	6	Increased O&M Cost			Savings Shortfall/ Erosion of ESCO's Margin	8	2	96	0.3	0.25
2G2	Select Cheapest Available Equipment to Meet Specifications	0.5	6	Reduced Equipment Service Life			Savings Shortfall/ Erosion of ESCO's Margin	3	3	54	0.4	0.5
2G3	Actual Climate Conditions Outside Range of Planned Conditions	0.6	7	Uncertainty in Factors Used to Predict Performance	Reduced Equipment Service Life		Savings Shortfall/ Erosion of ESCO's Margin	5	4	140	0.1	0.10
2G4	Actual Climate Conditions Outside Range of Planned Conditions	0.6	7	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin	4	6	168	0.05	0.05
2G5	ECM Constructability & Feasibility Issues	0.5	6	Uncertainty in Factors Used to Predict Performance	Reduced Energy Performance		Savings Shortfall/ Erosion of ESCO's Margin	2	9	108	0.05	0.05
2G6	ECM Constructability & Feasibility Issues	0.5	6	Rework			Savings Shortfall/ Erosion of ESCO's Margin	2	8	96	0.05	0.025

Table D-5 (cont'd)

	Cause	**%Likelihood Cause**	**Occurrence**	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**	**Severity**	**Detection**	**RPN**	**% Likelihood End Effect**	**Cost**
2G7	ECM Failure to Perform as Designed	0.02	1	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin	2	2	4	0.05	0.025
2G8	ECM Failure to Perform as Designed	0.02	1	Rework			Savings Shortfall/ Erosion of ESCO's Margin	7	5	35	0.05	0.1

Table D-6. Panelist RP-02-E SFMEA Worksheet

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1A1	Misunderstanding Existing Conditions	1	10	Presence of Asbestos-Containing Materials (ACM)			Remove/ Modify	6	2	120	0.625	0.12
1A2	Misunderstanding Existing Conditions	1	10	Presence of Asbestos-Containing Materials (ACM)			Manage in Place	4	2	80	0.4	0.05
1A3	Misunderstanding Existing Conditions	1	10	Presence of Lead-Based Paint			Remove/ Modify	5	6	300	0.3	0.03
1A4	Misunderstanding Existing Conditions	1	10	Presence of Lead-Based Paint			Manage in Place	5	6	300	0.8	0.03
1A5	Misunderstanding Existing Conditions	0.8	9	Presence of Fuel-Related Contaminants			Remove/ Modify	7	3	189	1	0.1
1A6	Misunderstanding Existing Conditions	0.8	9	Presence of Fuel-Related Contaminants			Manage in Place	7	3	189	0.0	0.1
1A7	Misunderstanding Existing Conditions	0.75	8	Presence of Buried Infrastructure			Remove/ Modify	6	6	288	0.5	0.1
1A8	Misunderstanding Existing Conditions	0.75	8	Presence of Buried Infrastructure			Manage in Place	5	6	240	0.5	0.06
1B1	Facility Age and Current Code Requirements	0.75	8	Fire Suppression and Alarm System Upgrades			Modify Affected System(s)	6	6	288	0.5	0.05
1B2	Facility Age and Current Code Requirements	1	10	Electrical System Upgrades			Modify Affected System(s)	7	5	350	0.8	0.08

Table D-6 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1B3	Facility Age and Current Code Requirements	0.8	9	Plumbing System Upgrades			Modify Affected System(s)	6	4	216	0.2	0.05
1B4	Facility Age and Current Code Requirements	0.8	9	Mechanical System Upgrades			Modify Affected System(s)	6	3	162	0.5	0.05
1B5	Facility Age and Current Code Requirements	0.2	3	Universal Access (ADA) Upgrades			Modify Affected System(s)	6	2	36	0.0	0.04
1B6	Facility Age and Current Code Requirements	1	10	OSHA-Related Upgrades			Modify Affected System(s)	5	2	100	0.0	0.03
1B7	Facility Age and Current Code Requirements	1	10	Specialty-Standard Upgrades			Modify Affected System(s)	6	6	360	0.15	0.03
1C1	Overstatement of Issues	0.15	2	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	8	4	64	0.7	0.1
1C2	Overstatement of Issues	0.15	2	Improper Equipment Repurposing			Difficulty Getting Financing	9	1	18	0.5	1
1C3	Overstatement of Issues	0.15	2	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	6	8	96	0.2	0.06

Table D-6 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1C4	Overstatement of Issues	0.15	2	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	7	3	42	0.5	0.04
1C5	Understatement of Issues	0.15	2	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	7	8	112	0.1	0.03
1C6	Understatement of Issues	0.15	2	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	7	8	112	0.1	0.03
1C7	Understatement of Issues	0.15	2	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	7	8	112	0.5	0.05
1C8	Understatement of Issues	0.15	2	Missed Opportunities	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	4	7	56	0.5	0.02
1D1	ESCO Lack of Experience with Facility Type	0.18	3	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M		Missed Opportunity for O&M Contract	8	5	120	0.2	0.02

Table D-6 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1D2	ESCO Lack of Experience with Facility Type	0.18	3	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Reduced Project Value for ESCO	7	6	126	0.5	0.05
1D3	ESCO Lack of Experience with Facility Type	0.18	3	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Savings Shortfall/ Erosion of ESCO's Margin	9	6	162	0.15	0.08
1D4	ESCO Lack of Experience with Facility Type	0.18	3	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Baseline	Savings Shortfall/ Erosion of ESCO's Margin	9	4	108	0.1	0.08
1D5	ESCO Lack of Experience with Facility Type	0.18	3	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Retrofit Design	Savings Shortfall/ Erosion of ESCO's Margin	9	4	108	0.2	0.1
1D6	ESCO Lack of Experience with Facility Type	0.18	3	Failure to Understand Facility Operations and Client Goals	Improper Construction Timing and Phasing	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	5	6	90	0.1	0.06
1D7	ESCO Lack of Experience with Facility Type	0.18	3	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	5	6	90	0.2	0.02

Table D-6 (cont’d)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1D8	ESCO Lack of Experience with Facility Type	0.18	3	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin	5	8	120	0.2	0.05
1D9	ESCO Lack of Experience with Facility Type	0.18	3	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	8	6	144	0.1	0.1
1D10	ESCO Lack of Experience with Facility Type	0.18	3	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin	8	7	168	0.2	0.2
1D11	ESCO Lack of Experience with Facility Type	0.18	3	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Occupant Use of Equipment for Other Purposes	Legal Impacts	9	8	216	0.11	0.25
1E1	Differing Stakeholder Needs	0.33	4	Inconsistent Information About Facility Operating Parameters (e.g., too hot, too cold, too much airflow, not enough airflow)	Retrofit Design Does Not Satisfy All Stakeholders	User Modification of ECMs/Override Operating Parameters	Savings Shortfall/ Erosion of ESCO's Margin	9	6	216	0.8	0.05

Table D-6 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1E2	Differing Stakeholder Needs	0.33	4	Codes and Standards Upgrades	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin	8	8	256	0.3	0.06
1E3	Differing Stakeholder Needs	0.33	4	Codes and Standards Upgrades	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity	Savings Shortfall/ Erosion of ESCO's Margin	9	6	216	0.4	0.05
1E4	Differing Stakeholder Needs	0.33	4	Increased Project Complexity	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin	6	6	144	1	0.01
1E5	Differing Stakeholder Needs	0.33	4	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity		Savings Shortfall/ Erosion of ESCO's Margin	6	3	72	0.6	0.02
1F1	IGA Conducted Too Quickly	0.25	3	Miss Critical Functions and Savings Opportunities			Savings Shortfall/ Erosion of ESCO's Margin	6	4	72	0.33	0.02
1F2	IGA Conducted Too Quickly	0.25	3	Miscount Existing Equipment (e.g., Lights)			Savings Shortfall/ Erosion of ESCO's Margin	5	4	60	0.25	0.01

Table D-6 (cont'd)

	Cause	**%Likelihood Cause**	**Occurrence**	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**	**Severity**	**Detection**	**RPN**	**% Likelihood End Effect**	**Cost**
1F3	IGA Conducted Too Quickly	0.25	3	Miscount Existing Equipment (e.g., Lights)	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	4	4	48	0.3	0.01
1F4	IGA Conducted Too Quickly	0.25	3	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	7	4	84	0.5	0.03
1F5	IGA Conducted Too Quickly	0.25	3	Missing Facility Information	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	6	4	72	0.8	0.02
1F6	IGA Conducted Too Quickly	0.25	3	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin	5	3	45	0.25	0.01
1F7	Facility Information Unavailable/ Inaccurate	0.35	4	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	9	6	216	0.2	0.1
1F8	Facility Information Unavailable/ Inaccurate	0.35	4	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin	5	6	120	0.5	0.01

Table D-6 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2A1	Security Concerns	0.15	2	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment	Rework	Savings Shortfall/ Erosion of ESCO's Margin	5	4	40	0.25	0.01
2A2	Security Concerns	0.15	2	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment		Savings Shortfall/ Erosion of ESCO's Margin	4	4	32	0.2	0.01
2A3	Security Concerns	0.15	2	Technology Breakage/ Damage Possibility by Occupants	Equipment Impacts	Total Costs of Operation	Savings Shortfall/ Erosion of ESCO's Margin	7	9	126	0.25	0.02
2A4	Security Concerns	0.15	2	Technology Breakage/ Damage Possibility by Occupants	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	6	4	48	0.05	0.02
2A5	Security Concerns	0.15	2	Occupant Use of Equipment for Other Purposes			Legal Impacts	7	4	56	0.05	0.05
2B1	Reduced Availability of “Low Hanging Fruit”	0.8	9	Increase in Project Complexity	Limited/Less Attractive Scope	Increased Opportunity for Diminished Savings	Savings Shortfall/ Erosion of ESCO's Margin	7	3	189	0.5	0.05
2B2	Reduced Availability of “Low Hanging Fruit”	0.8	9	Increase in Project Costs	IGA Scope Increase (No Additional Fee)		Savings Shortfall/ Erosion of ESCO's Margin	9	4	324	0.25	0.2

Table D-6 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2B3	Reduced Availability of "Low Hanging Fruit"	0.8	9	Less Opportunity for Non-Energy Benefits (NEBs)	Project Schedule Impacted		Savings Shortfall/ Erosion of ESCO's Margin	6	4	216	0.2	0.06
2CD1	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.8	9	Failure to Meet Owner Project Requirements	Rework		Savings Shortfall/ Erosion of ESCO's Margin	8	4	288	0.5	0.03
2CD2	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.8	9	Failure to Meet Owner Project Requirements	Comfort Complaints		Savings Shortfall/ Erosion of ESCO's Margin	6	5	270	0.5	0.03
2CD3	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.8	9	Failure to Meet Owner Project Requirements			Savings Shortfall/ Erosion of ESCO's Margin	5	3	135	0.1	0.02
2CD4	Operational Concerns	0.15	2	Failure to Meet Owner Project Requirements	Reduce Project Scope		Savings Shortfall/ Erosion of ESCO's Margin	9	3	54	0.1	0.25
2CD5	Safety Concerns	0.15	2	Failure to Meet Owner Project Requirements	Safety Incident		Legal Impacts	10	10	200	0.015	0.35
2E1	Unqualified Subcontractors	0.2	3	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	7	6	126	0.3	0.02

Table D-6 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2E2	Unqualified Subcontractors	0.2	3	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin	10	5	150	0.1	0.15
2E3	Unqualified Subcontractors	0.2	3	Unsafe Working Conditions/Injuries	Safety Incident		Legal Impacts	10	8	240	0.02	0.85
2E4	Unreliable Subcontractors	0.2	3	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	6	6	108	0.25	0.03
2E5	Unreliable Subcontractors	0.2	3	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin	10	6	180	0.01	0.15
2E6	Unreliable Subcontractors	0.2	3	Project Schedule Impacted			Savings Shortfall/ Erosion of ESCO's Margin	6	6	108	0.25	0.02
2F1	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.5	6	Require ESCO to use Fixed Overhead & Profit Rates	Overstate Project Soft Costs		Savings Shortfall/ Erosion of ESCO's Margin	6	1	36	0.75	0.10
2F2	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.5	6	Divide Procurement into Separate Phases	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin	7	3	126	0.15	0.06

Table D-6 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2F3	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.5	6	Incorrect Vendor Selection	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin	8	9	432	0.2	0.25
2G1	Select Cheapest Available Equipment to Meet Specifications	0.25	3	Increased O&M Cost			Savings Shortfall/ Erosion of ESCO's Margin	6	2	36	0.2	0.01
2G2	Select Cheapest Available Equipment to Meet Specifications	0.25	3	Reduced Equipment Service Life			Savings Shortfall/ Erosion of ESCO's Margin	7	6	126	0.25	0.06
2G3	Actual Climate Conditions Outside Range of Planned Conditions	0.2	3	Uncertainty in Factors Used to Predict Performance	Reduced Equipment Service Life		Savings Shortfall/ Erosion of ESCO's Margin	7	6	126	0.1	0.1
2G4	Actual Climate Conditions Outside Range of Planned Conditions	0.2	3	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin	7	6	126	0.25	0.1
2G5	ECM Constructability & Feasibility Issues	0.25	3	Uncertainty in Factors Used to Predict Performance	Reduced Energy Performance		Savings Shortfall/ Erosion of ESCO's Margin	7	6	126	0.30	0.15

Table D-6 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2G6	ECM Constructability & Feasibility Issues	0.25	3	Rework			Savings Shortfall/ Erosion of ESCO's Margin	8	6	144	0.5	0.2
2G7	ECM Failure to Perform as Designed	0.18	3	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin	7	6	126	0.25	0.1
2G8	ECM Failure to Perform as Designed	0.18	3	Rework			Savings Shortfall/ Erosion of ESCO's Margin	8	7	168	0.2	0.25

Table D-7. Panelist RP-03-O SFMEA Worksheet

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1A1	Misunderstanding Existing Conditions	1	10	Presence of Asbestos-Containing Materials (ACM)			Remove/ Modify	6	5	300	1	0.4
1A2	Misunderstanding Existing Conditions	1	10	Presence of Asbestos-Containing Materials (ACM)			Manage in Place	4	5	200	0.0	0.2
1A3	Misunderstanding Existing Conditions	1	10	Presence of Lead-Based Paint			Remove/ Modify	6	5	300	0.3	0.3
1A4	Misunderstanding Existing Conditions	1	10	Presence of Lead-Based Paint			Manage in Place	3	5	150	0.7	0.1
1A5	Misunderstanding Existing Conditions	0.9	10	Presence of Fuel-Related Contaminants			Remove/ Modify	5	6	300	1	0.2
1A6	Misunderstanding Existing Conditions	0.9	10	Presence of Fuel-Related Contaminants			Manage in Place	2	6	120	0.0	1
1A7	Misunderstanding Existing Conditions	0.8	9	Presence of Buried Infrastructure			Remove/ Modify	6	7	378	0.3	0.2
1A8	Misunderstanding Existing Conditions	0.8	9	Presence of Buried Infrastructure			Manage in Place	2	7	126	0.7	0.1
1B1	Facility Age and Current Code Requirements	0.5	6	Fire Suppression and Alarm System Upgrades			Modify Affected System(s)	2	3	36	0.7	0.1
1B2	Facility Age and Current Code Requirements	0.75	8	Electrical System Upgrades			Modify Affected System(s)	6	3	144	1	0.2

Table D-7 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1B3	Facility Age and Current Code Requirements	0.75	8	Plumbing System Upgrades			Modify Affected System(s)	5	3	120	1	0.2
1B4	Facility Age and Current Code Requirements	0.75	8	Mechanical System Upgrades			Modify Affected System(s)	5	3	120	0.75	0.2
1B5	Facility Age and Current Code Requirements	0.2	3	Universal Access (ADA) Upgrades			Modify Affected System(s)	3	4	36	0.2	0.1
1B6	Facility Age and Current Code Requirements	1	10	OSHA-Related Upgrades			Modify Affected System(s)	2	4	80	0.1	0.1
1B7	Facility Age and Current Code Requirements	1	10	Specialty-Standard Upgrades			Modify Affected System(s)	2	5	100	0.1	0.1
1C1	Overstatement of Issues	0.3	4	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	4	5	80	0.9	0.25
1C2	Overstatement of Issues	0.3	4	Improper Equipment Repurposing			Difficulty Getting Financing	2	1	8	0.05	0.3
1C3	Overstatement of Issues	0.3	4	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	4	5	80	0.6	0.25

Table D-7 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1C4	Overstatement of Issues	0.3	4	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	4	5	80	0.6	0.25
1C5	Understatement of Issues	0.3	4	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	4	5	80	0.9	0.25
1C6	Understatement of Issues	0.3	4	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	4	5	80	0.6	0.25
1C7	Understatement of Issues	0.3	4	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	4	5	80	0.6	0.25
1C8	Understatement of Issues	0.3	4	Missed Opportunities	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	4	5	80	0.7	0.25
1D1	ESCO Lack of Experience with Facility Type	0.5	6	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M		Missed Opportunity for O&M Contract	8	3	144	0.3	0.25

Table D-7 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1D2	ESCO Lack of Experience with Facility Type	0.5	6	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Reduced Project Value for ESCO	6	2	72	0.3	0.2
1D3	ESCO Lack of Experience with Facility Type	0.5	6	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Savings Shortfall/ Erosion of ESCO's Margin	7	3	126	0.3	0.2
1D4	ESCO Lack of Experience with Facility Type	0.5	6	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Baseline	Savings Shortfall/ Erosion of ESCO's Margin	7	3	126	0.25	0.3
1D5	ESCO Lack of Experience with Facility Type	0.5	6	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Retrofit Design	Savings Shortfall/ Erosion of ESCO's Margin	6	5	180	0.7	0.3
1D6	ESCO Lack of Experience with Facility Type	0.5	6	Failure to Understand Facility Operations and Client Goals	Improper Construction Timing and Phasing	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	7	3	126	0.7	0.4
1D7	ESCO Lack of Experience with Facility Type	0.5	6	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	7	4	168	0.7	0.4

Table D-7 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1D8	ESCO Lack of Experience with Facility Type	0.5	6	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin	7	3	126	0.8	0.4
1D9	ESCO Lack of Experience with Facility Type	0.5	6	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	7	3	126	0.7	0.2
1D10	ESCO Lack of Experience with Facility Type	0.5	6	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin	7	4	168	0.7	0.1
1D11	ESCO Lack of Experience with Facility Type	0.5	6	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Occupant Use of Equipment for Other Purposes	Legal Impacts	8	4	192	0.1	0.1
1E1	Differing Stakeholder Needs	0.8	9	Inconsistent Information About Facility Operating Parameters (e.g., too hot, too cold, too much airflow, not enough airflow)	Retrofit Design Does Not Satisfy All Stakeholders	User Modification of ECMs/Override Operating Parameters	Savings Shortfall/ Erosion of ESCO's Margin	7	6	378	0.8	0.8

Table D-7 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1E2	Differing Stakeholder Needs	0.8	9	Codes and Standards Upgrades	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin	8	4	288	0.7	0.8
1E3	Differing Stakeholder Needs	0.8	9	Codes and Standards Upgrades	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity	Savings Shortfall/ Erosion of ESCO's Margin	7	3	189	0.7	0.8
1E4	Differing Stakeholder Needs	0.8	9	Increased Project Complexity	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin	8	4	288	0.7	0.8
1E5	Differing Stakeholder Needs	0.8	9	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity		Savings Shortfall/ Erosion of ESCO's Margin	7	4	252	0.7	0.8
1F1	IGA Conducted Too Quickly	0.3	4	Miss Critical Functions and Savings Opportunities			Savings Shortfall/ Erosion of ESCO's Margin	8	6	192	0.9	0.3
1F2	IGA Conducted Too Quickly	0.3	4	Miscount Existing Equipment (e.g., Lights)			Savings Shortfall/ Erosion of ESCO's Margin	8	4	128	0.9	0.35

Table D-7 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1F3	IGA Conducted Too Quickly	0.3	4	Miscount Existing Equipment (e.g., Lights)	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	8	4	128	0.9	0.35
1F4	IGA Conducted Too Quickly	0.3	4	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	8	7	224	0.9	0.35
1F5	IGA Conducted Too Quickly	0.3	4	Missing Facility Information	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	8	7	224	0.9	0.35
1F6	IGA Conducted Too Quickly	0.3	4	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin	8	7	224	0.9	0.35
1F7	Facility Information Unavailable/ Inaccurate	0.7	8	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	8	7	448	0.9	0.35
1F8	Facility Information Unavailable/ Inaccurate	0.7	8	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin	8	7	448	0.9	0.4

Table D-7 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2A1	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment	Rework	Savings Shortfall/ Erosion of ESCO's Margin	7	5	315	0.8	0.2
2A2	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment		Savings Shortfall/ Erosion of ESCO's Margin	8	5	360	0.7	0.2
2A3	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Equipment Impacts	Total Costs of Operation	Savings Shortfall/ Erosion of ESCO's Margin	8	5	360	0.8	0.15
2A4	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	4	6	216	0.2	0.1
2A5	Security Concerns	0.8	9	Occupant Use of Equipment for Other Purposes			Legal Impacts	8	4	288	0.1	0.15
2B1	Reduced Availability of "Low Hanging Fruit"	0.8	9	Increase in Project Complexity	Limited/Less Attractive Scope	Increased Opportunity for Diminished Savings	Savings Shortfall/ Erosion of ESCO's Margin	6	2	108	0.8	0.5
2B2	Reduced Availability of "Low Hanging Fruit"	0.8	9	Increase in Project Costs	IGA Scope Increase (No Additional Fee)		Savings Shortfall/ Erosion of ESCO's Margin	6	2	108	0.8	0.5

Table D-7 (cont'd)

	Cause	**%Likelihood Cause**	**Occurrence**	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**	**Severity**	**Detection**	**RPN**	**% Likelihood End Effect**	**Cost**
2B3	Reduced Availability of "Low Hanging Fruit"	0.8	9	Less Opportunity for Non-Energy Benefits (NEBs)	Project Schedule Impacted		Savings Shortfall/ Erosion of ESCO's Margin	6	2	108	0.85	0.5
2CD1	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.4	5	Failure to Meet Owner Project Requirements	Rework		Savings Shortfall/ Erosion of ESCO's Margin	4	4	80	0.8	0.3
2CD2	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.4	5	Failure to Meet Owner Project Requirements	Comfort Complaints		Savings Shortfall/ Erosion of ESCO's Margin	4	6	120	0.7	0.4
2CD3	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.4	5	Failure to Meet Owner Project Requirements			Savings Shortfall/ Erosion of ESCO's Margin	3	7	105	0.6	0.3
2CD4	Operational Concerns	0.4	5	Failure to Meet Owner Project Requirements	Reduce Project Scope		Savings Shortfall/ Erosion of ESCO's Margin	2	7	70	0.8	0.3
2CD5	Safety Concerns	0.2	3	Failure to Meet Owner Project Requirements	Safety Incident		Legal Impacts	1	9	27	0.1	0.1
2E1	Unqualified Subcontractors	0.3	4	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	5	3	60	0.85	0.3

Table D-7 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2E2	Unqualified Subcontractors	0.3	4	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin	2	4	32	0.4	0.1
2E3	Unqualified Subcontractors	0.3	4	Unsafe Working Conditions/Injuries	Safety Incident		Legal Impacts	2	7	56	0.2	0.1
2E4	Unreliable Subcontractors	0.4	5	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	2	3	30	0.4	0.1
2E5	Unreliable Subcontractors	0.3	4	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin	5	3	60	0.85	0.3
2E6	Unreliable Subcontractors	0.4	5	Project Schedule Impacted			Savings Shortfall/ Erosion of ESCO's Margin	6	3	90	0.80	0.35
2F1	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.75	8	Require ESCO to use Fixed Overhead & Profit Rates	Overstate Project Soft Costs		Savings Shortfall/ Erosion of ESCO's Margin	7	3	168	0.7	0.4
2F2	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.75	8	Divide Procurement into Separate Phases	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin	7	3	168	0.85	0.4

Table D-7 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2F3	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.75	8	Incorrect Vendor Selection	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin	7	3	168	0.85	0.4
2G1	Select Cheapest Available Equipment to Meet Specifications	0.5	6	Increased O&M Cost			Savings Shortfall/ Erosion of ESCO's Margin	4	7	168	0.7	0.1
2G2	Select Cheapest Available Equipment to Meet Specifications	0.5	6	Reduced Equipment Service Life			Savings Shortfall/ Erosion of ESCO's Margin	4	8	192	0.7	0.1
2G3	Actual Climate Conditions Outside Range of Planned Conditions	0.3	4	Uncertainty in Factors Used to Predict Performance	Reduced Equipment Service Life		Savings Shortfall/ Erosion of ESCO's Margin	6	4	96	0.7	0.1
2G4	Actual Climate Conditions Outside Range of Planned Conditions	0.3	4	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin	6	4	96	0.70	0.10
2G5	ECM Constructability & Feasibility Issues	0.4	5	Uncertainty in Factors Used to Predict Performance	Reduced Energy Performance		Savings Shortfall/ Erosion of ESCO's Margin	5	7	175	0.6	0.1

Table D-7 (cont'd)												
	Cause	**%Likelihood Cause**	**Occurrence**	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**	**Severity**	**Detection**	**RPN**	**% Likelihood End Effect**	**Cost**
2G6	ECM Constructability & Feasibility Issues	0.4	5	Rework			Savings Shortfall/ Erosion of ESCO's Margin	7	4	140	0.2	0.25
2G7	ECM Failure to Perform as Designed	0.3	4	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin	6	4	96	0.7	0.1
2G8	ECM Failure to Perform as Designed	0.3	4	Rework			Savings Shortfall/ Erosion of ESCO's Margin	7	4	112	0.2	0.25

Table D-8. Panelist RP-04-M SFMEA Worksheet

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1A1	Misunderstanding Existing Conditions	1	10	Presence of Asbestos-Containing Materials (ACM)			Remove/ Modify	7	3	210	1	0.10
1A2	Misunderstanding Existing Conditions	1	10	Presence of Asbestos-Containing Materials (ACM)			Manage in Place	2	3	60	0	0.05
1A3	Misunderstanding Existing Conditions	N/A	N/A	Presence of Lead-Based Paint			Remove/ Modify	1	1		N/A	0.00
1A4	Misunderstanding Existing Conditions	N/A	N/A	Presence of Lead-Based Paint			Manage in Place	1	1		N/A	0.00
1A5	Misunderstanding Existing Conditions	N/A	N/A	Presence of Fuel-Related Contaminants			Remove/ Modify	1	1		N/A	0.00
1A6	Misunderstanding Existing Conditions	N/A	N/A	Presence of Fuel-Related Contaminants			Manage in Place	1	1		N/A	0.00
1A7	Misunderstanding Existing Conditions	0.8	9	Presence of Buried Infrastructure			Remove/ Modify	3	9	243	0.1	0.70
1A8	Misunderstanding Existing Conditions	0.8	9	Presence of Buried Infrastructure			Manage in Place	8	9	648	0.9	0.20
1B1	Facility Age and Current Code Requirements	0.8	9	Fire Suppression and Alarm System Upgrades			Modify Affected System(s)	6	2	108	0.8	0.05
1B2	Facility Age and Current Code Requirements	0.8	9	Electrical System Upgrades			Modify Affected System(s)	4	6	216	0.2	0.20

Table D-8 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1B3	Facility Age and Current Code Requirements	N/A	N/A	Plumbing System Upgrades			Modify Affected System(s)	4	6		N/A	0.05
1B4	Facility Age and Current Code Requirements	0.75	8	Mechanical System Upgrades			Modify Affected System(s)	6	3	144	0.7	0.30
1B5	Facility Age and Current Code Requirements	0.2	3	Universal Access (ADA) Upgrades			Modify Affected System(s)	2	2	12	0	0.05
1B6	Facility Age and Current Code Requirements	1	10	OSHA-Related Upgrades			Modify Affected System(s)	7	4	280	1	0.20
1B7	Facility Age and Current Code Requirements	0.75	8	Specialty-Standard Upgrades			Modify Affected System(s)	7	8	448	1	0.60
1C1	Overstatement of Issues	0.25	3	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	7	8	168	1	0.70
1C2	Overstatement of Issues	0.25	3	Improper Equipment Repurposing			Difficulty Getting Financing	7	2	42	0.75	0.10
1C3	Overstatement of Issues	0.25	3	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	7	2	42	0.25	0.20

Table D-8 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1C4	Overstatement of Issues	0.25	3	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	7	8	168	0.75	0.15
1C5	Understatement of Issues	0.75	8	Improper Equipment Sizing	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	9	8	576	0.75	0.30
1C6	Understatement of Issues	0.75	8	Improper Equipment Repurposing	Inaccurate Prediction of Service Life/O&M Schedule	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	9	8	576	0.25	0.20
1C7	Understatement of Issues	0.75	8	Customer-Specified Issues	Changes to the Size of the Project Scope	Inability to Meet Performance Expectations	Savings Shortfall/ Erosion of ESCO's Margin	3	9	216	0.75	0.10
1C8	Understatement of Issues	0.75	8	Missed Opportunities	Inability to Meet Performance Expectations		Savings Shortfall/ Erosion of ESCO's Margin	7	6	336	1	0.40
1D1	ESCO Lack of Experience with Facility Type	0.8	9	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M		Missed Opportunity for O&M Contract	4	7	252	0.8	0.70

Table D-8 (cont’d)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1D2	ESCO Lack of Experience with Facility Type	0.8	9	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Reduced Project Value for ESCO	7	9	567	1	0.30
1D3	ESCO Lack of Experience with Facility Type	0.8	9	Failure to Understand Facility Operations and Client Goals	Overestimate Client Capacity to Perform O&M	Reduced Savings Due to Poorly-Performed O&M	Savings Shortfall/ Erosion of ESCO's Margin	7	9	567	0.6	0.30
1D4	ESCO Lack of Experience with Facility Type	0.8	9	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Baseline	Savings Shortfall/ Erosion of ESCO's Margin	8	8	576	0.6	0.30
1D5	ESCO Lack of Experience with Facility Type	0.8	9	Failure to Understand Facility Operations and Client Goals	Lack of Foresight About Future Building Use and Occupant Changes	Improper Retrofit Design	Savings Shortfall/ Erosion of ESCO's Margin	8	9	648	0.9	0.70
1D6	ESCO Lack of Experience with Facility Type	0.8	9	Failure to Understand Facility Operations and Client Goals	Improper Construction Timing and Phasing	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	8	8	576	0.9	0.30
1D7	ESCO Lack of Experience with Facility Type	0.8	9	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	9	3	243	0.8	0.70

Table D-8 (cont'd)

	Cause	**%Likelihood Cause**	**Occurrence**	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**	**Severity**	**Detection**	**RPN**	**% Likelihood End Effect**	**Cost**
1D8	ESCO Lack of Experience with Facility Type	0.8	9	Failure to Understand Facility Operations and Client Goals	Overestimate Productivity Rates	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin	9	5	405	0.75	0.30
1D9	ESCO Lack of Experience with Facility Type	0.8	9	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Project Schedule too Short	Savings Shortfall/ Erosion of ESCO's Margin	9	5	405	0.9	0.70
1D10	ESCO Lack of Experience with Facility Type	0.8	9	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Underestimate Project Costs	Savings Shortfall/ Erosion of ESCO's Margin	9	6	486	0.7	0.80
1D11	ESCO Lack of Experience with Facility Type	0.8	9	Failure to Understand Facility Operations and Client Goals	Improper Consideration of Security Concerns	Occupant Use of Equipment for Other Purposes	Legal Impacts	6	9	486	0.6	0.05
1E1	Differing Stakeholder Needs	0.2	3	Inconsistent Information About Facility Operating Parameters (e.g., too hot, too cold, too much airflow, not enough airflow)	Retrofit Design Does Not Satisfy All Stakeholders	User Modification of ECMs/Override Operating Parameters	Savings Shortfall/ Erosion of ESCO's Margin	9	8	216	0.2	0.30

Table D-8 (cont'd)

	Cause	**%Likelihood Cause**	**Occurrence**	**Intermediate Effect 1**	**Intermediate Effect 2**	**Intermediate Effect 3**	**End Effect**	**Severity**	**Detection**	**RPN**	**% Likelihood End Effect**	**Cost**
1E2	Differing Stakeholder Needs	0.2	3	Codes and Standards Upgrades	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin	6	5	90	0.1	0.30
1E3	Differing Stakeholder Needs	0.2	3	Codes and Standards Upgrades	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity	Savings Shortfall/ Erosion of ESCO's Margin	7	5	105	0.1	0.10
1E4	Differing Stakeholder Needs	0.2	3	Increased Project Complexity	Retrofit Design Does Not Satisfy All Stakeholders	Comfort-Related Callbacks after Construction Complete	Savings Shortfall/ Erosion of ESCO's Margin	7	5	105	0.2	0.20
1E5	Differing Stakeholder Needs	0.2	3	Increased Project Complexity	Controls Scope of Work Lacks Adequate Detail and Specificity		Savings Shortfall/ Erosion of ESCO's Margin	7	5	105	0.1	0.30
1F1	IGA Conducted Too Quickly	0.75	8	Miss Critical Functions and Savings Opportunities			Savings Shortfall/ Erosion of ESCO's Margin	9	9	648	1	0.8
1F2	IGA Conducted Too Quickly	0.75	8	Miscount Existing Equipment (e.g., Lights)			Savings Shortfall/ Erosion of ESCO's Margin	9	8	576	0.4	0.2

Table D-8 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
1F3	IGA Conducted Too Quickly	0.75	8	Miscount Existing Equipment (e.g., Lights)	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	7	7	392	0.7	0.2
1F4	IGA Conducted Too Quickly	0.75	8	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	7	7	392	0.9	0.2
1F5	IGA Conducted Too Quickly	0.75	8	Missing Facility Information	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	9	3	216	0.9	0.2
1F6	IGA Conducted Too Quickly	0.75	8	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin	9	5	360	0.9	0.3
1F7	Facility Information Unavailable/ Inaccurate	0.75	8	Inaccurate Baseline	Energy Model Calibration Errors		Savings Shortfall/ Erosion of ESCO's Margin	8	5	320	0.9	0.6
1F8	Facility Information Unavailable/ Inaccurate	0.75	8	Missing Facility Information			Savings Shortfall/ Erosion of ESCO's Margin	8	5	320	0.9	0.6

Table D-8 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2A1	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment	Rework	Savings Shortfall/ Erosion of ESCO's Margin	8	8	576	0.70	0.2
2A2	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Change in Design Intent for Impacted Equipment		Savings Shortfall/ Erosion of ESCO's Margin	8	8	576	0.80	0.1
2A3	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Equipment Impacts	Total Costs of Operation	Savings Shortfall/ Erosion of ESCO's Margin	7	8	504	0.70	0.3
2A4	Security Concerns	0.8	9	Technology Breakage/ Damage Possibility by Occupants	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	8	8	576	0.90	0.7
2A5	Security Concerns	0.8	9	Occupant Use of Equipment for Other Purposes			Legal Impacts	6	8	432	0.70	0.05
2B1	Reduced Availability of "Low Hanging Fruit"	0.8	9	Increase in Project Complexity	Limited/Less Attractive Scope	Increased Opportunity for Diminished Savings	Savings Shortfall/ Erosion of ESCO's Margin	7	8	504	0.8	0.70
2B2	Reduced Availability of "Low Hanging Fruit"	0.8	9	Increase in Project Costs	IGA Scope Increase (No Additional Fee)		Savings Shortfall/ Erosion of ESCO's Margin	7	8	504	0.9	0.30

Table D-8 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2B3	Reduced Availability of "Low Hanging Fruit"	0.8	9	Less Opportunity for Non-Energy Benefits (NEBs)	Project Schedule Impacted		Savings Shortfall/ Erosion of ESCO's Margin	3	5	135	0.8	0.10
2CD1	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.9	10	Failure to Meet Owner Project Requirements	Rework		Savings Shortfall/ Erosion of ESCO's Margin	7	8	560	0.6	0.60
2CD2	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.9	10	Failure to Meet Owner Project Requirements	Comfort Complaints		Savings Shortfall/ Erosion of ESCO's Margin	7	5	350	0.6	0.60
2CD3	Some ECMs (e.g., Lighting) are Difficult to Demonstrate before Installation	0.9	10	Failure to Meet Owner Project Requirements			Savings Shortfall/ Erosion of ESCO's Margin	7	8	560	0.9	0.60
2CD4	Operational Concerns	0.75	8	Failure to Meet Owner Project Requirements	Reduce Project Scope		Savings Shortfall/ Erosion of ESCO's Margin	8	9	576	1	0.40
2CD5	Safety Concerns	0.5	6	Failure to Meet Owner Project Requirements	Safety Incident		Legal Impacts	9	8	432	0.5	0.70
2E1	Unqualified Subcontractors	0.5	6	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	3	6	108	0.5	0.10

Table D-8 (cont'd)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2E2	Unqualified Subcontractors	0.5	6	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin	3	6	108	0.1	0.30
2E3	Unqualified Subcontractors	0.5	6	Unsafe Working Conditions/Injuries	Safety Incident		Legal Impacts	5	6	180	0.2	0.30
2E4	Unreliable Subcontractors	0.5	6	Rework	Project Schedule Impacted	Delay in Accruing Savings	Savings Shortfall/ Erosion of ESCO's Margin	5	6	180	0.7	0.70
2E5	Unreliable Subcontractors	0.5	6	Unsafe Working Conditions/Injuries	Safety Incident	Project Schedule Impacted	Savings Shortfall/ Erosion of ESCO's Margin	5	6	180	0.2	0.20
2E6	Unreliable Subcontractors	0.5	6	Project Schedule Impacted			Savings Shortfall/ Erosion of ESCO's Margin	9	6	324	0.75	0.60
2F1	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.75	8	Require ESCO to use Fixed Overhead & Profit Rates	Overstate Project Soft Costs		Savings Shortfall/ Erosion of ESCO's Margin	9	2	144	0.75	0.40
2F2	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.75	8	Divide Procurement into Separate Phases	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin	7	6	336	0.1	0.50

Table D-8 (cont’d)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2F3	Prepare Technical Scope of Work Based on Standard Public DBB Procurement	0.75	8	Incorrect Vendor Selection	Disconnect Between IGA and Retrofit Design		Savings Shortfall/ Erosion of ESCO's Margin	7	8	448	0.75	0.60
2G1	Select Cheapest Available Equipment to Meet Specifications	0.8	9	Increased O&M Cost			Savings Shortfall/ Erosion of ESCO's Margin	9	5	405	1	0.30
2G2	Select Cheapest Available Equipment to Meet Specifications	0.8	9	Reduced Equipment Service Life			Savings Shortfall/ Erosion of ESCO's Margin	7	5	315	0.2	0.10
2G3	Actual Climate Conditions Outside Range of Planned Conditions	0.25	3	Uncertainty in Factors Used to Predict Performance	Reduced Equipment Service Life		Savings Shortfall/ Erosion of ESCO's Margin	6	6	108	0.25	0.30
2G4	Actual Climate Conditions Outside Range of Planned Conditions	0.25	3	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin	6	8	144	0.9	0.25
2G5	ECM Constructability & Feasibility Issues	0.9	10	Uncertainty in Factors Used to Predict Performance	Reduced Energy Performance		Savings Shortfall/ Erosion of ESCO's Margin	8	8	640	0.9	0.70

Table D-8 (cont’d)

	Cause	%Likelihood Cause	Occurrence	Intermediate Effect 1	Intermediate Effect 2	Intermediate Effect 3	End Effect	Severity	Detection	RPN	% Likelihood End Effect	Cost
2G6	ECM Constructability & Feasibility Issues	0.9	10	Rework			Savings Shortfall/ Erosion of ESCO's Margin	6	5	300	0.2	0.20
2G7	ECM Failure to Perform as Designed	0.75	8	Reduced Energy Performance			Savings Shortfall/ Erosion of ESCO's Margin	9	5	360	1	0.70
2G8	ECM Failure to Perform as Designed	0.75	8	Rework			Savings Shortfall/ Erosion of ESCO's Margin	9	5	360	1	0.80

Risk Scenario Maps

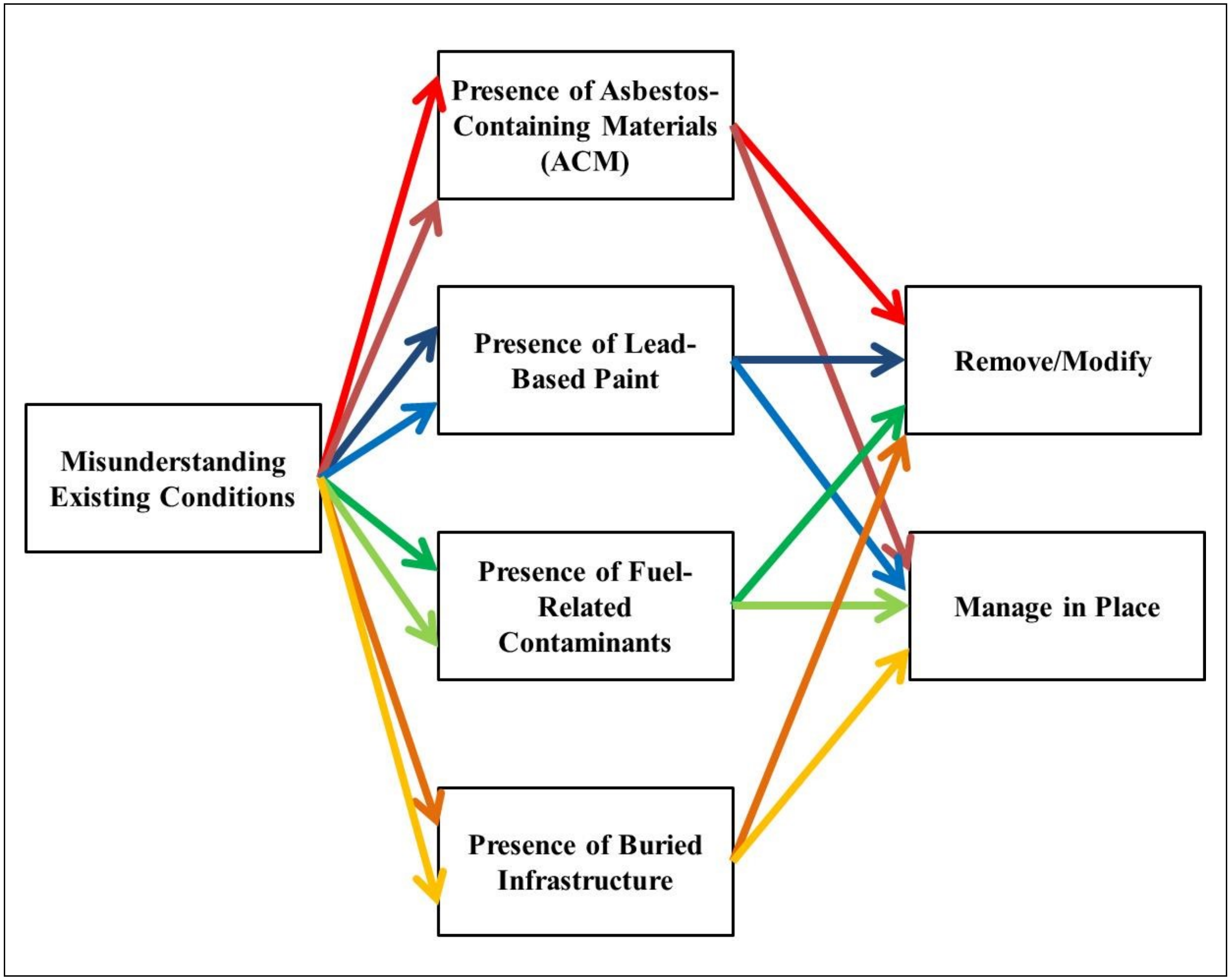


Figure D-1. Risk Scenario Map 1A

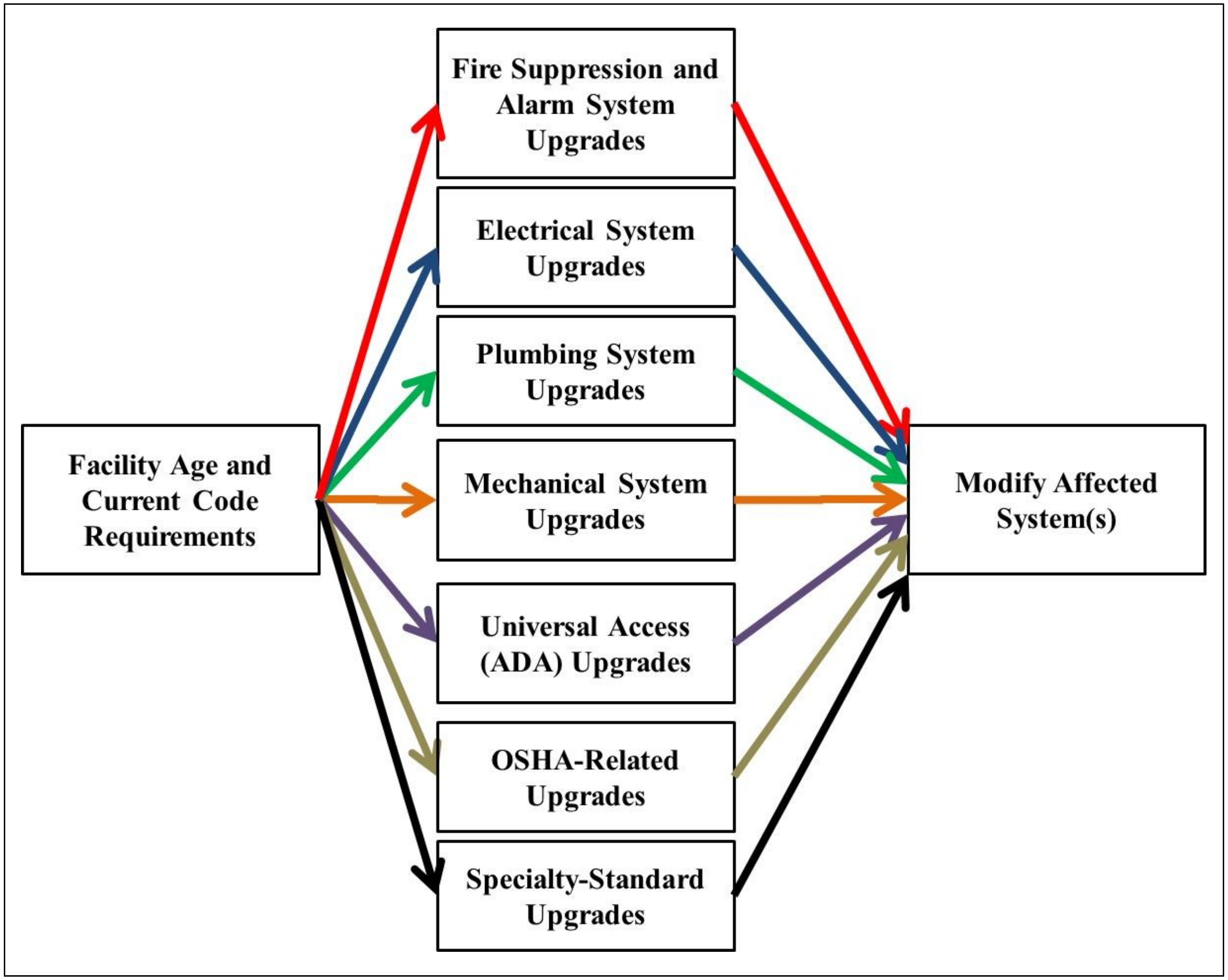


Figure D-2. Risk Scenario Map 1B

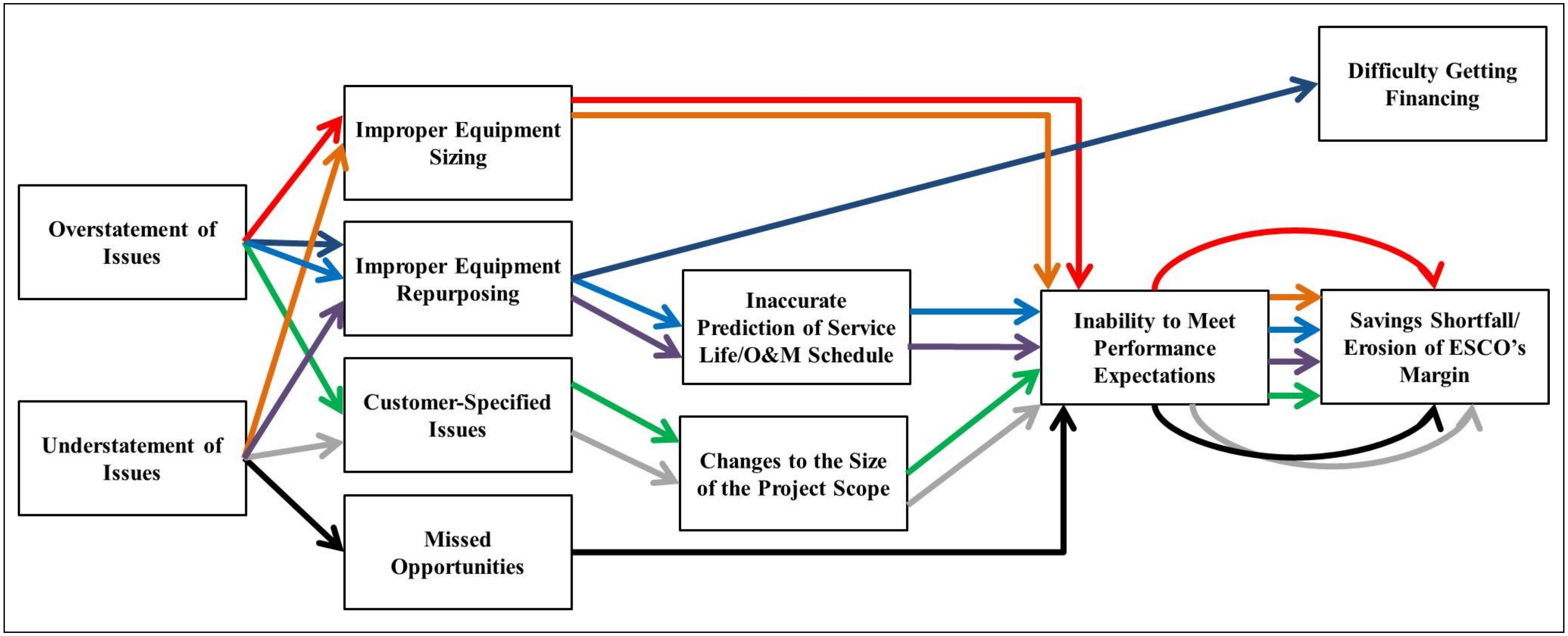


Figure D-3. Risk Scenario Map 1C

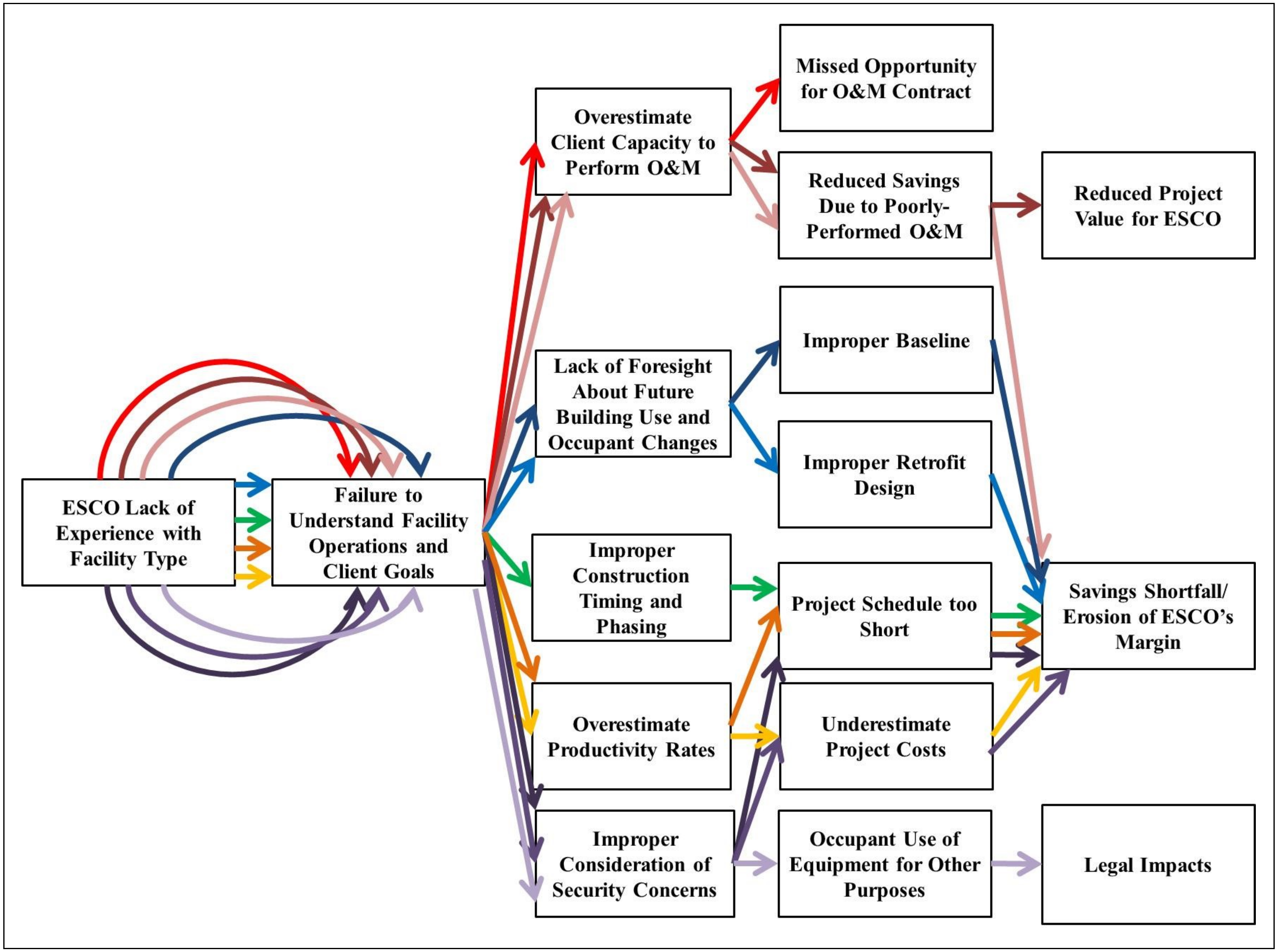


Figure D-4. Risk Scenario Map 1D

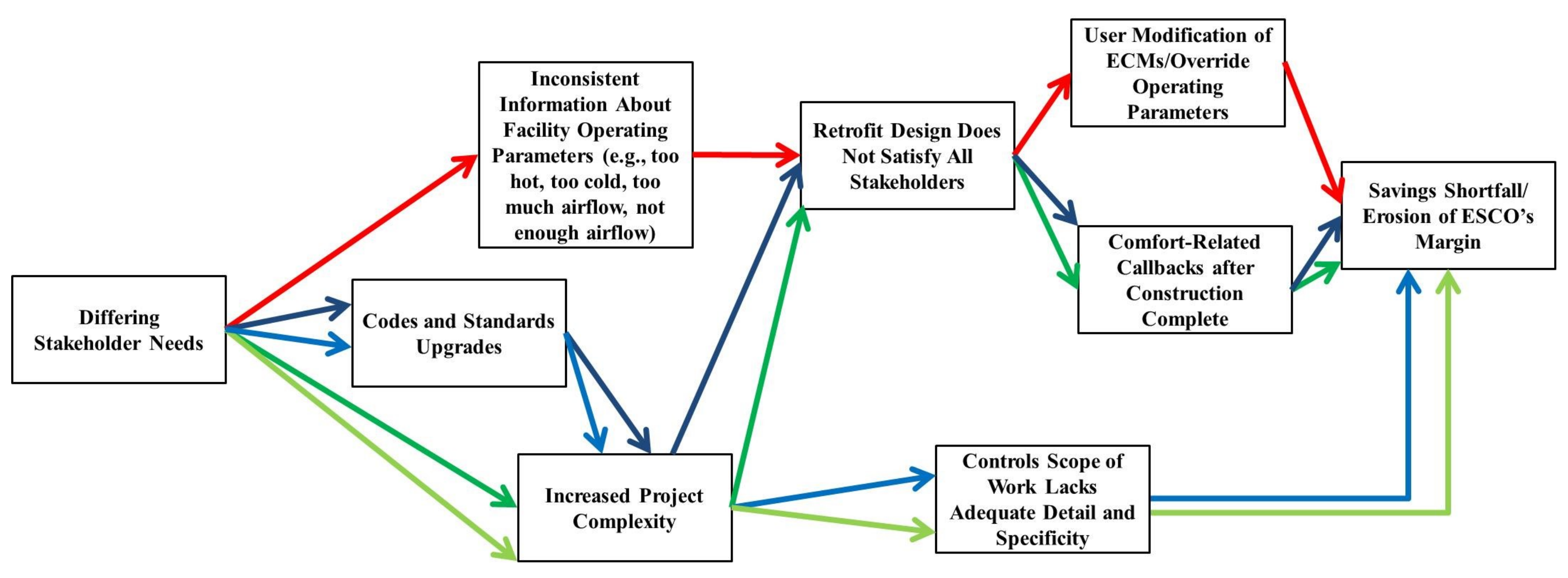


Figure D-5. Risk Scenario Map 1E

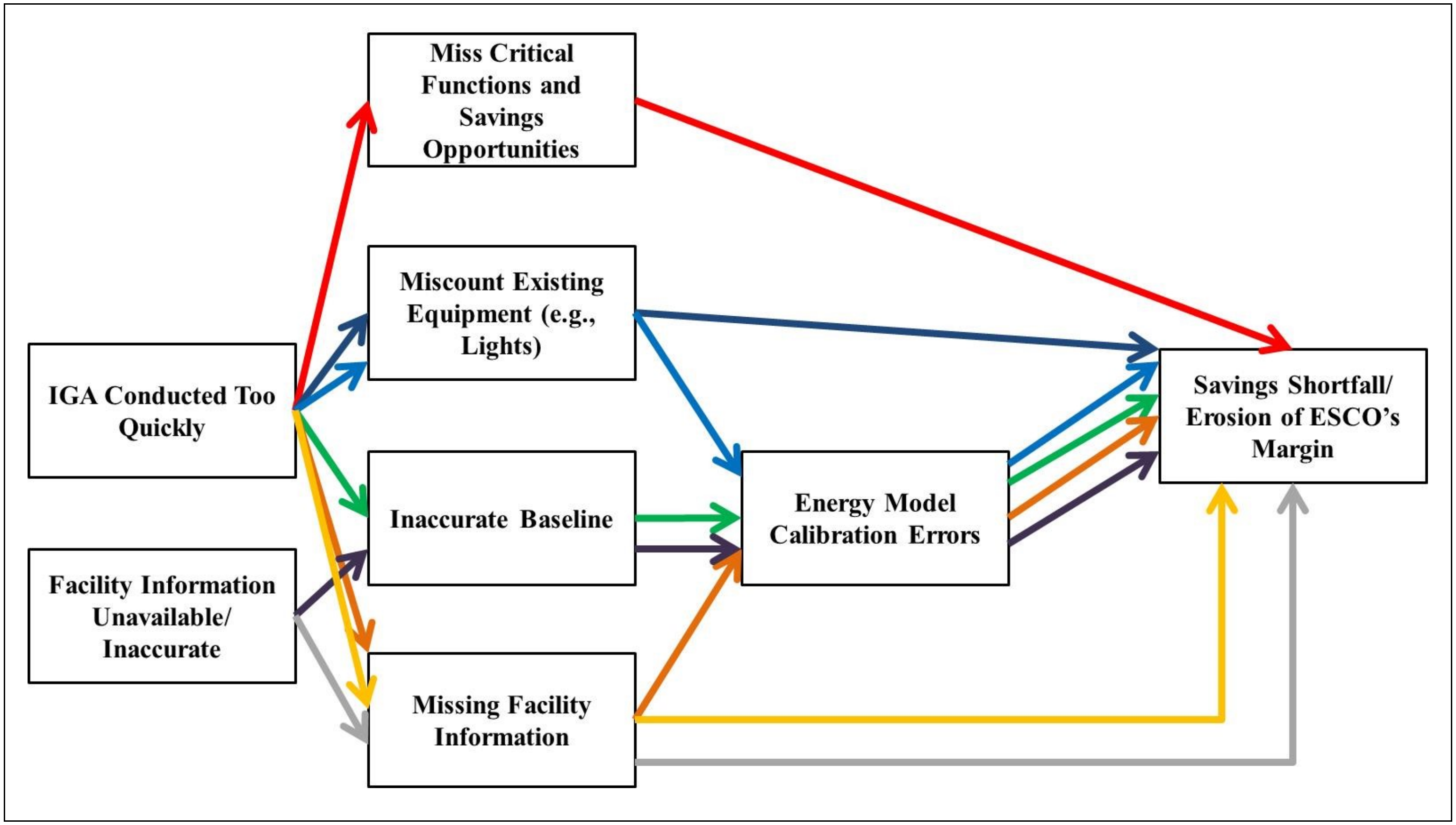


Figure D-6. Risk Scenario Map 1F

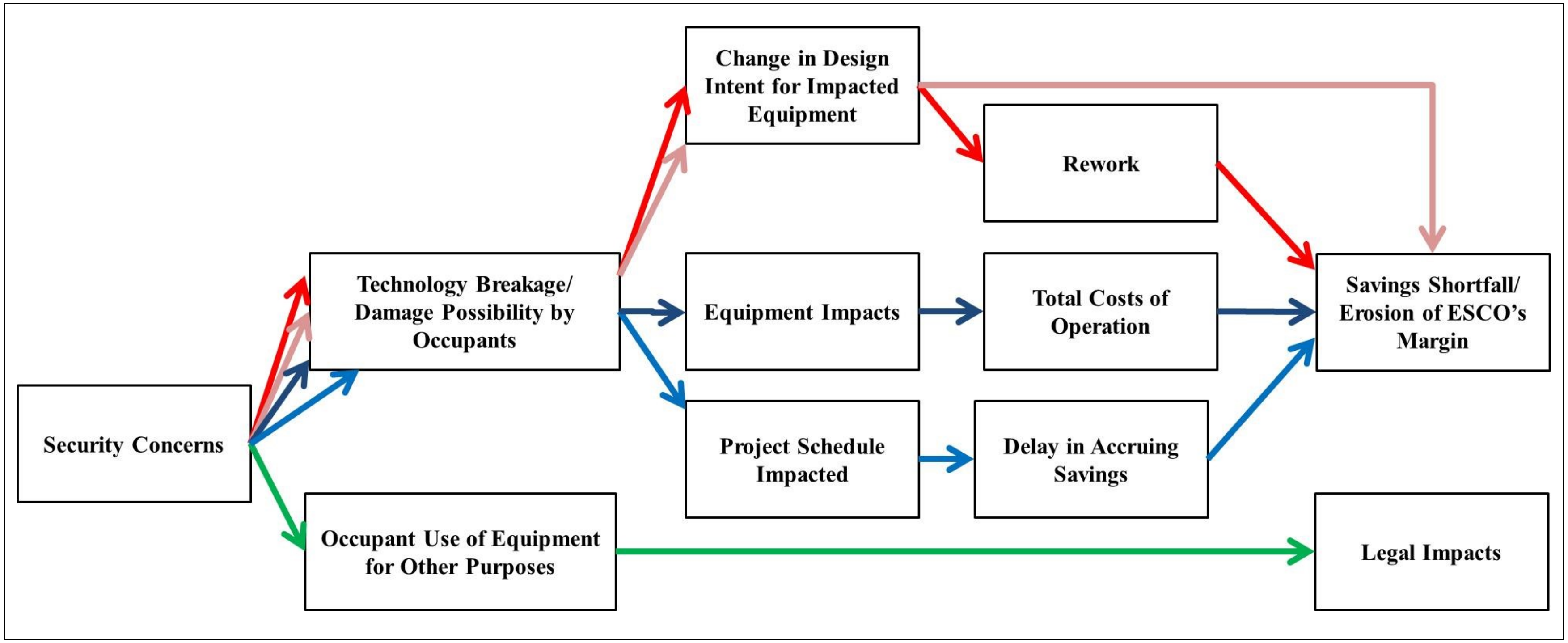


Figure D-7. Risk Scenario Map 2A

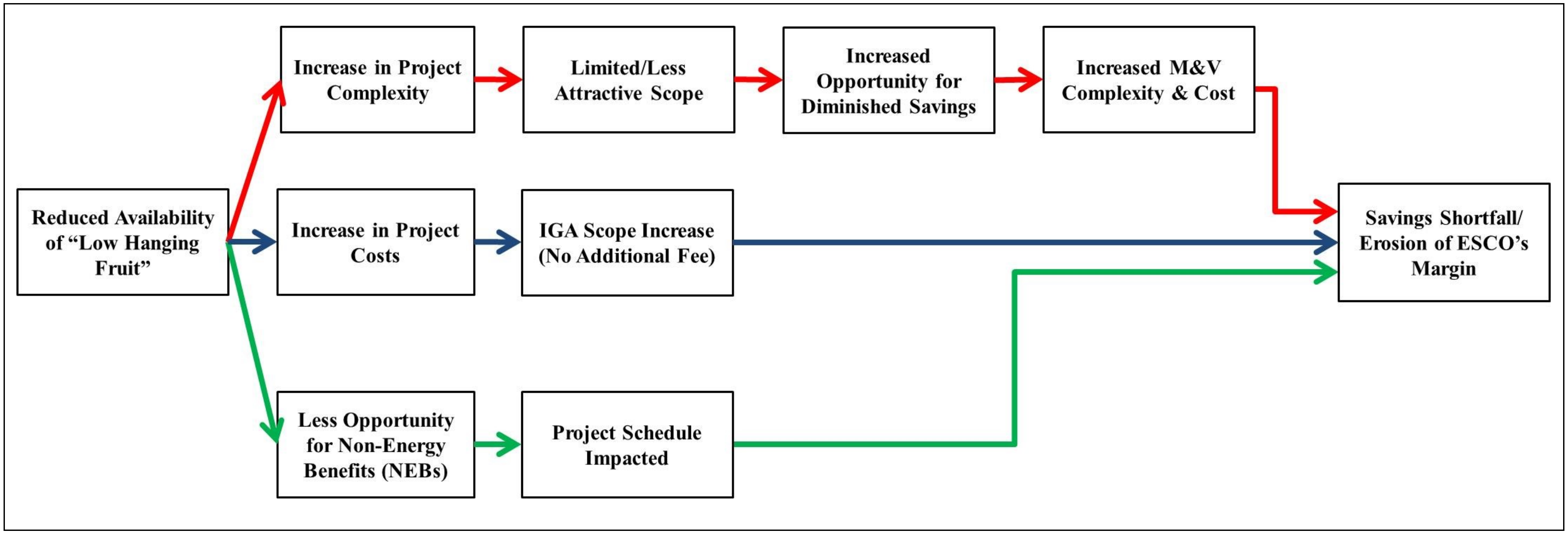


Figure D-8. Risk Scenario Map 2B

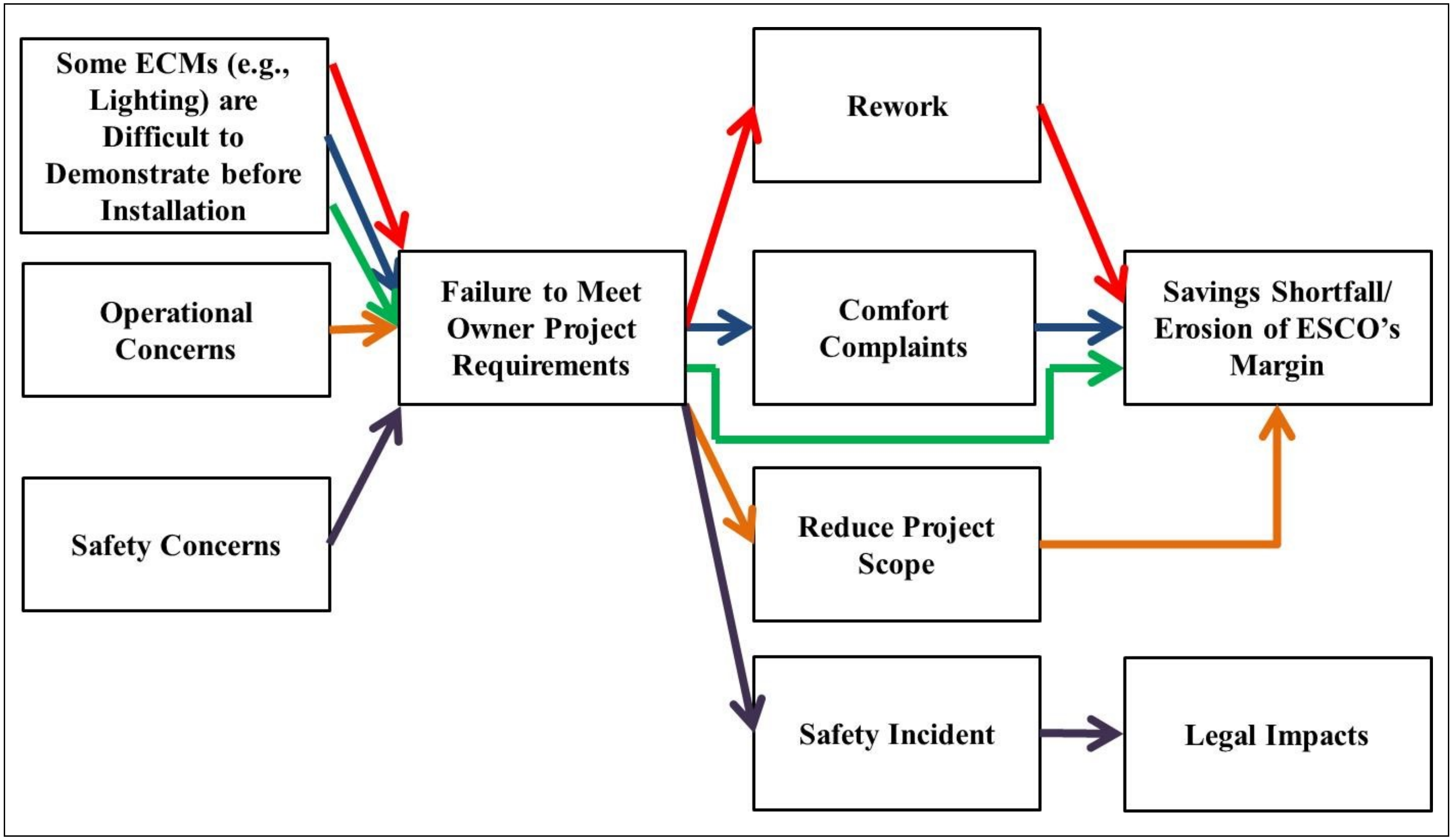


Figure D-9. Risk Scenario Map 2CD

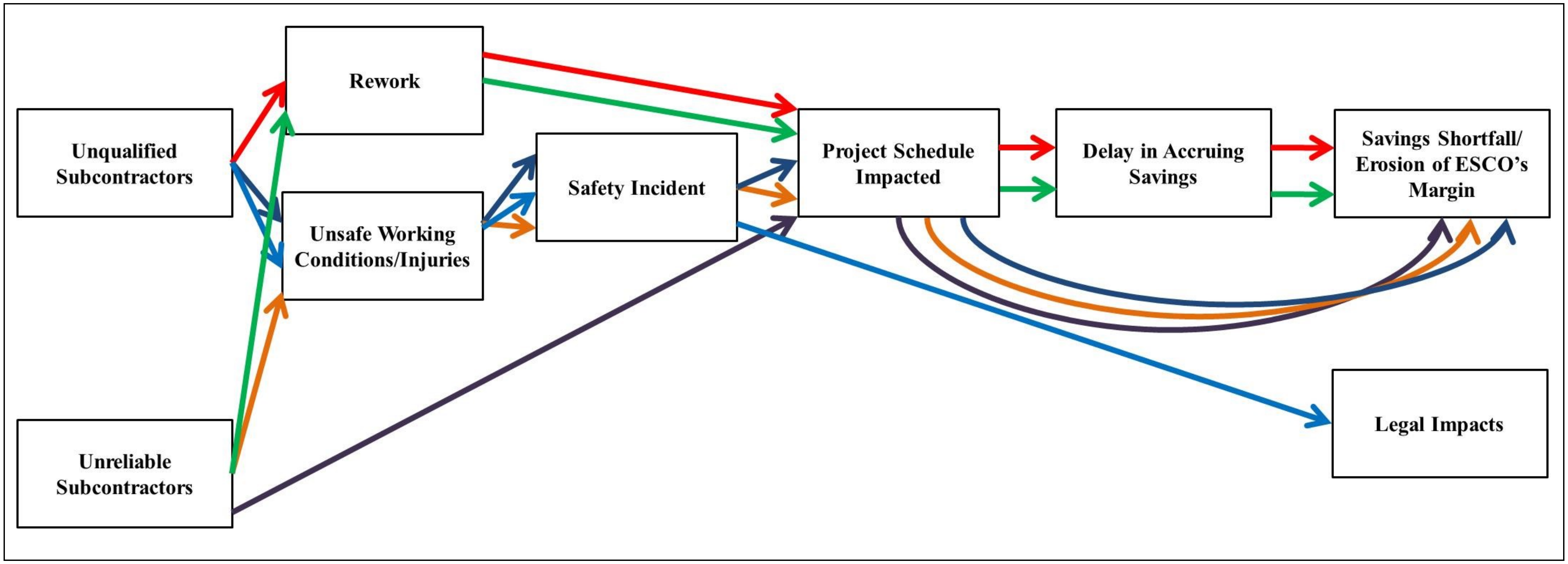


Figure D-10. Risk Scenario Map 2E

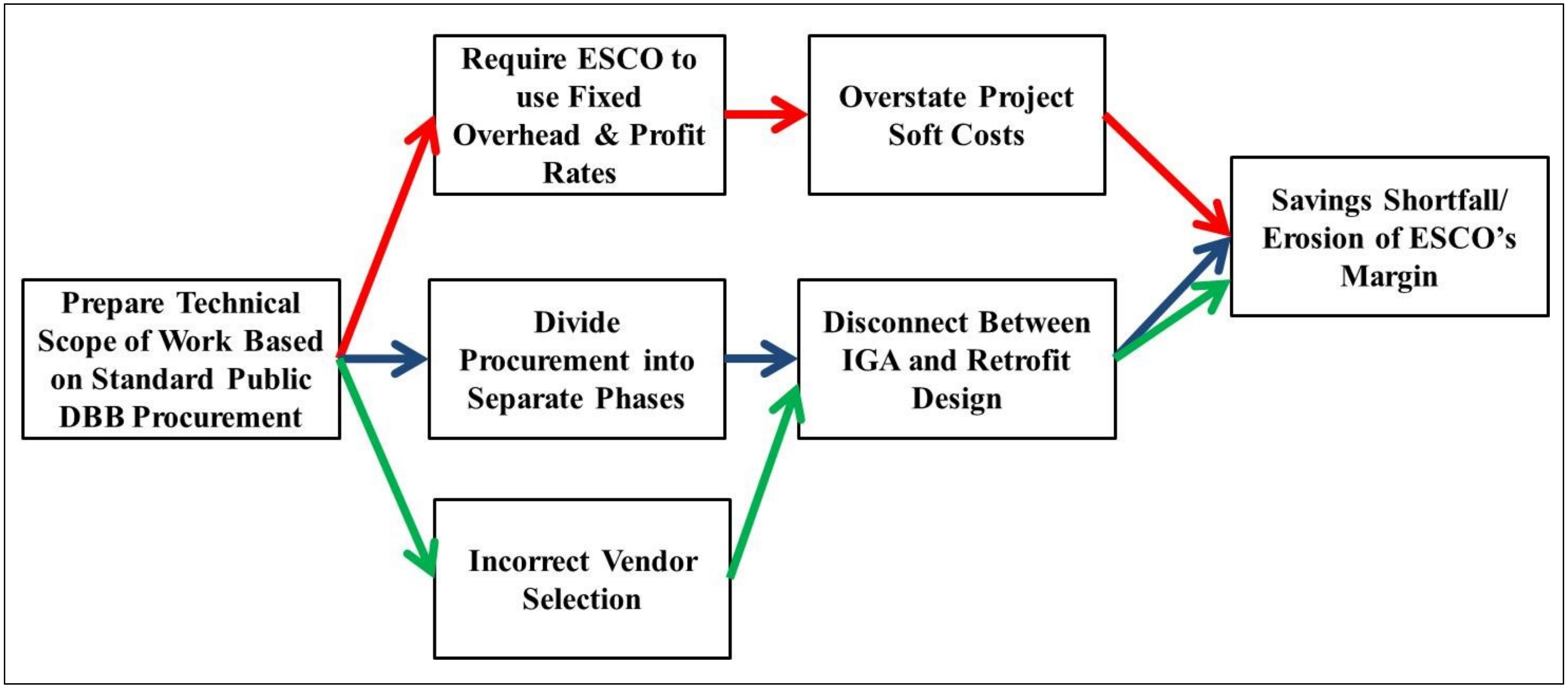


Figure D-11. Risk Scenario Map 2F

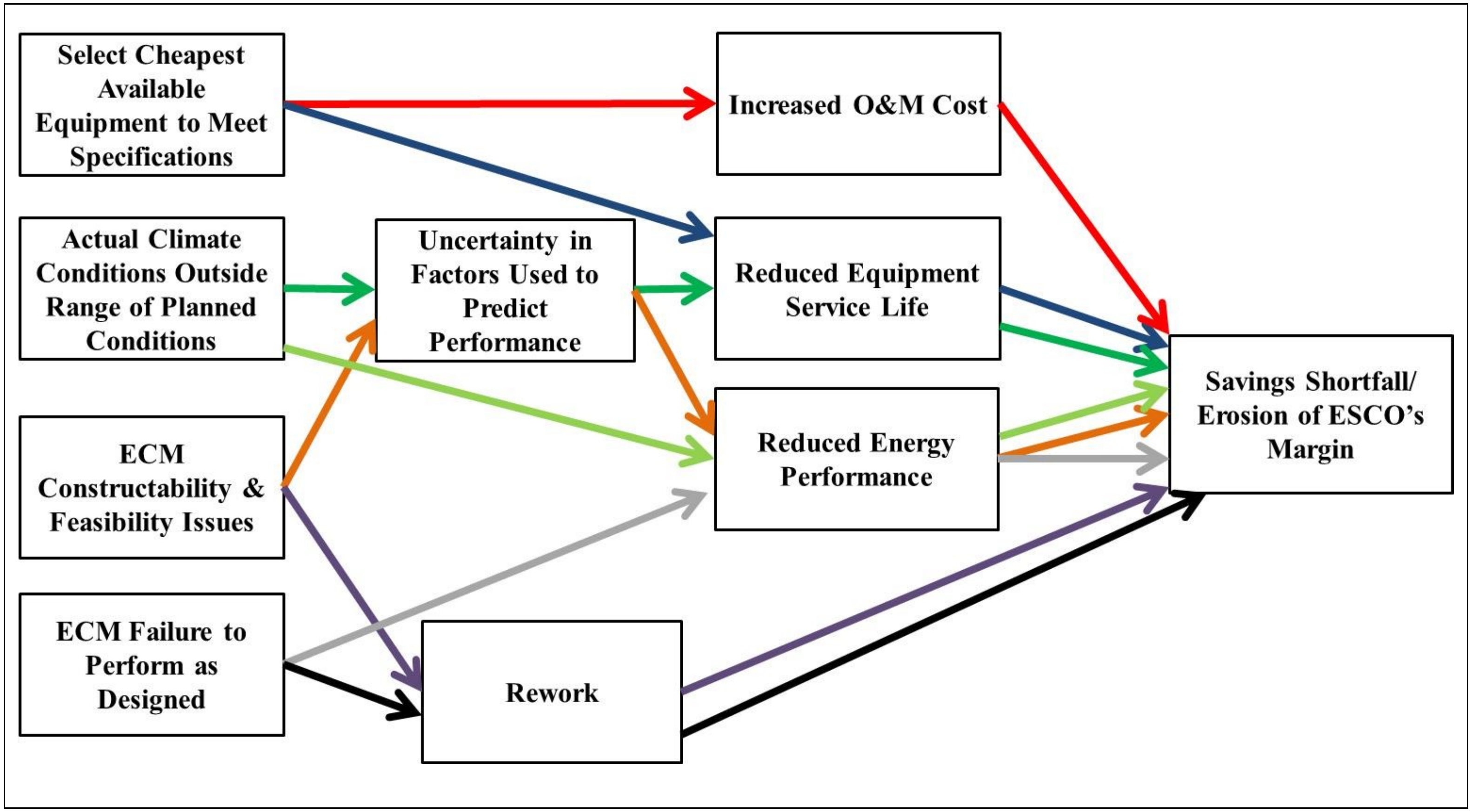


Figure D-12. Risk Scenario Map 2G

APPENDIX E

RISK MODEL PILOT TEST - CASE STUDY DETAILS

Case Study Location Description

The Parnall Correctional Facility is located in Blackman Township, Jackson County, Michigan. It is currently a minimum-security prison with a capacity for 1,696 prisoners. It was originally part of the former State Prison of Southern Michigan, until elements of the larger facility were closed and others were divided into new facilities, as shown in Figure E-1 (Michigan Department of Correction 2014). Parnall consists of 47 buildings, constructed between 1925 and 2002, and includes five housing units and a land area of 45 acres.

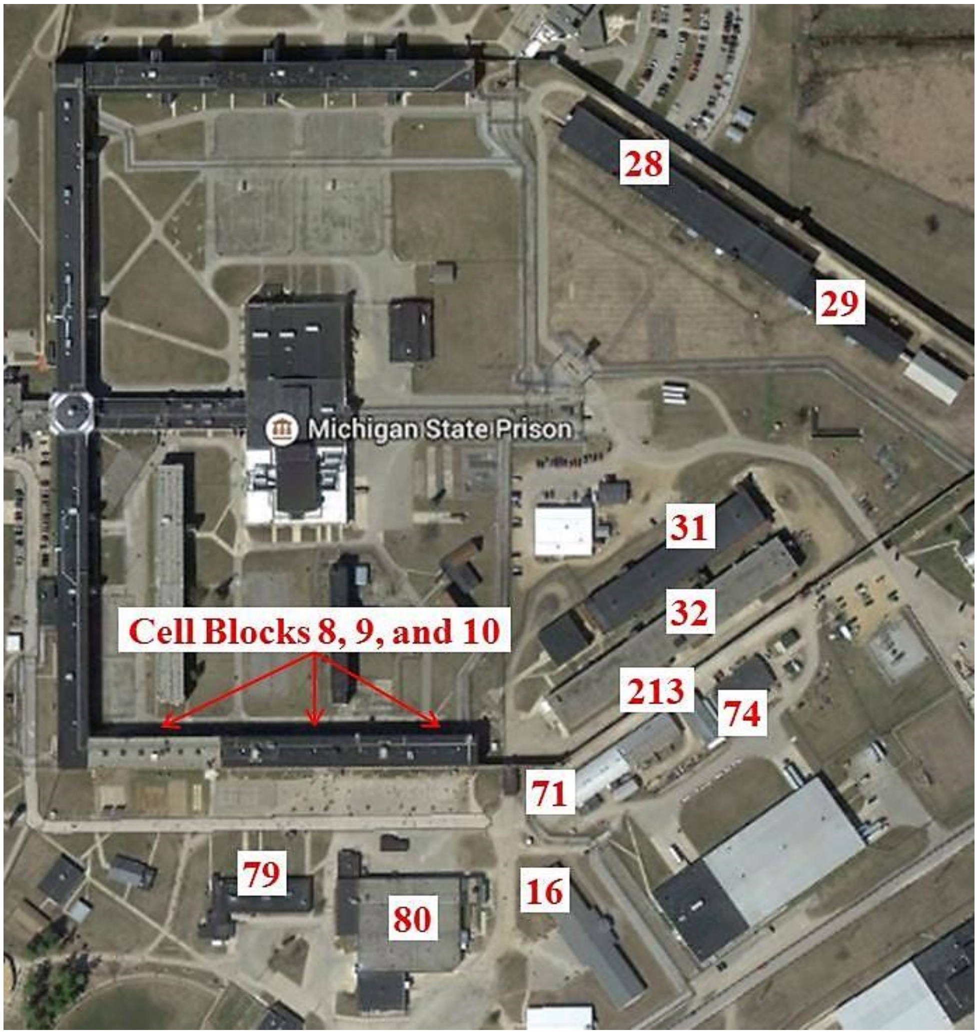


Figure E-1. Parnall Correctional Facility
Note: Numbers refer to building locations in Table E-2
(Aerial Photograph Source: Google Earth)

Energy Performance Contract Overview

The Michigan Department of Technology, Management, and Budget, in conjunction with the Michigan Department of Corrections, executed three pilot energy performance contracting (EPC) retrofits at selected correctional facilities in 2011, which were partially funded through the American Recovery and Reinvestment Act (Michigan Department of Licensing and Regulatory Affairs 2011). Parnall was one of the facilities selected for this project. The Parnall Correctional Facility is part of a four-facility campus designated as SMR, consisting of Parnall, the G. Robert Cotton Correctional Facility, the Charles E. Egeler Reception Guidance Center, and the Cooper Street Correctional Facility. The State of Michigan determined that Parnall was responsible for 38% of the campus' total utility consumption, based on building area (Energy Systems Group 2010).

The utility baseline was completed for the facility and showed and annual cost for energy and water/wastewater of $2.91 million (Table E-1). With 1,696 inmates, the utility cost per inmate was $1,716, far exceeding national, regional, and statewide averages (Stephan 2004). Stephan's (2004) reported 2001 costs data was calculated using the consumer price index to 2010 costs:

- National average utility cost - $979/inmate (2010 dollars)
- Midwest Region average utility cost/inmate - $1,017/inmate (2010 dollars)
- Michigan average utility cost/inmate - $967/inmate (2010 dollars)
- G. Robert Cotton utility cost/inmate was reported as $450 (Energy Systems Group 2010)

Table E-1. Baseline Energy and Water Consumption

Utility Type	Annual Usage	Annual Cost
Electricity	9,442,290 kWh	$741,220
Natural Gas	560,016 therms	$441,405
Steam	1,083,181 therms	$1,234,500
Steam Adjustment – Textile Building	(24,000) therms	($27,353)
Water and Sewer	174 Mgal – water 157 Mgal - sewer	$520,784
	Total Cost:	**$2,910,556**

(Source: Energy Systems Group 2010)

Retrofit activities were directed toward specific technologies in targeted buildings (Table E-2). The building numbers are aligned with the labels in Figure E-1. Most of the energy conservation measures (ECMs) targeted older buildings, many of which were still connected to the inefficient central steam plant or utilized original, circa 1930s vintage, hydronic heating units. Additionally, the cell blocks utilize a five tier design (Figure E-2) and are on an uncontrolled hydronic loop with each block receiving the same inlet temperature. As a result, the cell blocks at the front of the loop overheat in order to maintain adequate temperature for the blocks in the back of the loop (Energy Systems Group 2010). Overheating is controlled through increased ventilation; however, there is routinely a wide vertical temperature variation in the cell blocks which leads to inmate grievances (Berghorn and Vallad 2013).

Table E-2 lists selected ECMs by the building or buildings in which they were installed; however, ECMs #1, #4, and #5 are not included in this table. Savings resulting from a negotiated steam purchase agreement were the subject of ECM #1, thus there was no building modification involved. The lighting and water conservation retrofits in ECMs #3 and #4 are campus-wide efforts; therefore, while the buildings in Table E-2 may have included these retrofit measures, this would not be an exhaustive list. Parnall ECMs are described in Table E-3.

Figure E-2. Parnall Correctional Facility Cell Block 7
(Photo credit: Nick Dentamaro - Jackson Citizen Patriot)

Table E-2. Building Subject to EPC Retrofit Activities

Building Number	Description	Year Built	Gross SF	ECMs Included
CB 8	Correctional Security	1930	47,000	ECM #8
CB 9	Correctional Security	1932	33,800	ECM #2 ECM #3
CB 10	Correctional Security	1932	47,000	ECM #2 ECM #3
16	Correctional Security	2002	23,939	ECM #3
28	MI State Industries - Textiles Manufacturing	1928	145,900	ECM #6
29	MI State Industries – Dye Plant	1925	13,300	ECM #3
31	Shoe and Sign Factory	1937	103,100	ECM #3 ECM #7
32	Metal Furniture Factory	1930	173,800	ECM #3
71	Main Garage	1929	16,300	ECM #3
74	Maintenance	1967	7,200	ECM #3
79	Trusty Dining Hall	1955	15,200	ECM #3 ECM #9
80	Health Care Services	1999	9,060	ECM #3
213	Pole Storage	1990	5,200	ECM #3

Table E-3. ECM Descriptions	
ECM #	**Description**
ECM #1	Incinerator Steam Cost Savings – purchase steam from Jackson county at a price that is below the cost to produce steam from the central plant.
ECM #2	New HVAC System for Cell Blocks 9 and 10 – Original hydronic piping and radiators from the 1930s have exceeded their service life; replace with radiant panels. Install roof-mounted constant volume air rotation systems for fresh air ventilation and air heating.
ECM #3	Decentralize Building Utility Systems – Older, less efficient buildings remain connected to the central steam power plant; replace with natural gas systems.
ECM #4	Interior Campus Lighting Retrofit – Replacement, relamping, reballasting, and retrofitting with T8 lamps, high output T5 lamps, and high efficiency ballasts.
ECM #5	Campus Water Conservation Retrofit – Retrofit cells with electronic plumbing controls and install more efficient fixtures.
ECM #6	Prepare Textiles Building for Abandonment – Decommission all HVAC systems.
ECM #7	Minimize Heating 2nd Floor of Building 31 – Minimize heating in an unoccupied space; retrofit systems based on ECM #3 to provide base level of heating to protect fore suppression system.
ECM #8	Minimize Heating of Cell Block 8 – Minimize heating in an unoccupied space; maintain base level of heating to protect fire suppression system and due to adjacent occupied cell blocks; contingent on ECM #3 and utilizes elements of ECM #2.
ECM #9	Replace Cafeteria Dishwasher – Replace steam-heated model with natural gas.

In addition to the nine installed ECMs, 10 candidate retrofit measures were also considered, as described in Table E-4. These ECMs typically had rather lengthy simple payback periods or anticipated energy savings that were difficult to calculate. While this was not always the primary factor in deciding not to implement, it was a significant concern.

Table E-4. Proposed ECMs not Selected for Project	
ECM Description	**Simple Payback Period**
Solar-Assisted Domestic Hot Water Heating	377 years
Roof Replacement	355 years
Window Replacement	222 years
Integrated Building Automation System	Difficult to calculate energy savings
Exterior Lighting Retrofit	19 years
Add Air Conditioning to Lower Level Bldg 31	No savings due to new energy end-use
Exterior Security Lighting (LEP or LED)	40 years
Creamery Steam Process and Bldg 218 Boiler	16 years
Chapel Building Automation System	44 years
Electrical Power Monitoring	Difficult to calculate energy savings
(Source: Energy Systems Group 2010)	

The total costs and savings associated with the nine selected ECMs are detailed in Table E-5. The project financial summary is provided in Table E-6 and the baseline condition and annual expected energy and water savings are detailed in Table E-7.

Table E-5. Proposed Costs and Savings for Recommended ECMs

	Project Costs					Annual Project Savings			
ECM	**Design**	**Material**	**Labor**	**Commissioning**	**Total Cost[a,b]**	**Energy Cost Avoidance**	**Energy Avoidance**	**Simple Payback**	**Service Life**
ECM #1	$ -	$ -	$ -	$ -	$ -	$724,170	0	0 yrs	20 yrs
ECM #2	$339,818	$2,572,907	$2,281,635	$22,608	$5,216,968	$158,466	139,005 therms	32.9 yrs	30 yrs
ECM #3	$301,155	$2,280,170	$2,022,037	$49,655	$4,653,017	$667,177	421,653 therms	7.0 yrs	30 yrs
ECM #4	$50,440	$381,905	$338,672	$ -	$771,017	$65,396	833,067 kWh	11.8 yrs	15 yrs
ECM #5	$121,223	$917,832	$813,926	$ -	$1,852,981	$205,911	68,797 kGal	9.0 yrs	15 yrs
ECM #6	$4,757	$36,021	$31,943	$ -	$72,721	$30,819	39,100 therms	2.4 yrs	30 yrs
ECM #7	$ -	$ -	$ -	$ -	$ -	$7,560	9,592 therms	0.0 yrs	30 yrs
ECM #8	$14,661	$111,003	$98,436	$5,201	$229,301	$13,252	16,813 therms	17.3 yrs	30 yrs
ECM #9	$4,324	$32,736	$29,032	$ -	$66,092	$8,523	10,824 therms	7.8 yrs	20 yrs
Subtotal	**$836,378**	**$6,332,574**	**$5,615,681**	**$77,464**	**$12,862,097**	**$1,881,274**		**6.8**	
Audit Cost					**$29,528**				
Total					**$12,891,626**				

Notes:

a\Costs for training and warranties were not included in this analysis.

b\ Annual maintenance costs were anticipated to be the same or less than the existing cost.

(Adapted from Energy Systems Group 2010)

Table E-6. Project Financial Summary	
Total Project Cost:	$12,891,626
Incentives/Rebates:	$0
Committed Capital Funding:	$0
Financed Investment Cost:	$12,891,626
Rate of Financing:	4.50%
Term of Financing:	7 years
Total Savings over Term:	$15,646,197
Annual Utility Rate Increase:	3.40%
Annual Operational Savings Increase:	3.40%
Annual Cost of Capital Increase:	0.00%
Total Net Cash Flow:	$545,931
Simple Payback:	6.80 years
(Source: Energy Systems Group 2010)	

Table E-7. Base Year Condition and Expected Energy and Water Savings			
Utility Type	**Base Year Utility Usage**	**Base Year Utility Cost**	**Annual Savings**
Electricity	9,442,290 kWh	$741,220	$65,396
Natural Gas	560,016 therms	$441,405	N/A
Steam	1,083,181 therms	$1,234,500	$885,777
Steam Adjustment – Textile Building	(24,000) therms[a]	($27,353)	Note b
Steam Cost Adjustment	N/A	N/A	$724,170
Water and Sewer	Water: 174 Mgal Sewer: 157 Mgal	$520,784	$205,911
Totals		**$2,910,556**	**$1,881,254**[c]

Notes:

a\ This represents the fuel load for operating the

b\ The savings attributed to the space heating fuel load (46,000 therms/year or $30,819/year) is included in the "Steam" annual savings in the immediately preceding row.

c\ Annual savings figures are slightly mismatched between Table E-5 and this table, as a result of rounding errors in the calculations

(Source: Energy Systems Group 2010)

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REFERENCES

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