THE IMPACT OF VISIBILITY AND INFORMATION SHARING ON FIRM PERFORMANCE: A MULTI-METHOD STUDY OF FIRM PERFORMANCE AND RESILIENCE UNDER CONDITIONS OF SUPPLY DISRUPTION

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ABSTRACT

THE IMPACT OF VISIBILITY AND INFORMATION SHARING ON FIRM PERFORMANCE:
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The structure of supply chain relationships is an important dimension of supply chain design, and there is evidence that supply chain design determines the specific capabilities of the supply chain. From a design perspective, there are widely differing views on *how* to design supply chains, particularly on how to structure relationships between firms in the supply chain. This dissertation focuses on one aspect of supply chain design -- the structure of supply chain relationships between firms and how this choice affects visibility and information sharing capabilities and consequently affects firm performance.

The contributions from this dissertation include the development of a theoretical framework of important factors that firms should consider when choosing an supply chain relationship structure on the modularity-integration continuum, with specific focus on the visibility and information sharing dimension of supply chain relationship structure (SCRS), and a limited test of the SCRS framework to evaluate how firm performance differs under conditions of supply disruption by SCRS-related visibility and information sharing practices, using empirical data from two firms to parameterize

lower (LDV) and higher demand variation (HDV) conditions in a simulation model to generate data for analysis.

From this analysis, firm performance differed between the LDV and HDV cases under normal conditions and conditions of supply disruption. The LDV case, with demand derived from a just-in-time production operation, resulted in no differences in firm performance using visibility and information sharing practices associated with modular and integrated SCRS's, under both normal and supply disruptions conditions. The high degree of system coupling created almost immediate performance effects on the focal firm in the LDV case under supply disruption.

For the HDV case, firm performance differed depending on whether a modular or integrated SCRS was employed. While both types of SCRS performed well under normal conditions, conditions of supply disruption affected performance. In this case, the integrated SCRS outperformed the modular SCRS and an interactive effect was observed between SCRS and disruption duration for the HDV case.

This limited test does not suggest this will be true in all cases, since the number of cases is small and supplier switching costs under periods of high environmental uncertainty and other limitations were not considered. In addition, performance effects from robustness and resilience observed from supply disruptions of specified durations appear to be nonlinear, and further investigation of functional relationships and interrelationships is needed.

DEDICATION

I wish to dedicate this work to my family, who, despite my long hours, extensive travel, and limited accessibility for the past several years, decided to keep me in the family anyway. This dissertation was preceded by several years of graduate work in complex systems, adding to the duration and depth of family challenges as I pursued my interest and dreams and continued on to pursue a Ph.D.

This work is dedicated to my wife, Liz, who supported me and our children throughout this long and arduous process – I couldn't have done this without you. It helps to have a spouse who has also completed graduate school, but it doesn't make it any easier. You have more patience and love for me than I deserve, and I am grateful for your understanding and support.

This work is also dedicated to our children, Michelle and Eric, who endured the stresses and challenges I faced while their father was in graduate school (again) for so many years - while they studied college-level coursework during their high school years. I was still completing this dissertation at Michigan State University while they also attended Michigan State University. Apparently my example of the challenges and stresses of graduate school was not convincing. Michelle enters graduate school this fall, and Eric is planning on graduate school next year. These were their decisions – honest.

ACKNOWLEDGEMENTS

My academic journey began with some valuable advice soon: *choose your dissertation committee wisely*. With advice and support from my Dissertation Chairperson, Dr. Steven A. Melnyk, I was able to form an excellent dissertation committee, including Dr. Roger J. Calantone, Dr. Gary L. Ragatz, and Dr. Joan L. Luft. Together they formed a most knowledgeable and supportive committee, providing truly sage advice on a wide range of academic topics necessary to complete the dissertation. Much later in the dissertation process they were of immense help in teaching me how to reduce an overly complex dissertation with an underdeveloped academic writing style into a coherent and presentable academic document.

Dr. Melnyk provided continual and invaluable guidance throughout the entire process, and his wide ranging mastery of many subjects within and outside of academia continues to amaze me. Dr. Calantone, in addition to his mastery of complex methodologies, provided timely advice and guidance every time I needed it (which was often). Dr. Ragatz was able to calmly bring me back to the big picture and ask how my work fit on numerous occasions, a skill that I admire and will try to emulate (both the big picture fit and the calmness). Dr. Luft provided excellent technical guidance on the intricacies (and errors) of my financial measures and, despite the inevitable craziness (from the student perspective) surrounding the completion of the dissertation, reminded me of how rewarding it is to be able to work with faculty and students in our academic environment. To all of you, please accept my heartfelt gratitude.

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KEYS TO SYMBOLS OR ABBREVIATIONS

HDV	Higher demand variance
LDV	Lower demand variance
SC	Supply chain
SCD	Supply chain design
SCRS	Supply chain relationship structure

CHAPTER 1

1 INTRODUCTION

The last two decades of research on supply chains has provided significant evidence that supply chains are an important aspect of firm competitiveness (cf. Lee and Billington, 1992; Fisher, 1997; Lee, 2004). This is now widely recognized by academics and practitioners (Melnyk, Lummus, Vokurka, Burns and Sandor, 2009); as a result, for many firms *how* they compete has changed over these last two decades. Firms are now moving away from the perspective of firms competing against firms and are viewing the competitive environment as supply chains competing against supply chains (Christopher, 2000; Ketchen and Hult, 2007).

But what is a supply chain? By definition, a supply chain spans from extraction of raw material to delivery of the final product to an end customer, and includes the return cycle for sustainable products. Yet few firms have significant control or influence over customers and suppliers across their supply chains, and their influence is typically limited to down one tier to immediate customers and up one tier to immediate suppliers (Storey, Emberson, Godsell and Harrison, 2006).

Even with this limited span of influence, many firms have achieved significantly improved performance through leveraging their supply chains while others firms have not benefited or have been harmed for ineffective supply chain practices. For example, firms recognized as having high performing supply chains according to AMR Research

(2008b) reported average stock market returns for 2007 for *Supply Chain Top 25* companies that were more than 500% of the average stock market returns for the S&P 500 and more than 250% of the Dow Jones Industrial Average returns. Yet many firms have had difficulties in effectively managing their supply chains. For example, Hendricks and Singhal (2005b) examined 827 supply disruption announcements over the period 1989 – 2000 and identified that firms experiencing supply chain "glitches" report average abnormal stock returns of -40% in the period surrounding the disruption. In another study, examples of financial losses to firms due to supply disruptions were in the range of tens of millions to over a billion dollars (Craighead, Blackhurst, Rungtusanatham and Handfield, 2007).

This provides evidence that the presence of a supply chain can contribute to enhanced or improved performance. However, it is important to recognize that for every successful supply chain, there are other less than successful implementations. Understanding the differences between successful and unsuccessful implementations is an important research theme since it focuses on one factor that can potentially explain at least part of these differences – supply chain design.

Supply chain design (SCD) can be viewed as being the template used in determining how to put together the appropriate firms and link them suitably to achieve desired strategic outcomes (Melnyk, Davis, Spekman and Sandor, 2010). That is, supply chain design determines the specific capabilities of the supply chain. It also affects the properties of a supply chain – properties such as visibility, control, coordination, and the level of buffers present (in the form of lead time, capacity or inventory). However, at the heart of this view is an important consideration – supply chains are outcome-driven (Melnyk et al., 2010). That is, this study takes the view that there is no such thing as a "generic" or "one size fits all" supply chain design. How managers put together the supply chain will be largely influenced by the desired outcomes for that supply chain. Consequently, this study views supply chain design as highly contingent in nature – it is contingent or dependent on the specific outcome being pursued.

This contingent view of supply chain design has important implications for the firm. For example, while there appears to be little disagreement over the importance of supply chain design (Fisher, 1997; Lee, 2004), there are widely differing views on *how* to design supply chains, particularly on how to structure relationships between firms in the supply chain. Some authors advocate extensive visibility and information sharing to improve control and influence over multiple tiers (Christopher and Lee, 2004a; Buhman, Kekre and Singhal, 2005), while others advocate flexibility and responsiveness to market and technological changes (Schilling and Steensma, 2001; Prahalad and Krishnan, 2008).

These differing views have important implications for firms; structuring supply chain relationships based on adopting one of these strategic viewpoints suggests that the capabilities developed will be very different than if the firm adopted the alternative view. To state this logic from a strategy-structure-performance perspective, the firm must make strategic decisions on how to structure relationships between firms in the supply chain to support achievement of the outcomes. These decisions influence the design of the supply chain, which results in firms developing specific capabilities that directly affect firm performance (Fine, 1998). These capabilities can be viewed as sets of business processes that are strategically driven (Stalk, Evans and Shulman, 1992); thus the development of supply chain capabilities is intended to solve specific supply chain problems for the firm, which directly affects firm performance.

It is noted that while the development of supply chain capabilities is determined by SCD decisions (Fine, 1998; Lee, 2004), these decisions may be made implicitly or explicitly by firms. When a firm only considers the structure of supply chain relationships with adjacent firms, it implicitly or explicitly decides that relationships further upstream and downstream are the responsibility of the direct supplier or customer. Firms may also explicitly decide to work toward extend influence beyond adjacent tiers.

How firms make decisions on structuring supply chain relationships is still an open question. As there is yet no widely accepted framework identifying important decision dimensions upon which a firm makes choices that result in the structure of supply relationships. Investigating these choices and their effect on firm performance from an outcome-neutral perspective is of interest in this study.

1.8 Focus of this study

This dissertation focuses on one aspect of supply chain design -- the structure of supply chain relationships between firms and how this choice affects visibility and information sharing capabilities and consequently affects firm performance. Specifically, it explores how the two extremes of the relationship structure continuum – modular and integrated – affect design and ultimately performance. In this study, the structure of supplier relationships is called *supply chain relationship structures* (SCRS). SCRS is defined as *the implementation and management of specific types of relationships between firms in a supply chain that are intended to help the firm achieve certain outcomes.*

Developing successful supply chain relationships is not a trivial issue. Developing closely integrated relationships requires resource investments by firms and imposes certain requirements on each participating company to maintain the relationship (Spekman and Davis, 2004). It is also very time-consuming. For example, in an integrated SCRS firms must make investments in human capital, software, integrated information systems, and management systems to sustain and support them.

Developing highly modular relationships also requires resource investments to develop standards for interfaces between firms to improve strategic flexibility, developing capabilities to minimize switching costs while selecting qualified suppliers, and managing a larger number of suppliers for key products and components (Fine, 1998). These investments in modularity improve strategic flexibility in dynamic environments but come with the costs of redundant suppliers, lower volume leverage, and managing a larger number of relationships.

Thus, the choice of SCRS imposes costs on the firm, and firms must strategically choose the appropriate SCRS to gain maximum benefits from their resource investments. Furthermore, these structure decisions must be consistent with and supportive of the desired outcomes. Yet as noted, the results of research on choosing an appropriate SCRS are mixed and there is no widely accepted framework that provides guidelines on decisions firms must make in choosing an appropriate SCRS. This problem is further complicated when the outcome is considered. As Melnyk et al noted (2010), supply chains focus on developing a mix of six outcomes: cost, responsiveness, sustainability, resilience, security, and innovation.

Therefore, to effectively study supply chain design overall and the impact of supply chain relationships specifically, the specific outcome that the supply chain is to pursue must first be identified. For the purposes of this study, it was decided to pursue the focus of the resilience-cost mix of outcomes. That is, this study is interested in studying how the decision of supply chain relationships contributes to the performance of a firm when management is interested in reducing the costs of having a resilient supply chain.

There are several reasons for focusing on this set of outcomes. First, by focusing on resilience, this study addresses how the supply chain design can deal with unexpected disruptions. There has recently been a great deal of interest in how supply chains deal with disruptions (cf. Christopher *et al.*, 2004a; Zsidisin, Melnyk and Ragatz, 2005; Craighead *et al.*, 2007). Second, by focusing on disruptions, this study focuses on how the choice of relationships can affect performance under conditions of extreme stress. Like stress is used to test and evaluate engineering designs, in this study stress is created by a supply chain disruption to evaluate and assess performance effects from the resulting supply chain designs. It is with these considerations in mind that the research problem for this dissertation is presented.

1.9 Research problem

The research problem in this dissertation is focused on a specific aspect of SCRS:

Given a supply chain that is desired to be efficient and resilient:

a) To what extent do visibility and information sharing capabilities of integrated as compared to modular supply chain relationships significantly affect overall firm performance, and

b) To what extent does this choice of strategy-structure significantly affect firm performance under varying conditions of supply disruption?

1.10 Methodology

To investigate the research problem, a multi-method approach is needed, consisting of case research and a simulation model. The case research serves two purposes:

a) To evaluate and refine the theoretical framework generated from the literature review, and

b) to provide empirical evidence and data from which the resulting simulation model can be built.

The simulation model will be used to provide an initial answer to the second part of the research problem by replicating basic aspects of the supply chains for two differing demand conditions and then inducing conditions of supply disruption to see if performance differs by SCRS. To simplify the simulation model and reduce confounding effects, one simulation model will be used for both demand conditions – lower demand variation (LDV), such as in just-in-time production, and higher demand variation (HDV), such as for globally outsourced durable consumer products.

Data will be generated for each demand condition using the simulation model and demand-specific parameters (such as demand variation). This will be done first using the information sharing practices of a modular SCRS as identified from the SCRS framework in Chapter Three as a baseline of performance, and then updating model parameters to use information sharing practices of an integrated SCRS for the same demand condition. Next, supply disruptions will be induced at the supplier level, with data on firm performance generated for each SCRS under the disruption scenarios using the experimental design in Chapter Four.

Statistical analysis by demand condition will be performed on the data generated, providing a comparison of the same demand condition using the two SCRS archetypes, modular and integrated, while reducing the confounding effects of comparing very different demand conditions that are characteristic of different industries against each other.

Because of how supply chains operate, it is necessary to look beyond using a survey design method, which focuses on what people know or have been exposed to in their work. In this case what people know or have experienced is not relevant because the research interest is on what can best be described as "what-if" analysis – the domain of simulation. The expected results of this dissertation are two potentially useful contributions to the literature.

1.11 Expected contributions

There are two expected contributions from this dissertation:

a) Development of a theoretical framework of important factors that firms should consider when choosing an SCRS on the modularity-integration continuum, with specific focus on the visibility and information sharing dimension of SCRS, and
b) a limited test of the SCRS framework to evaluate how firm performance differs under conditions of supply disruption by SCRS-related visibility and information sharing practices, using empirical data from two firms to parameterize lower and higher demand variation conditions in a simulation model to generate data for analysis.

These contributions are an incremental contribution to the literature on how to structure supply chain relationships based on the impact of different visibility and information sharing practices, and the initial test of how the structure of these relationships using the simulation model may provide an additional tool for firms to use in this process.

1.12 Chapter summary

This chapter started with the recognition that supply chains are now widely considered to be of strategic importance to firms, and that recent research has identified that firms seek improvements in SCD and SCRS to gain additional competitive advantage. It was identified that firms develop specific capabilities to help achieve desired strategic outcomes, and that structuring relationships between firms in a supply chain is of critical importance in this process. However, the evidence for which SCRS to choose is mixed; therefore, this study is intended to contribute insights into this through investigation of the research problem.

In this Chapter, the research problem of this study was presented: develop a framework for SCRS by identifying important factors firms must consider when developing an appropriate SCRS, specifically focusing on differences in visibility and information sharing practices, and conduct an initial and limited test of how the choice of SCRS may influence firm performance under conditions of supply disruption.

Investigating the research problem requires a multi-method approach. A literature review and case studies are used to identify important factors influencing a firm's decision on SCRS and to obtain data to parameterize and provide basic structure for the simulation model. The simulation model is used to generate data for statistical analysis to test whether a firm employing a desired strategic outcome of resilience may observe performance differences, by SCRS, under conditions of supply disruption. In this Chapter, definitions were also provided for supply chain, SCD, and SCRS.

The literature review in Chapter Two includes a brief overview of supply chains, desired strategic outcomes, and SCD. The costs and benefits that firms may realize from effective and ineffective SCD will be briefly discussed, and the focus of the study will then be placed specifically on SCRS as an important aspect of SCD. Modular and integrated SCRS's will be defined in the discussion on SCRS, with a specific emphasis on differences in visibility and information sharing practices for purposes of the initial limited test of the framework, and some of the challenges and benefits for both will be provided.

Chapter Three will present the need for an SCRS framework, establish the scope of the study, present the SCRS framework, and provide a description of the important strategic decisions from the framework that firms should make when explicitly making decisions on how to structure relationships in supply chains. Then the initial test of the framework will be explained, including how the role of resilience as a desired strategic outcome is an important aspect of the test, how the impact of SCRS will be evaluated in the analysis of the data generated from the simulation model, and what performance measures are used in this study.

Chapter Four will provide details of the research methodology; including how the case studies were conducted, a description of the demand conditions identified for the study and the source of empirically grounded data selected for the study, a description of the simulation model, the experimental design, and the analysis strategy. Chapter Five includes a discussion on the implementation of the simulation model, analysis of data by demand condition, findings from the study, and managerial implications. Chapter Six provides a summary of the study, including contributions from the study, limitations of the study, and areas for future research.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Chapter Objectives

There are several objectives for this Chapter, including establishing the theoretical foundations for the SCRS framework Chapter Three and the basis for the experimental design in Chapter Four. With these goals in mind, the objectives of this Chapter are to:

- position this study within prior studies on supply chains, particularly studies on supply chain design that pertain to structuring supply chain relationships,
- identify a conundrum, or puzzle, of why some firms succeed with a strategic approach to supply chains while others fail,
- provide a brief introduction to the literature on SCD and SCRS that will be used to develop the SCRS framework in Chapter Three, including costs and benefits of alternate SCRS choices,
- discuss SCRS in the context of resilience as a desired strategic outcome, and how supply disruptions and resilience provide an appropriate test environment in Chapter Four for evaluating firm performance under different choices of SCRS, and
- provide definitions that are important to the study.

The discussion begins on the importance of supply chains.

2.2 Importance of Supply Chains

The importance of supply chains has become widespread since initial research in the 1980's, and is now widely recognized as an important strategic opportunity and challenge for many firms. This discussion on supply chains begins with a question: *what is a supply chain*? In Chapter One, an introductory discussion was provided on how a supply chain is a set of firms involved in a series of processes, from firms removing raw materials from the ground to firms serving end customers, with a return process for sustainable products. A more formal definition is provided by Christopher and Peck (2004b, p. 4), who define a supply chain as "the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer".

As the strategic importance of supply chains continues to grow, manufacturing and service firms recognize that much is at stake. In early 2008 AMR Research (2008b) reported that firms in the "Supply Chain Top 25" reported an average total stock market return for 2007 of 17.89%, while the Dow Jones Industrial Average (DJIA) had average returns of 6.43% and the S&P 500 index had average returns of 3.53% during the same period.

At the time the Supply Chain Top 25 included firms in the computer, electronics, automotive, retail, beverage, health care, apparel, and pharmaceutical industries, indicating a widespread recognition of the value of effective supply chain practices.

Later in 2008, when the stock markets were down substantially, the Supply Chain Top 25 were down significantly less than the DJIA and S&P 500 indices (AMR Research, 2008a).

But it is not all good news for firms participating in supply chains. The downside of ineffective supply chain practices can have a substantial negative effect on firm performance as well. In a study of supply chain "glitches", Hendricks and Singhal (2005b) found that when publically traded firms experienced supply chain disruptions, the average abnormal financial returns to the firms over the subsequent two year period was close to -40%, and the equity risk of the firms increased at the same time.

But supply chain problems are not limited to supply disruptions. Boeing introduced the design for the new 787 Dreamliner several years ago, but has had numerous production problems with supply availability, collaborative design and development challenges, and problems developing new materials for production (Weber and Matlack, 2009). In a different industry, Ericsson experienced a supplier problem when a small fire eliminated supply of a critical cell phone chip, and the firm never recovered (Zsidisin *et al.*, 2005). There are many examples of how firms have suffered from ineffective management of supply chains, but regardless of the specific causes firms recognize that mere participation in competitive supply chains does not mean the firm will gain potential benefits.

These issues present a conundrum: why do some firms gain significant advantage for supply chains, while others do not and may even underperform relative to their competition? Why is this important? Because planning and implementing effective supply chain practices requires managers to make decisions today that affect how well firms will perform in the future, and the costs of poor decisions today have dramatic effects on future firm performance.

2.3 A Conundrum

Why do some firms achieve success with their supply chain practices while others underperform to their potential? One potential answer to this puzzle lies in understanding the difference between the breadth of an overall supply chain versus the effective span of control or influence that a firm has on its particular supply chain, and how the span of influence can be used to competitive advantage. For example, Toyota and Wal-Mart have worked to extend their span of control in supply chains beyond their immediate suppliers while working to implement strategic information systems that provide increased visibility of information in their supply chains to help improve flow of product, reduce inventories, and reduce overall supply chain costs. This increased visibility also provides early warning of problems that may be developing in the supply chain, providing additional reaction time that may mean the difference between a supply disruption and effective performance.

The value of increased visibility has strategic benefits to firms. As an example, in a recent article on Proctor & Gamble (P&G), Supply & Demand Chain Executive (2010) reported that developing near-real time visibility to orders, inventory and shipments has helped P&G reduce inventory carrying costs by 24%, reduce lead times by 28%, and improved on-time customer delivery from 33 to 74%. But effectively increasing visibility of information in supply chains requires extensive cooperation of numerous suppliers and investment of resources by participating firms.

Some firms, particularly large firms that have the power of high purchase volumes to induce suppliers to participate in supply chain initiatives may do very well in return. But there are limits on span of control in multi-firm relationships and many firms do not achieve the ability to increase their span of control and leverage in supply chains (Storey *et al.*, 2006).

2.3.1 Effective SC Span of Control

What happens when a firm's effective span of control in a supply chain is less that the span of the total supply chain? If the firm cannot see problems that occur beyond its supply chain span of control, the unforeseen problems can affect business continuity and supply chain performance with no prior warning (Christopher *et al.*, 2004a; Zsidisin *et al.*, 2005). The Ericsson example above, where the customer was not aware of the extensive contamination of the chip production plant that resulted in months of delays, is but one example. And increased visibility is not a panacea. In 2003, When Apple was planning to launch its G5 computer using chips from IBM, the launch was delayed by a multi-state power outage because Apple was using a single source strategy in its supply chain for the CPU processor chip.

These issues of visibility, control, and coordination all fall under the realm of SCD. They require investments in developing specific capabilities that substitute for the internal control that would be available through vertical integration (Davis and Spekman, 2004).

This observation suggests that superior SCD provides another potential answer to the puzzle of why some firms performance better than others through the use of effective supply chain strategies. This leads to a discussion of SCD.

2.4 Supply Chain Design

SCD is a topic with a number of dimensions. Several of them will be presented briefly before one important dimension of SCD, *SCRS*, becomes the focus of this Chapter. When viewed from a strategic perspective, SCD is focused on achieving certain strategic outcomes (Melnyk *et al.*, 2010). Once the desired strategic outcomes are articulated by the firm, the task is to structure the design of the supply chain to achieve these strategic choices (Miles and Snow, 2007).

Structuring the supply chain design requires the development of specific capabilities designed to support the desired strategic outcomes (Fine, 1998). This theoretical logic has been observed in practice, where Melnyk et al. (2009) found empirical evidence that firms are becoming increasingly aware that the development of appropriate supply chain capabilities needs to be focused on achieving desired strategic outcomes. The discussion on SCD capability starts with how to define SCD.

2.4.1 Defining SCD and capabilities

Fine (1998) argues that effective SCD develops specific strategic capabilities and that these capabilities affect a firm's ability to achieve strategic outcomes. In a subsequent article he continues this argument, and frames his approach to SCD as follows:

> *The ultimate core competency of an organization is "supply chain design," which I define as choosing what capabilities along the value chain to invest in and develop internally and which to allocate for development by suppliers. In a fast-clockspeed world, that means designing and redesigning the firm's chain of capabilities for a series of competitive advantages (often quite temporary) in a rapidly evolving world (Fine, 2000, p. 213).*

This definition is conceptual in nature, as it cannot be operationalized to determine specifically what is and is not included in SCD. However, his focus on intentional preplanning and design of the supply chain is evident. Fine's approach clearly makes a distinction between supply chain management and SCD: the former is concerned with superior management of current capabilities within the firm and the supply chain; the latter is concerned with intentionally *developing* superior capabilities to maximize firm performance and future competitive advantage.

This strategy relies on the firm establishing desired strategic outcomes, and then designing or influencing the design of the supply chain to achieve them. From the perspective of SCD, it follows that how the firm structures the supply chain affects how well or poorly the supply chain supports achievement of the firm's desired strategic outcomes. Fine's approach to the development of specific capabilities to support desired strategic outcomes and his definition of SCD are adopted for this study.

The term *capability* is drawn from the strategy literature on the resourced based view of the firm (Wernerfelt, 1984). In this study, the term is applied to the supply chain context where supply chain capabilities are defined as *the systems, processes, routines, and skills that the organization develops through its supply chain to solve specific types of* *problems*. This definition provides a link between SCD and expected firm performance. The goal of SCD, conceptually, is to mistake-proof (poka yoke) the SCD process by developing specific capabilities that make the intended desired strategic outcome inevitable. Thus if a firm could poka yoke the SCD process, the outcome would be consistently achieved.

What is the problem with this simple logic? There are at least two. First, capabilities are not typically observed directly. They are "seen" through evidence of their influence on system behavior and firm performance, specifically where the behaviors are directly associated with the observed performance effects. These behaviors associated with firm performance effects are called properties in this study. The second problem is that supply chain design is a very complicated topic, involving numerous activities along many SCD dimensions (Fine, 1998; Sheffi, 2005). In the following sections a discussion on the relationship between capabilities and properties is provided, followed by a discussion on dimensions of SCD.

2.4.1.1 Capabilities are related to properties

As previously noted, when firms develop specific capabilities in supply chains these capabilities influence how the supply chain performs. Thus, once a capability is implemented it changes the behavior of the system. When the underlying behavior of a organizational system is systematically influenced, it is said to have *properties* that are identified with that behavior (Simon, 1962). For example, firms develop capabilities to improve responsiveness in uncertain environments, and once successfully implemented, these firms are said to have *agility* (Christopher, 2000). Agility is one of many properties that have been identified in supply chains, as noted below.

To build on this introduction to properties the discussion turns to defining the term *properties*, and then examples of properties are provided within a supply chain context. This is done to establish a foundation for subsequent discussion later in the dissertation. A property, according to one dictionary definition (Webster's Revised Unabridged Dictionary, 1998) is "that which is proper to anything; a peculiar quality of a thing; that which is inherent in a subject, or naturally essential to it; an attribute; as, sweetness is a property of sugar." Properties of metals, for example, include tensile strength and corrosion resistance.

In this study, it is observed from a review of the literature that there are a number of properties that have been identified in supply chains, such as visibility (Smaros, Lehtonen, Appelqvist and Holmstrom, 2003; Christopher *et al.*, 2004a), resilience (Sheffi, 2005; Melnyk *et al.*, 2010), robustness (Yongyut and Nilay, 2007; Klibi, Martel and Guitouni, 2010), flexibility (Worren, Moore and Cardona, 2002; Sánchez and Pérez, 2005), agility (Christopher, 2000; Lee, 2004), and responsiveness (Fisher, Hammond, Obermeyer and Raman, 1997; Reichhart and Holweg, 2007).

To clarify the distinction between capabilities and properties, capabilities are generally latent constructs that cannot be observed directly. Properties are generally observable outcomes or behaviors that result from the presence of capabilities employed by the firm, such as agility being observed in a firm's response to uncertainty in supply or demand. As observed from the literature, supply chain properties may be visible or hidden (Holland, 1995; Simon, 1996), and the presence of these properties may influence performance beyond those intended by firms. For example, the effects of demand variation as it propagates through the supply chain are not always fully observed by firms, resulting in unintended consequences on supply chain performance (Lee, Padmanabhan and Whang, 1997).

These supply chain properties play an important role in determining the performance envelope of firms in the supply chain. Two properties are of specific interest in this study: robustness and resilience. Robustness is the ability of a firm to resist the onset of a disruption (Yongyut *et al.*, 2007). Resilience in this study focuses on firm performance, specifically on the ability of a system such as a firm to survive and return to stability near an equilibrium steady state after a disturbance to the system (Sheffi, 2005). Examples of resilience include supply chain recovery after supply shortages due to dock and labor strikes, and natural disasters. Both robustness and resilience will be discussed in more detail later in this Chapter.

2.4.2 Potential dimensions of SCD

There are several dimensions of SCD that have been identified in the literature. While a comprehensive discussion of SCD is well beyond the scope of this study, a brief discussion will serve to illustrate the complexities involved in SCD. In addition to including firms identifying *desired strategic outcomes* as an important dimension of SCD, there are several other dimensions identified from the literature, including: SCRS (Fine, 1998), supply chain duration – evergreen and temporary (Van Wassenhove, 2006), stages of the product life cycle (Fixson, 2005), supply chain drivers (Fisher, 1997; Hull, 2005), supply chain life cycle (Vonderembse, Uppal, Huang and Dismukes, 2006), global competitive environment (Christopher, Peck and Towill, 2006), industry effects (Porter, 1979), and supply chain performance measures (Beamon, 1999). Of these and other potentially important dimensions of SCD, *SCRS* is the SCD dimension that is relevant to this study.

2.5 Supply Chain Relationship Structure

A recent article in morebusiness.com (2006, p. 1) points out that *"Supply chain relationships should be treated as invaluably as customer relationships. The argument could be made that you are the customer and therefore you should be on the receiving end of customer relationship management, the reality is that you need to be on the giving end of supply chain relationship management."* This perspective emphasizes the need for firms to not only receive benefits in a supply chain relationship but also to give benefits to other firms to support achievement of the focal firm's intended results. The article points out challenges in supply chain relationships, such as being supplied by a distributor when you are only one of several important customers to the distributor, and firms needing to develop supply chain practices to gain preferential attention from suppliers.

This and other articles focus on how to develop closer relationships with suppliers to increase influence and leverage when challenges in the supply chain relationship emerge. But this is not easy; Davis and Spekman (2004) identify a number of conditions and challenges that firms face when extending their influence in supply chains. Studying aspects of SCRS is a complex issue that has been the subject of many research studies. One aspect of SCRS that is of interest in this study is how firms evaluate trade-offs between choosing an SCRS and how firms estimate how much to invest in an SCRS. This approach helps focus the study on structuring supply chain relationships rather than on how far to collaborate.

The domain of supply chain relationship structures can be conceptually viewed as a continuum between highly integrated and highly modular. Integrated SCRS's, such as those used in lean production systems, exploit advantages of tight coupling between firms across boundary-spanning processes and business practices through increased cooperation, collaboration, communication, visibility, and information sharing to increase competitive advantage (Saeed, Malhotra and Grover, 2005). Modular SCRS's rely on loosely coupled but clearly specified interfaces and performance standards between organizations, such as observed in the personal computer industry, to allow increased flexibility and responsiveness to changing environmental conditions (Schilling *et al.*, 2001).

But how do firms decide on which SCRS to use? It appears to depend, in part, on organizational goals, competitive strategy, the structure and clockspeed of the industry, and the evolution of firm and inter-firm capabilities. This observation that the appropriate choice of SCRS may affect firm performance provides another potential answer to why some firms perform better than others when deploying supply chains strategies. In the next section the background to the two SCRS archetypes, *modular* and *integrated*, is developed in preparation for the development of the SCRS framework in Chapter Three.

2.5.1 Integrated SCRS

Integrated supply chain relationships have been popularized by lean production systems, with one of the most popular examples being Toyota and its highly interconnected supply chain (Spear and Bowen, 1999). Integrated SCRS's use a high degree of collaboration and cooperation in product and process development, as well as in information sharing of production schedules, advance shipment notices, shipments, process performance, problem areas, and areas of opportunity where joint participation will result in higher performance for the supplier chain and ultimately for the focal firm (Christopher and Towill, 2001). Visibility and information sharing has received considerable attention in the literature in playing a key role in supply chain integration. Differences in information sharing capabilities between an integrated and a modular SCRS on firm performance are the primary focus of the initial test of the SCRS framework later in this study.

There is a considerable research stream on supply chain integration and the resulting benefits. Conversely, there is a corresponding dearth of research that suggests integration is detrimental. This raises the question: if integration is so beneficial, why doesn't every firm employ it? The answer appears to reside in a deeper understanding of the benefits and costs an integrated SCRS as compared to a modular SCRS, the details of which are pursued in this study.

2.5.2 Modular SCRS

Modular supply chain relationships focus on identifying and leveraging key interfaces between buyer and supplier firms. Modularity in interorganizational relationships exploits the use of clearly specified interfaces between firms, and treats the internal activities of the firms as a "black box" when these internal activities are not of concern to the other firms, as long as the *interfirm* interactions follow protocol and the expected performance from the relationship is achieved (Schilling *et al.*, 2001). In the extreme, what a given firm does internally is of no concern to other firms as long as performance in the interfirm relationship is as expected.

Modular supply chain relationships are more common in: a) industries with high rates of innovation and technological change, and b) industries where component parts or services are interchangeable due to national or international product standards (Fine, 1998). Modular *product* interfaces are most commonly employed in component and assembly design during product development, an area of where there is a significant research stream. However there is also literature on the value of modular interorganizational interfaces between firms in a supply chain (Ethiraj and Levinthal, 2004). Many firms in the computer industry, for example, use modular supply chain relationships in addition to their widely known use of modular product designs.

In addition, many manufacturing and software firms are exploiting global research and development expertise through modular relationships with external companies. But there are other service related examples of modular interfaces in key supply chain relationships, such as in banking, logistics service, and information technology relationships. In the recent book by Prahalad and Krishnan (2008), the authors advocate much more extensive use of modular supply chain relationships. They argue that there is no longer any value in making distinctions between product and process innovations because the focus should be on innovative customer experiences that leverage global relationships between firms, and they argue that modularity in global supply chain relationships is critical to future success.

2.5.3 SCRS Costs and benefits

In choosing an SCRS, for every benefit there is a corresponding cost. With a modular SCRS, the expected increase in flexibility and responsiveness comes at the cost of more relationships to manage, more suppliers to qualify, more inter-firm interface standards to define/gain acceptance, and a spread of purchase volume commitments to more than one company, resulting in lower purchase volume leverage. For a firm employing a modular SCRS, the benefits of lower switching costs and responsiveness are traded-off by lower visibility to identify potential problems and the loss of lower total system costs that are available through more extensive coordination and communication practices.

For an integrated SCRS, the advantages of higher visibility, improved coordination, lower inventories, and lower system cost come at the expense of investments in more integrated information systems, more human capital to maintain closer relationships, and lower flexibility and higher switching costs during dynamic competitive environments. When relationships are switched in an integrated SCRS, the new relationships and integrated processes have to be integrated over time, increasing investments in new suppliers and increasing human capital to aid in the transition.

In addition, if a firm over-invests in a relationship, it negates some of the performance benefits, particularly financial performance. If a firm under-invests, it loses some of the potential benefits. Thus there are trade-offs that firms must consider between increased coordination and investment, and between control versus flexibility during environmental change (van Hoek and Weken, 1998; Bensaou, 1999). These SCRS-related costs and benefits need to be placed in the context of a firm's desired strategic outcome.

2.6 Desired Strategic Outcome: Resilience

The choice of SCRS made by firms should be made in the context of firm strategy. As noted in Chapter One, this study focuses on assessing key dimensions of SCRS relationships in the context of a firm pursing a desired strategic outcome of resilience. In the context of resilience, Melnyk et al. (2010, p. 34) state that "resilience ensures that the supply chain can recover quickly and cost-effectively from disruptions caused by natural disasters (such as earthquakes), social factors (employee strikes), medical emergencies (epidemics such as H1N1 flu), economic setbacks (the bankruptcy of a critical link in the chain) or technological failures (a software crisis)."

Resilience in a supply chain, therefore, is the ability of a firm to endure a supply disruption and return to a state of stable performance after the disruption ceases. The less time and cost for a firm to attain stabile performance after a disruption, the better. The ability of a firm and its supply chain to be resilient in the face of disruptions is considered critical by executives (Sheffi, 2005; Melnyk *et al.*, 2010), and the ability of a firm to exhibit resilience can significantly affect firm performance during conditions of supply disruption (Sheffi and Rice, 2005). Because of its importance in this study, a brief discussion of resilience and of supply disruptions follows to build the foundation for the SCRS framework in Chapter Three and the experimental design in Chapter Four.

2.6.1 Measures of resilience

Resilience is often measured in terms of the time duration under which the firm is resilient, from the onset of the disruption until firm performance stabilizes after cessation of the disruption (Sheffi, 2005). The financial cost of the disruption is often an associated measure (Craighead *et al.*, 2007). In theory, the time duration under which a firm is resilient is an indicator of a firm's capability to survive in times of distress, but in practice it becomes an ex post observation of what a firm was able to survive, not its potential to survive certain events.

From a theoretical perspective, knowing how long a firm could "suffer yet survive" could be very useful in times of resource scarcity as well as in periods of higher competitive intensity. But from a practical standpoint, during periods of resilience firms take active measures to reduce the duration and impact of the disruption, and have no interest in how long the firm could actually endure the performance effects of a disruption to test its "true" resilience capabilities.

In light of this, in the literature a more appropriate measure is often used in practice, such as measuring resilience of firms that experienced instances of supply disruption as a *"disruption of duration x"* and if possible including the measure *"at a cost of y"*. As Sheffi (2005) notes, from the perspective of firm performance the duration of the disruption is more important that the specific cause. Focusing on duration and cost provides a rough estimate by which managers can assess the trade-off of the risk of disruptions as a function of cost and time against the potential benefits of ex ante resource investments to help manage or mitigate anticipated disruptions.

Another observable property of performance, *robustness*, is also used in the context of disruptions as a measure of time duration during which firm performance does not degrade after the onset of a disruption (Yongyut *et al.*, 2007). During supply disruptions, firm performance may demonstrate a time period of robustness followed by a time period of resilience before recovery to stable performance following cessation of the disruption (Sheffi, 2005). More specific measures of resilience and robustness for this study will be presented in Chapter Four.

The next section introduces a discussion on supply disruptions. While supply disruptions are not the focus of this study, they do provide an environment from which to ascertain how firm performance may differ by firm choice of SCRS under normal conditions and adverse conditions such as supply disruptions. In this study, supply disruptions will be used in Chapter Four in the experimental design as part of a "stress test" from which to test differences in firm performance based on choice of SCRS and duration of disruption.

2.6.2 Supply disruptions

Recent literature has provided considerable insight into the causes and impact of supply disruptions to firms and has identified practices that firms may use to manage or mitigate anticipated disruptions. From this perspective, following is a very brief overview of supply disruption as they pertain to this study.

2.6.2.1 What is supply chain disruption?

Disruptions in supply are widely recognized and are of serious concern to practitioners and academics (Sheffi, 2005; Melnyk *et al.*, 2009). Disruptions are costly, and firms seek to mitigate the effects of disruptions in several ways, including by seeking to improve supply chain resilience. But what is a supply chain disruption? Kleindorfer and Saad (2005, p. 53) define supply disruptions as disruptions arising from "operational risks (equipment malfunction, unforeseen discontinuities in supply, human centered issues from strikes to fraud), and risks arising from natural hazards, terrorism, and political instability".

They distinguish supply disruptions from problems arising from the risks of coordinating demand and supply among multiple supply chain actors. This definition is adopted in this study, the focus of which is to understand how differences in a firm's choice of SCRS influences firm performance during disruptions in an effort, in part, to increase knowledge of how supply chain resilience to disruptions may be related to a firm's choice of SCRS.

2.6.2.2 Effects of supply disruption

Recent research indicates the effects of disruptions can be expensive and long lasting. In a second paper by Hendricks & Singhal (2005a) on supply chain glitches, the authors found a significant and negative relationship between announcements of glitches by publically traded firms and return on sales and on return on assets. They also found that firms that experience glitches report on average 6.9% lower sales growth, 10.7% higher growth in cost, and 12.9% higher growth in inventories.

The costs of supply chain disruptions to firms can be significant. Blackhurst, Craighead, Elkins and Handfield (2005) noted that an 18 day labor strike in 1996 at a North American automotive supplier resulted in an estimated reduction in earnings of $900 million for the company, and in 1997 an aerospace manufacturer had an estimated loss of $2.6 billion due to supply failures. In another study on financial impact of disruptions and aspects of SCD, Papadakis (2006) examined stock market returns to companies after supply disruptions, and found a significant difference between push- and pull-type supply chains. He found that investors associated the more tightly coupled pull-type supply chains with lower returns after a disruption, indicating widespread investor expectations of causality between SCD and firm performance under adverse supply conditions. With such high performance penalties at stake, firms have developed mitigation strategies to help mitigate and manage risks from SC disruption.

2.6.2.3 Mitigating risks of SC disruption

Several researchers have investigated how firms plan for and mitigate disruptions in supply. In this section, a few related studies are provided to establish the relationship between supply chain risk and potential resource investments by firms to manage and mitigate them. Recent studies have examined the sources and drivers of supply chain risk (Zsidisin, Ellram, Carter and Cavinato, 2004; Peck, 2005), while other studies have investigated techniques and practices designed to identify, assess, manage and mitigate supply risk and business continuity (Zsidisin *et al.*, 2005; Tang, 2006).

These and numerous additional studies in supply chain risk and disruptions highlight the increasing importance that managers and academics place on understanding supply chain risk and developing strategies for improving supply chain performance under conditions of disruption. Many researchers and managers seek to improve supply chain performance under conditions of disruptions by developing more resilient supply chains.

One of the challenges to managers in determining the level of resources a firm should commit to managing and mitigating SC disruptions is estimating how the firm would perform under conditions of disruption. Without this insight, managers have only experience and intuition to guide them as they made decisions on resource investments in risk management and mitigation practices. This approach to more accurately assessing how firms can estimate financial performance during potential supply disruptions is used as an initial test in Chapter Four that is based on the SCRS framework developed in Chapter Three. From here, the Chapter Summary is provided before proceeding to Chapter Three.

2.7 Chapter Summary

This Chapter began with a discussion on the widespread recognition that supply chains are an increasingly important aspect of firm strategy, and that effective or ineffective use of supply chain strategies can have significant effects on firm performance. In this Chapter a conundrum was identified: if firms widely recognize that supply chains are critical to firm performance, why don't all firms benefit from this insight? Part of the answer appears to lie in how firms establish relationships with other firms to design, or influence the design, of the supply chain, including the challenges and costs firms face as they make strategic decisions on supply chains.

In this Chapter, SCD was recognized as having a number of important dimensions. After defining SCD and capability, potentially important dimensions of SCD were introduced. One of the SCD dimensions, SCRS, was then identified as the focus of this study. Two distinct archetypes of SCRS were identified, modular and integrated. From there, a key dimension of SCRS was identified as the focal point of the initial test of differences in SCRS on firm performance, that of visibility and information sharing. In addition, costs and benefits typically associated with modular and integrate SCRS's were identified from the literature, and the discussion on SCRS was placed in the context of the desired strategic outcome selected for this study, that of resilience. Resilience and robustness were defined in this Chapter, and initial measures of both were provided. There were several constructs and building blocks for constructs developed in the Chapter that will be used in subsequent Chapters. A summary of these is provided in Appendix 2A.

The final section of this Chapter focused on supply chain disruptions as a potential "stress test" to be used in Chapter Four for evaluating how firm performance may change when employing a particular SCRS under normal conditions and conditions of supply disruption. The significant negative effects from potential supply disruptions were identified from prior cases in the literature, and the trade-offs managers must make in evaluating the potential costs of supply disruptions against the costs and benefits of employing mitigation and management practices were identified. Through these discussions this Chapter provided important definitions and studies that provide the theoretical foundations from which the SCRS framework is developed in Chapter Three.

In Chapter Three, the need for an SCRS framework is identified and grounded in the literature. The framework is used to provide a structure by which key elements of SCRS are related to SCD, and then the scope of the SCRS framework is identified. After presentation of the framework, the scope of the initial test of the SCRS framework that will be used in Chapter Four is presented.

CHAPTER 3

3 THEORETICAL FRAMEWORK

3.1 Objectives of the Chapter

There are three objectives to this Chapter. The first objective is to explain the relationship between supply chain design, supply chain relationship structure, and performance. The second is to identify and explain the critical dimensions of SCRS as they pertain to SCD, particularly the SCRS dimension of visibility and information sharing as the focal point of this study. The third is to establish the theoretical foundations for the experimental design that is subsequently implemented in this study as an initial and limited test of SCRS using the dimension of visibility and information sharing.

3.2 Broad Theoretical Framework of SCD and SCRS

From a conceptual perspective, the elements of a theoretical strategy-structure-performance framework have been previously established in this study. That is, strategically firms first develop *desired outcomes* to drive the development of *desired supply chain capabilities*, which then drive *realized firm performance*. As noted, developing desired supply chain capabilities is determined by firms making specific decisions on dimensions of SCD, particularly decisions on *structure*, *types of relationships*, and *resource investments*, among others. This section focuses on a detailed decomposition of elements of desired outcomes, desired capabilities, and realized outcomes, starting with a discussion of desired outcomes.

3.2.1 Desired outcomes in this study

It has been recognized earlier that desired outcomes developed by firms are shaped by a number of factors, including the external environment (such as number of suppliers, location of suppliers, and governmental regulations), the competitive landscape, and customer goals and objectives. This broad spectrum of factors is outside the scope of this study, yet they are recognized as important because they shape and influence the specific desired outcomes that are demanded or desired of the supply chain. In this study the choice of desired outcomes is held constant, and a specific set of desired outcomes is assumed as the basis of the study.

This study focuses on a blended desired strategic outcome consisting of cost and resilience as based on the desired outcomes framework developed by Melnyk, Davis, Spekman and Sandor (2010). There is additional theoretical support for this approach from Lee (2004), who argues that blended outcomes are better than a single desired outcome because companies focusing on only one desired outcome are more vulnerable to competitors.

By applying this logic and using these two desired outcomes from a strategic planning perspective, a firm is expected to subsequently develop desired capabilities that enable the achievement of lower cost production while reducing simultaneously reducing the costs incurred by supply chain disruptions. The presence of resilience as one of the desired outcomes strongly suggests that firms have concerns regarding the negative effects of disruptions in the supply chain (Melnyk *et al.*, 2009). This leads to a discussion of key factors of supply disruptions that affect cost and resilience.

3.2.1.1 Key factors in supply disruption

There are three factors that affect the impact on firm performance from supply disruption: *duration*, *location*, and *degree* (Sheffi, 2005). *Duration* is the length of the disruption, from the onset of the disruption until cessation and return to normal supply conditions. *Location* of disruption refers to the location in the supply chain where the disruption occurs, such as in the immediate tier one supplier, a supplier further upstream, or in a transportation mode between firms. *Degree* of disruption is the magnitude of impact, and is affected by factors such as full (100% disruption) or partial disruption (such as reduced supplier capacity to some percent of pre-disruption rate), as well as rate of disruption onset (gradual or immediate) and rate of disruption cessation, where cessation may comprise a gradual improvement or full and immediate return to normal supply.

These key factors in supply disruption will be an important part of the experimental design for testing the SCRS framework in Chapter Four. An introduction to the experimental design is provided at the end of this Chapter, after a discussion on how the desired supply chain capabilities are influenced by important decisions on seven dimensions of the SCRS framework and how realized outcomes for the initial test will be evaluated in this study.

3.3 Desired supply chain capabilities influenced by SCRS decisions

In making decisions on which desired supply chain capabilities to develop, firms face challenges in evaluating trade-offs between higher levels of *control and influence* against greater *flexibility and responsiveness* to dynamic environments, leading to "tension" in decisions on how to choose an appropriate SCRS. As will be seen in the SCRS framework below, firms focusing on cost as a desired outcome are more likely to employ a highly integrated SCRS, yet improving resilience to lower the cost of supply disruptions requires higher flexibility and responsiveness during supply disruptions. This tension is not resolved in the literature as there appears to be no specific guidelines for how firms should structure supply chain relationships when focusing on more than one desired outcome.

3.3.1.1 Linking capabilities and desired outcomes in this study

To develop desired capabilities through SCD, and more specifically through decisions on SCRS, the process starts with what the firm is trying to achieve. This is illustrated by using the desired outcomes of this study, those of cost/ efficiency and resilience. Cost and efficiency are measured at the firm level through effects on profitability – more is better. But what is the firm trying to accomplish by developing capabilities to achieve resilience?

With resilience as a desired outcome, it is argued that the firm is trying to design the supply chain to generate capabilities that result in certain predictable and observable behaviors and performance characteristics, or *properties*, of the supply chain as defined in Chapter 2. A property of resilience in supply chains, for example, is survivability and recovery from supply disruptions at lowest cost to the firm. To evaluate whether resilience has been achieved, it must be measured.

Resilience can be measured two ways:

1) From a firm performance perspective, resilience can be measured as the cost to the firm from the disruption of a given duration, as measured by comparison to baseline performance, and
2) As a time series profile measured as the time from onset of disruption to a return to steady state.

The first measure, cost, is used in this study since the focus is on assessing resilience to specific durations of supply disruption at the lowest cost to the firm. The second measure involves investigating the complexities of time series profiles of supply disruptions. However, to assess the time series implications within the data generation scheme (simulation) employed by this dissertation requires statistical techniques that are not currently available. Consequently, this dimension will not be evaluated in this study.

The unit of analysis in this study is the firm, with a focus on firm financial performance. While resilience from an overall *supply chain* perspective is of long term interest, using the supply chain as the unit of analysis is very difficult and there are few widely accepted measures of supply chain performance (Cuthbertson and Piotrowicz, 2008).

For example, consider the SCOR model of supply chain performance measures. While the SCOR model emphasizes best practices in supply chain management, the benchmark firm performance measures from the SCOR model focus on the impact of the supply chain on the firm.

This focus on firm performance is developed further later in this Chapter, where a discussion of realized performance measures is provided that is focused on setting up the initial test of the SCRS framework. The initial test that is fully developed in Chapter Four is intended to make an initial link between outcomes desired by the firm and performance that is actually realized after making decisions on SCRS. To set up the basis for this, attention now turns to developing the framework of SCRS.

3.4 Supply Chain Relationship Structures

SCRS is one of many important dimensions of SCD, and the one that is the specific focus of this dissertation. To "set the stage" for this discussion, it was previously noted that how a firm best structures interorganizational relationships is a subject of discussion and confusion in the literature, particularly on objectively evaluating the benefits of supply chain relationships that are more modular (Prahalad *et al.*, 2008) or more integrated (Kopczak and Johnson, 2003).

In this study the interest is not on *which* SCRS is more appropriate for a particular firm, but on *how* firms can evaluate trade-offs on important decisions that are explicitly or implicitly made when choosing an SCRS and how firms can estimate firm performance differences based on choice of SCRS. These are accomplished via the SCRS framework and the initial test of the framework. Through use of the SCRS framework and the initial test, this study provides an approach that helps firms make better decisions on structuring supply chain relationships.

But the span of supply chain relationship structures that a firm may choose in the SCRS continuum is quite broad, so the focus is narrowed to the two main archetypes of SCRS from the literature: *modular* and *integrated*. The proposed SCRS framework, presented next, is the mechanism by which firm can decompose the "large" decision on choice of SCRS into a set of decisions that focus on choices on key dimensions of SCRS.

3.4.1 SCRS framework

The proposed SCRS framework is presented in Table 3.1. Decisions on these theoretical *decision dimensions* and resulting predictions of *strategic stances* by SCRS were derived from the literature and refined based on insights from and observations of the empirical supply chains of firms participating in this study. The choices that firms may make on each of the decision dimensions are called strategic stances in this study. These strategic stances are choices that reflect decisions made by firms that affect degrees of visibility, control, and flexibility. These decisions are made in the context of anticipated costs and expected benefits as firms pursue achievement of desired outcomes.

The vertical axis of the SCRS framework is comprised of seven SCRS decision dimensions, each of which provides a choice that firms make on a particular dimension of SCRS and which affects the subsequent development of specific capabilities. While there are other factors that firms may consider, these seven dimensions are important aspects of SCRS and are predicted to differ between a modular and integrated SCRS, thus offering insights to firms on how to make a more appropriate choice of SCRS.

The horizontal axis is comprised of the two extreme cases in the continuum of SCRS, modular and integrated (Fine, 1998). Once a firm makes choices on strategic stances for each of the seven decision dimensions, the set of strategic stances chosen by the firm defines the choice of SCRS within in the fully modular- fully integrated continuum. As shown in Table 3.1, it is predicted that firms implementing a fully modular SCRS will have different predicted strategic stances on these SCRS decision dimensions than firms that implement a fully integrated SCRS.

Table 3.1 SCRS framework with predicted strategic stances

SCRS Framework *with predicted strategic stances*		***Structural Dimensions***	
		Modular	**Integrated**
Decision Dimensions	Visibility & information sharing (Kraljic, 1983; Lee *et al.*, 1997; Fine, 1998; Christopher *et al.*, 2004a)	low	high
	Relationship coupling (Simon, 1996; Fine, 1998; Williamson, 2008)	loose	tight
	Interorganizational problem solving (Balakrishnan, Kalakota, Ow and Whinston, 1995; Pavlak, 2004; Bodendorf and Zimmermann, 2005)	proactive, planned	reactive, responsive
	Interorganizational slack resources (Hambrick and D'Aveni, 1988; Greenley and Oktemgil, 1998; Clark and Lee, 2000; Voss, Sirdeshmukh and Voss, 2008)	lower	higher
	Interorganizational investment intensity (Langlois and Robertson, 1992; Channon, 1999; Saeed *et al.*, 2005)	lower	higher
	Industry clockspeed (Fine, 1998)	higher	lower
	Time intensity (Blair, 1932; Bloom, Duizer and Findlay, 1995; Papadakis, 2006)	lower	higher

The SCRS framework in Table 3.1 is not a strict classification system since few firms are likely to match all of the predicted strategic stances for a modular or integrated SCRS, and in practice most firms are expected to lie in the continuum between a highly modular or highly integrated SCRS. Therefore, firms are classified on the modular/integrated continuum in terms of general consistency between predicted strategic stances from the SCRS framework. This approach is similar to that of Fine (1998) and Miles and Snow (1978), where the latter describe the categorization of firms in their framework according to descriptions of the "pure" form (Miles *et al.*, 1978, p. 550).

Two dimensions of the SCRS framework are if importance in this dissertation, *information sharing and visibility* and *relationship coupling*. These two and the other five dimensions of the SCRS framework are briefly discussed to establish a proper perspective from the literature on closely related and key dimensions of supply chain relationships before attention is turned to the two dimensions of interest in this study. In the following section each of the seven SCRS decision dimensions is briefly introduced, followed by a characterization of a firm's predicted strategic stance on each decision dimension for stances that more closely align with a modular or an integrated relationship structure.

3.4.2 Visibility and information sharing within the supply chain

Visibility is an outcome of sharing particular sets of information between firms in a supply chain, where the outcome is the ability to "see" and thus respond to information in advance, such as receiving forecast and planned order information much earlier than would be received via traditional transactional processes (Lee *et al.*, 1997; Christopher *et al.*, 2004a).

From the literature it is observed that companies using a modular SCRS focus more resources on developing specified interfaces and standards for interorganizational processes and less on extensive interorganizational sharing of information and multi-tier cooperation, and for these companies interorganizational interactions almost always focus on adjacent tiers in the supply chain (Fine, 1998).

Companies that have highly integrated processes extensively share sales and inventory data, as well as advanced shipment notices, upcoming product introductions, planned promotions, capacity constraints, and other relevant information as part of a collaborative planning process (Fine, 1998). In highly integrated supply chains, companies may share information across several echelons in the supply chain, particular for critical components or where adequacy of long term availability is key (Kraljic, 1983).

Thus, it is predicted that firms employing a modular SCRS are more likely to invest in lower levels of interorganizational visibility and information sharing practices and instead rely more on developing specified interfaces and communication protocols, while firms employing an integrated SCRS are predicted to invest in higher levels of visibility and information sharing for interorganizational processes. This view of differences in visibility and information sharing practices by SCRS becomes the basis of the initial and limited test of SCRS outlined in Chapter 4.

3.4.3 Relationship coupling

Firms may differ by choice of SCRS on interorganizational coupling, which focuses on the type and degree of interaction between firms. Fine (1998, p. 136) identifies differences between integrated and modular interorganizational processes by stating: *"An integral supply chain architecture features close proximity among its elements. Proximity is measured along four dimensions: geographic, organizational, cultural, and electronic"*. He continues by noting that not all of the proximities are necessary conditions in a given instance, but rather serve as indicators of the degree of integration. According to Fine, modular interorganizational processes exhibit low proximity on most or all of the four dimensions.

From these insights, it is observed that modular relationship coupling does not rely on high levels of proximity between organizations because firms embed the mechanisms of coordination and communication into structured transactional interfaces rather than by direct coordination (Williamson, 2008). These specified interfaces replaced human interactions with forms of hierarchical coordination that are embedded by design into the technical interface itself in a loosely coupled system (Simon, 1996).

Integrated relationship coupling relies on high levels of proximity, particularly on information sharing, coordination of production and service processes, sharing of strategic plans, and collaboration in product and service development to reduce costs and increase process efficiencies (Monczka, Petersen, Handfield and Ragatz, 1998;

Saeed *et al.*, 2005). Systems such as supply chains with high levels of interdependencies are considered tightly coupled systems (Simon, 1996).

Thus, it is predicted that firms employing a modular SCRS are more likely to be loosely coupled since they exhibit lower levels of physical proximity, organizational proximity, cultural proximity, and electronic proximity, while firms employing an integrated SCRS are more likely to be tightly coupled because they exhibit higher levels of these elements of proximity.

3.4.4 Interorganizational problem solving

There are different approaches that firms can choose when solving problems in interorganizational relationships. Within the SCRS framework, firms may choose a strategic stance between a reactive and a proactive problem solving approach (Pavlak, 2004).

Reactive interorganizational problem solving is a capability developed between firms to effectively resolve problems in a highly responsive manner (Balakrishnan *et al.*, 1995). Reactive problem solving requires investments in interfirm relationships for the firms to rapidly assess and jointly solve problems that arise in processes and relationships, and is typically identified with firms employing an integrated SCRS.

Proactive problem solving uses a preventive stance, whereby early detection and preplanned responses form part of an active risk management strategy for interorganizational problems (Bodendorf *et al.*, 2005). Internally, these firms may be highly reactive and collaborative, but the focus here is on *interorganizational* problem solving processes. A proactive problem solving stance requires ex-ante investments to establish and maintain effective problem resolution procedures, and requires tools to identify, classify, and decompose anticipated problems and risks into actionable activities that can be included in preplanned mitigation strategies and response plans.

Based upon the literature and investigation of the firms participating in this study, it is predicted that firms employing a modular SCRS are more likely to "design-in" proactive and planned problem solving strategies by which the interorganizational interfaces are robust to problem resolution without high degrees of interorganizational interaction. It is predicted that firms employing an integrated SCRS are more likely to employ reactive and highly responsive problem solving processes in interorganizational relationships to accommodate time-intensive processes.

3.4.5 Interorganizational slack resources

Empirical evidence suggests a positive relationship between slack resources and firm performance (Hambrick *et al.*, 1988). Greenley and Oktemgil (1998, p. 377) provide a literature review on slack resources and performance, and report:

> *Slack resources are those resources that have not been optimally deployed, but which allow a company to adapt to environmental change, by providing the means for achieving flexibility in developing strategy options to pursue opportunities.*

In this study on SCRS, a specific form of slack is of interest: *interorganizational slack* (Clark *et al.*, 2000) that is available for technical collaboration, problem solving, communication, and joint product and process development (Voss *et al.*, 2008).

From the perspective of interorganizational slack resources, firms employing a modular SCRS are predicted to invest in lower levels of interorganizational slack resources after developing appropriate interorganizational interface standards, while firms employing an integrated SCRS are predicted to invest in higher levels of interorganizational slack resources to facilitate interorganizational collaboration, problem solving, and product and process development.

3.4.6 Interorganizational investment intensity

Investment intensity traditionally relates to the level of investment in fixed capital of a firm, including net book value of plant and equipment plus working capital (Channon, 1999). This traditional view focuses on the firm level, but in the context of supply chain design interorganizational investments must also be considered. Interorganizational levels of investments may include, for example,

- investments in information sharing technologies such as EDI (Electronic Data Interchange) systems and collaborative web portals,
- shared facilities space for VMI inventory and personnel, and
- engineering, quality and other personnel who have primary or shared responsibilities for providing coordinating activities between firms in the supply chain.

For interorganizational investment intensity, it is predicted that firms employing a modular SCRS are more likely to have lower levels of investment intensity in interorganizational processes and technologies (Langlois *et al.*, 1992), while firms employing an integrated SCRS are predicted to have higher levels of interorganizational investment intensity because they expect higher financial returns from investments to develop and maintain close interorganizational relationships (Saeed *et al.*, 2005).

3.4.7 Clockspeed

Firms that experience higher clockspeed environments must respond effectively to dynamic environments. Fine (1998) has argued that firms in high clockspeed environments must pay more attention to supply chain design and structure supply chain relationships due to the hyper-competitive nature of certain industries. He argues that the relationships between clockspeed, product design, and supply chain structure must be considered in the process of designing and implementing supply chain designs. Yet the author still recognizes that both integrated and modular supply chains will continue to exist, and argues that "integral products tend to be developed and built by integral supply chains, whereas modular products tend to be designed and built by modular supply chains" (Fine, 1998, p. 140).

From this perspective, it is argued that firms that employ a modular SCRS are more likely to experience a higher industry clockspeed and a more dynamic competitive environment, while firms employing an integrated SCRS are more likely to experience a lower industry clockspeed and a less dynamic competitive environment.

3.4.8 Time intensity

Time intensity focuses on the time available for reacting to problems (or potential problems) before decay in performance occurs. Time intensity can be considered as the response rate over time (Blair, 1932; Bloom *et al.*, 1995), and is a measure of the ramp-up and decay of response to a stimulus. In the context of supply chains this concept is construed as follows: higher time intensity necessitates a faster response rate to problems in a given time period; lower time intensity suggests that more time is available to respond before the lack of response affects system performance.

To illustrate this concept, it is noted that firms in many industries employ just-in-time production practices and rely on multiple shipments per day to keep lean production processes running on schedule while employing very few buffers in the system. In highly integrated systems, recognition of high time intensity and operational performance is critical in these integrated systems, since even short delays quickly degrade performance across the supply chain (Papadakis, 2006).

In other industries, where loose coupling is a result of long geographical distances and higher-run production processes, buffers are often built into the system in terms of safety stock and alternatives such as the availability of expedited logistics. Such systems use buffers to run smoothly despite the particular characteristics of the production process and inherent variation resulting from more geographically dispersed logistics processes.

In the context of supply chains, companies employing a modular SCRS are predicted have lower time intensity because they are more likely to employ buffer strategies and standardization to reduce complexity and decouple interorganizational processes, while companies that employ a highly integrated SCRS are predicted to have higher time intensity because they are more likely to be highly conscious of the integral nature that timing plays in the smooth function of integrated supply chains.

These seven decisions dimensions comprise the key strategic issues relative to specific choices firm make on aspects of SCRS, and comprise the SCRS framework. The development of this framework is one of the major contributions of this study. The final section of the strategy-structure-performance paradigm in this study is realized outcomes, which is the subject of the next section.

3.5 Realized Outcomes

Realized outcomes, as defined is this study, are the actual outcomes that result from implemented desired supply chain capabilities. These are used to verify whether the desired outcomes that drove the development of the capabilities were actually *realized*, in other words, did the strategy work?

This raises an important question: how can this result be evaluated, and what are the measures of performance? In a real supply chain, firms could wait until the system performs under normal conditions for a sufficient amount of time as a baseline of performance, and verify whether lower costs were realized under normal conditions. And for conditions of supply disruption, the firm could evaluate whether "sufficient" resilience was achieved. But this approach is fraught with difficulties, including evaluating what an appropriate baseline of performance is, what "lower costs" means, and what determines "sufficient" resilience, among others.

In this study, an alternative approach is used that can be used ex-ante to make a basic evaluation of realized outcomes through the use of simulation methods. Rather than wait until time has passed to evaluate actual performance, the supply chain can be models using its basic aspects, and a reasonable approximation of system performance can be made under various operating conditions. Due to the focus on firm financial performance in this study, the measures used will be cost-based measures. In particular, the initial test of the framework in Chapter Four will focus on differences in gross profit in the experimental design scenarios that result from differences in cost from baseline performance under normal operating conditions as compared against firm performance under various durations of supply disruption. Specific details of the gross profit calculations and cost differences are provided in the next Chapter.

3.6 Link to the Experimental Design in Chapter Four

The three elements of the strategy-structure-performance paradigm in this study, desired outcomes, desired capabilities, and realized performance, are applied to the initial test of the SCRS framework through the experimental design and simulation model developed in Chapter Four.

The elements of this Chapter have been integrated into the experimental design. The desired outcomes chosen for this study provide the focus in Chapter Four on evaluating whether performance differences exist between firm choices of SCRS, which in turn provides a focus on how these potential differences may or may not affect resilience in firm performance. The SCRS framework is employed to structure the experimental design, specifically focusing on differences between visibility and information practices in a modular and an integrated SCRS, and the financial measures are employed to evaluate whether the realized outcomes have been achieved. Before providing a Chapter summary, a brief introduction to the experimental design is provided to link the elements of the SCRS framework to the experimental design.

There are three levels to the experimental design in Chapter Four: SCRS archetype (modular, integrated), six levels of disruption duration (ranging from 0 to 30 days), and demand stream variation (LDV - low demand variation, and HDV - high demand variation). Demand stream variation is used as a control factor to reduce confounding effects. This is accomplished by simulating each demand stream (LDV, HDV) separately using the same computer model, and using relevant empirical costs, demand data, and transaction processes (e.g., order policies, inventory policies, shortage penalties) as parameters in the simulation model. Each demand stream (LDV, HDV) is modeled separately for both types of SCRS and for all durations of supply disruption. This concludes the initial introduction to the experimental design. A summary of this Chapter is provided before proceeding to the next Chapter.

3.7 Chapter Summary

This Chapter focused on explaining the theoretical relationship between supply chain design, supply chain relationship structure, and performance using the strategy-structure-performance paradigm. Using this approach, the desired outcomes of cost and resilience were chosen for this study, and a discussion was provided of how these desired outcomes drive the development of specific desired capabilities that the firm needs to develop to achieve realized outcomes that align with the desired outcomes.

Desired supply chain capabilities are influenced by SCRS decisions, and firm choices for developing appropriate supply chain relationships were decomposed into several decisions dimensions in the proposed SCRS framework. From this, predicted strategic stances were provided by choice of modular or integrated SCRS. It was noted that important dimensions of this framework will be used in Chapter Four to define the experimental design, focusing on differences in visibility and information sharing across choice of SCRS. In addition, an introduction to the experimental design was provided.

In Chapter Four, details of the research methodology are provided, including important aspects of the empirical case studies used to obtain relevant data and process parameters that will be incorporated into the simulation model. The simulation model is used to generate data through execution of the experimental design. This data will subsequently be analyzed in Chapter Five to assess whether there are firm performance differences based on choice of SCRS and disruption duration from baseline firm performance.

CHAPTER 4

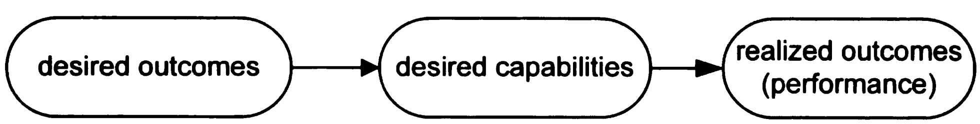
4 RESEARCH METHODOLOGY

There are three major objectives of this Chapter on research methodology, which uses a multi-method approach for the initial test of the SCRS framework. The first is to operationalize the conceptual model presented in Chapter Three, in preparation for conducting the test. The second is to provide details of the data generation process, specifically to outline important aspects of the simulation model developed in this study. The third objective is to provide the strategy for data analysis that is used in Chapter Five.

4.1 Conceptual Model

In Figure 4.1, the conceptual strategy-structure-performance model developed in Chapter Three is presented. In this Chapter, this model is operationalized for the initial test of the SCRS framework. This section starts with a brief discussion on the desired capabilities and realized outcomes to prepare the groundwork for the operational model.

Figure 4.1 Conceptual strategy-structure-performance model for supply chains



The focus in this study is on how firm choice of SCRS, which drives the development of desired capabilities, can subsequently affect firm performance. As argued in Chapter

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Three, these desired capabilities are the result of specific decisions on several important dimensions of SCRS, which are posited to be driven by desired outcomes. Implementing these decisions on dimensions of SCRS is posited to affect the behavior of the supply chain, which may be observed as properties that affect realized performance.

Through this process, when firms identify capabilities necessary to support newly established desired outcomes, a gap occurs between the current capabilities of the firm and the desired capabilities. From a theoretical perspective, this *capabilities gap* could be measured and used as a scale of investments in resources and time that the firm needs to close the gap. The larger the gap, the more investments in resources and time needed to implement desired capabilities. This is an interesting and promising area for future research, but one that is outside of the scope of this study. For the current study, the desired outcome (a blend of resilience and cost) has been identified, and as noted previously SCRS decisions on visibility and information sharing and on geographical proximity will be used to operationalize the simulation model for the initial test of the SCRS framework. Prior to that discussion, a brief discussion on realized outcomes is provided.

From the perspective of supply chains, realized outcomes are the actual outcomes observed in firm performance, and may be based on financial, operational, customer or other performance measures. In this initial test, measures of financial performance are employed in the experimental design as defined below. The next step is to define how this conceptual model is operationalized in this initial test of the SCRS framework.

4.2 Operationalizing the conceptual model

There are three steps to operationalize and develop the conceptual model for the initial test of the SCRS framework:

a) determine the desired outcomes,

b) restate the research questions into testable and falsifiable hypotheses, and

c) operationalize the model with definitions and an experimental design to generate data to test the hypotheses.

4.2.1 Desired outcomes for the initial test

It was identified in Chapter Three that the desired outcomes for this initial test are a mixed outcome of cost and resilience. Restated, this study is interested in how decisions that are made by firms on the structure of supply chain relationships contributes to firm performance when management is interested in reducing costs and improving resilience. It was from this perspective that this set of desired outcomes was chosen as an appropriate and feasible initial test of the SCRS framework. Additional extensions based on other desired outcomes are of interest for future studies. From here, the next step in operationalizing the conceptual model is restating the research questions into testable and falsifiable hypotheses.

4.2.2 Hypotheses

In Chapter One, the research problem was comprised of two questions. The questions are as follows.

Given a supply chain that is desired to be efficient and resilient:

1. To what extent does the use of integrated as compared to modular supply chain relationships significantly affect overall performance?, and
2. To what extent does this choice of strategy-structure significantly affect firm performance under varying conditions of supply disruption?

From these research questions, three hypotheses were developed. The first hypothesis addresses the first research question, as follows:

$H1_O$: There will be no difference in firm performance by SCRS.

$H1_A$: There will be differences in firm performance by SCRS.

H1 focuses on the research question of whether firm choice of SCRS matters to firm performance, and as noted is specifically focused on differences in performance resulting from visibility and information sharing practices. If no performance differences are identified (as defined below), then we can argue that the firm does not have to worry about SCRS – it can focus on those relationships that are easiest or least expensive to implement. But if differences in performance are detected, costs can be incurred or saved based on appropriate selection of SCRS. In addition, it is possible that a firm employing an SCRS that is optimal under normal operating conditions may find the same SCRS is less than optimal under conditions of supply disruption. This opens the possibility of trade-offs in strategic SCRS decisions.

To evaluate this hypothesis, performance will be measured as the *difference* in firm financial performance between the modular (baseline) and integrated SCRS's under normal conditions for H1. *Significant differences* are defined as both statistically significant and managerially significant to the firm. Since the direction of the difference is not predicted, a two-tailed test is used.

The second research question focuses on the extent to which the choice of strategy-structure significantly affects firm performance under conditions of supply disruption. It is here that two specific properties introduced in Chapter Two are invoked: robustness and resilience.

Earlier In this study, robustness in a supply chain context was defined as the ability of a firm to resist the onset of a disruption. Resilience was defined earlier as the ability of a firm to endure a supply disruption and return to a state of stable performance after the disruption ceases. Translating these into operational definitions for the initial test of the SCRS framework requires restating the earlier definitions, as follows.

a) Robustness under conditions of supply disruption is defined as firm performance not degrading for some measurable period of time due to supply disruption. Thus the definition of robustness inherently includes a dimension of time duration.
b) Resilience under conditions of supply disruption is defined as firm performance degrading for some period of time but the firm survives and eventually firm performance returns to stability.

At this point, the second research question is revisited. If the properties of robustness and resilience are exhibited during supply disruption and induce differences by SCRS in firm financial performance, then this becomes an important consideration for the firm. To address the question of robustness, the second hypothesis is:

$H2_O$: There will be no difference in firm robustness due to firm choice of SCRS.

$H2_A$: There will be differences in firm robustness due to firm choice of SCRS.

Similarly, for resilience the third hypothesis is:

$H3_O$: There will be no difference in firm resilience due to firm choice of SCRS.

$H3_A$: There will be differences in firm resilience due to firm choice of SCRS.

For robustness (H2), it is predicted that processes that are tightly coupled will suffer adverse effects quicker that loosely coupled systems that employ inventory buffers, particularly for those tightly coupled systems that employ tight geographical proximity. Thus there is predicted to be support for H2A for loosely coupled systems but not for tightly coupled systems.

For resilience (H3), a decrease in performance and then a return to stable performance is predicted for both tightly and loosely coupled systems, particularly for longer disruption durations. These three hypotheses comprise the operational hypotheses for the initial test of the SCRS framework. The next section provides operational definitions that will be incorporated into the experimental design.

4.3 Operational definitions

There are several important factors considered in the experimental design, which follows this discussion. The dimensions of the experimental design require operational definitions. These operational definitions are implemented in the simulation model are as follows:

4.3.1 Modular and integrated SCRS

The simulation model implements visibility and information sharing practices differently between a modular and integrated SCRS, which become more important during model execution when a disruption occurs. The mechanisms employed in the model are as follows:

4.3.1.1 Modular SCRS

Levels of visibility and information sharing practices for a modular SCRS are "low" per the SCRS framework. As implemented in the simulation model, this is limited to providing demand information through actual orders and receiving shipment information after shipments have been shipped. When a disruption occurs, as defined below and implemented in the simulation model, the disruption is not "identified" immediately by the focal firm when using a modular SCRS due to low visibility. Under low visibility, the disruption is recognized only when shipments haven't shipped on time from the supplier via ocean transit. This is how supply disruptions are actually identified in the HDV case (HDV") from the empirical supply chain, and thus this approach was implemented in the model for the experimental design for the modular case.

It is at this point of delayed recognition in the modular SCRS case that the firm "reacts" in the simulation to notice of a disruption, signaling to the supplier that when production commences after the disruption, subsequent shipments should be expedited to fill waiting orders and to expedite refilling the supply pipeline. The parameters for standard and expedited shipping times and costs are implemented in the model are noted in Appendix 4A. Actual transport costs and shipment times are employed in these scenarios.

For the LDV case ("LDV"), the standard shipment schedule for the actual supply chain is several times per day for product produced that same day, and the actual transport time is around 30 minutes, which is less than "one day" in the simulation model. Therefore for LDV, the standard shipment times are so short that the expedited times cannot be faster than "one day" in the simulation model. This results in the expedited shipment time and costs available during supply disruptions for LDV being equal to the standard shipping times and costs, as noted in the parameter settings by company in Appendix 4A. This is a direct result of the tight geographical proximity for LDV, as discussed further below.

4.3.1.2 Integrated SCRS

Visibility and information sharing practices for an integrated SCRS as implemented in the simulation model include "communication practices" such as immediate identification by the focal firm of supply disruptions at the tier 1 supplier when they actually occur. Thus, during a supply disruption a firm employing an integrated SCRS has earlier notice of a supply disruption and can therefore initiate response strategies earlier.

This includes, as appropriate, the ability to "expedite" completed production shipments that have not left the foreign supplier's "port" via ocean freight in an attempt to boost arriving inventories in anticipation of potential shortages. The firm can continue expediting when supply recommences until company inventories and the supply chain pipeline are back to normal inventory levels. Additional expediting costs are tracked in the simulation model.

4.3.2 Other dimensions from the SCRS framework

Other dimensions from the SCRS framework, such as interorganizational problem solving, interorganizational slack resources, interorganizational investment intensity, industry clockspeed, and time intensity are less prominent in the literature, and are held constant in the study to reduce confounding effects.

4.3.3 Geographical proximity

One of important factors in degree of coupling, *geographical proximity*, is implemented using fixed parameters in the simulation model via transportation times and inventory levels that directly reflect the degree of geographical proximity for each company. This factor is included because geographical proximity is recognized as being important in the literature because it directly affects supply chain performance (Fine, 1998) and is a key dimension in the SCRS framework.

Attempting to model geographical proximity as variable parameters or experimental scenarios has proven difficult since there is no guidance in the literature or insight from the companies in the study as to how to "convert" a firm's native geographical proximity, such as very short transportation times and very low inventories for tight geographical proximity LDV, into alternative scenarios such as loose geographical proximity using long transport times and higher inventories.

The difficulty arises since the latter requires arbitrary choices that are difficult to justify and that can artificially influence model performance. For a specific example, in the case of LDV the question arises as to how might one "approximate" converting the low inventories and very short transport times of their native integrated SCRS into those appropriate for a modular SCRS. With little guidance and the presence of challenges to justify a given choice, it was decided to model each company using its own native characteristics of geographical proximity. As noted, these fixed parameter settings are provided in Appendix 4A.

4.3.4 Disruption

A supply disruption is a full disruption of supply for a specified duration at supplier tier 1. In theory, disruptions can be characterized by several dimensions: (1) location of the disruption (where in the supply chain the disruption occurs); (2) impact of the disruption (when the disruption occurs, what percentage of production, μ, that is lost due to the disruption, where $0 <= \mu <= 100$); (3) the slope of the loss impact (where the loss can be sudden and dramatic or gradual); and, (4) the duration of the loss (how long the disruption at the source is experienced). In this study, the disruption is modeled in terms of the impact and duration only. That is, it is assumed that the disruption has a sudden and dramatic impact on product and that the loss due to the disruption is total (i.e., μ=100%). The primary experimental factor is the duration of the disruption.

Based on the literature and interviews with managers from LDV and HDV companies, several disruption durations were selected for the experimental design, including disruption durations of 0 (baseline), 5, 10, 20 and 30 days.

4.3.5 Demand stream variation

For this study, there are levels of demand stream variation, LDV and HDV. Each of the two levels of demand variation is modeled separately in the experimental design as a control factor using parameters appropriate for each level of demand variation. As noted in Chapter One, this control factor is used for this study since there are many factors that affect firm performance. Examples of differences between LDV and HDV companies that may affect performance differently include significantly different demand patterns, different cost and profit margin structures, different transportation times, different production processes (MTO - make to order, MTS - make to stock), and different inventory policies. Testing and evaluating the same demand stream variation under modular and integrated conditions provides a control factor to simplify the analysis and reduce confounding results.

With this in mind, two companies in different industries are used to provide an initial but limited step in generalizability and to provide LDV- and HDV-appropriate parameter settings and decision criteria, such as visibility and information sharing practices that are appropriate for a modular and an integrated SCRS. The parameters used and detailed backgrounds (by company) are provided in Appendix 4A.

4.4 Experimental design

The scenarios for the initial test of the SCRS framework comprise a 2x2x6 experimental design (Table 4.1). The experimental design is based on important dimensions of the SCRS framework presented in the previous Chapter, and focuses on three experimental factors: SCRS archetype, company, and disruption duration.

Table 4.1 Experimental design scenarios

		Disruption durations	
		0	**1, 5, 10, 20, 30**
LDV	Modular	Scenario A1[1]	Scenarios A2-A6
	Integrated	Scenario A7	Scenarios A8-A12
HDV	Modular	Scenario B1[2]	Scenarios B2-B6
	Integrated	Scenario B7	Scenarios B8-B12

Notes: 1. LDV Scenarios A2-12 are compared to the baseline scenario A1
2. HDV Scenarios B2-12 are compared to the baseline scenario B1

The baseline scenario for each demand stream in the experimental design is a modular SCRS under normal supply conditions, i.e., with zero days of disruption, to provide a baseline of performance for subsequent comparison with firm performance under conditions of supply disruption. Either SCRS could have been chosen for the zero-disruption baseline scenario; since only one was needed the choice was arbitrary. The zero day disruption provided a baseline of "normal" supply from which disruptions could be compared. In executing the experimental design the baseline scenario is executed first, followed by the other scenarios in sequentially execution. *Differences in firm* *performance*, as operationally defined below, are used to compare performance from the baseline scenario. The number of simulation runs per scenario is discussed later in this Chapter. The measure of performance employed in the data analysis is firm financial performance.

4.4.1 Firm financial performance

In this study, financial performance is focused on incremental cash flows, as represented by gross profit generated (Equation 4.1). This approach focuses on the revenues generated and direct costs, and ignores other firm-specific accounting practices such as taxes and the allocations of overhead costs. Operationally, it is defined as:

Equation 4.1 Gross profit calculations

$$
\begin{aligned}
FP = \text{T0 gross profit} = & \sum(\text{T0 units shipped} * \text{T0 sell price}) - \\
& \sum(\text{T0 production costs}) - \\
& \sum(\text{T0 raw material costs} + \text{T1 transport costs}) - \\
& \sum(\text{T0 holding costs} + \text{T0 shortage costs} + \text{T0 backorder costs})
\end{aligned}
$$

where T0 represents costs to the focal firm (LDV or HDV case) and T1 represents costs incurred in transporting materials from suppliers. For the purposes of this study, factors such as the reallocation of unit fixed costs across fewer units during supply disruption are not considered.

It is noted that this approach to using financial performance as a key measure involves some loss of insight into other operational aspects of performance. For example, during a disruption, the quantity of units shipped changes (affecting financial performance), but so do backorder charges and inventory carrying costs. Since this study focuses on firm-level financial effects, the net financial effect becomes the important measure rather than a detailed focus on the individual costs. It is recognized that evaluating the interactions between differential internal performance measures is also important and is left to a future study.

4.4.2 Normalizing financial performance

For comparability and to maintain confidentiality, the financial performance results for each firm are normalized after the simulation runs for all scenarios have completed, using the modular SCRS under normal conditions as the base case. Differences in normalized performance outcomes in all other cases are compared to the base case by class of demand stream.

Thus the *difference in performance* is the dependent variable in firm financial performance in this study. To illustrate this, LDV is used as an example, using *arbitrary data for this example* so as not to reveal sensitive company information for the LDV case. For example, if the average financial performance (across the simulation runs) using a modular SCRS was $100,000 and the standard deviation was $20,000, this case would be normalized by subtracting $100,000 from the final outcome performance for each run and dividing the result by $20,000. Performance results for each of the other scenarios in the experimental design for this company also have the same $100,000 baseline subtracted from each of these simulation runs and the result for each run would then be divided by the $20,000 baseline standard deviation.

Normalizing and scaling the results to the base case in this manner this allows comparisons of relative performance changes across companies that may differ by more than one order of magnitude in size – a challenge for running statistical analysis with variables of different magnitudes. It also provides some ability to compare standardized results from the base case and disruption cases both within a specific demand stream (company) and potentially across companies in different industries, which may have widely differing scales of annual product sales and profitability. While this is not a perfect comparison, it helps to alleviate the absolute differences resulting from industry or company variation by focusing on the standardized change in performance.

4.4.3 Primary focus on intra-demand stream comparisons

These performance measures are the same for LDV and HDV; however, from a performance comparison standpoint one can only cleanly compare the baseline results of LDV with the other experimental design scenarios of LDV, and similarly for HDV, since the underlying demand streams for the companies are very different and compete in very different industries. This inter-firm comparison allows observations of differing performance from the base case so that the dependent variable is the result of applying dimensions of different SCRS's rather than to the influence of company-specific effects when working with small sample sizes. This issue will be partially alleviated in subsequent studies as more companies are added in extensions of this study. Now that the translation from the general model to the specific model used in this study has been provided, the discussion turns to how data is generated for subsequent analysis in this study.

4.5 Data generation

This study uses a simulation model (Banks, 1998; Law, 2006) to generate data for the initial test of the SCRS framework. An alternative method to consider data generation would be survey data, but survey data is only useful for situations where respondents have encountered the specific topics under study. Another method that may be considered is scenario planning, but employing scenario planning to investigate the possible scenarios requires an understanding of how the supply chain would react under each set of circumstances in the scenario planning. Since this has not been examined previously, no basis for predicting the expected outcomes using scenario planning is available.

The multi-method approach of using empirical data to simulate supply chains to build theory (Davis, Eisenhardt and Bingham, 2007) brings together several different but complimentary approaches. Specifically, it begins by studying two "real" supply chain systems – LDV and HDV. These two systems are studied in terms of demand data, system network structure/attributes, and system management policies (as they pertain to demand and disruptions). In beginning with empirical analysis, this study recognizes that there are currently no widely accepted simulation models that can be used as generic study sites. Consequently, this study must begin with actual systems. By taking this approach, generalizability is traded-off in favor or relevance and validity.

The current investigation employs simulation to conduct experimental tests using a "what-if" approach, while specifically using actual company parameters associated with each class of demand stream to evaluate the likely effects on firm performance resulting from supply disruptions. This approach is used in this study since the cost of field experiments in actual settings is far too high for any firm to consider testing directly. The use of simulation allows investigation of particular aspects of organizational or interorganizational systems, such as resilience in supply chains, at lower risk to the firm under study.

One of the major benefits of simulation is the ability to simulate important aspects of the focal systems without having to also simulate aspects that are unrelated to the study, such as marketing promotions and compensation practices (Simon, 1969). To conduct a simulation, specific behaviors and parameters of the system under study must be "captured" and translated into operational terms as the simulation model is developed.

4.6 Developing the simulation model

To operationalize the model, the following steps were required.

1. Select the simulation approach and modeling platform,
2. Identification of key aspects of the simulation model,
3. Selection of appropriate actual supply chains to parameterize the model,
4. Development of the model, and
5. Verification and validation of the simulation model.

4.6.1 Simulation approach and modeling platform

In this section, the choice of approach for developing the simulation is addressed. Since the interactions between firms is based on discrete transactions and information sharing, a discrete event simulation approach is employed (Law, 2006). The discrete event simulation software used in this study is Arena version 11.0, produced by Rockwell Software. Arena is a GUI (graphical user interface) based simulation package that using flowchart-type icons for processes, decisions, and entity generation (such as daily demand to drive the model). In the model in this study, specific model parameters by class of demand stream are input into an Excel worksheet, which is read into the Arena models upon initiation of the simulation runs. Output of performance is also generated in Excel spreadsheets.

4.6.2 Key aspects of the simulation model

Development of the simulation model started with identifying important parameters necessary to simulate real supply chains. Parameters such as demand, inventory, processing time, transport time, cost, selling price, ordering policies, and response strategies during disruptions were necessary to sufficiently replicate the inputs, internal processes, outputs, and financial flows of the firms under study. This information was obtained through focused case studies specifically executed for this purpose. Relevant details and model parameters for the companies selected to participate in the study are provided Appendix 4A.

4.6.3 Criteria for firm selection to parameterize the simulation

The choice of participating firms used a purposeful stratified sampling process (Miles and Huberman, 1994) to provide suitable comparisons across small purposeful samples. The two firms selected for the initial test closely matched the strategic stances on SCRS decision dimensions for a modular and integrated SCRS, respectively. A comparison of the strategic stances predicted in the SCRS framework and the actual stances chosen by the two participating companies is provided in Appendix 4A. In selecting samples for this study, the focus was bounded to firms that:

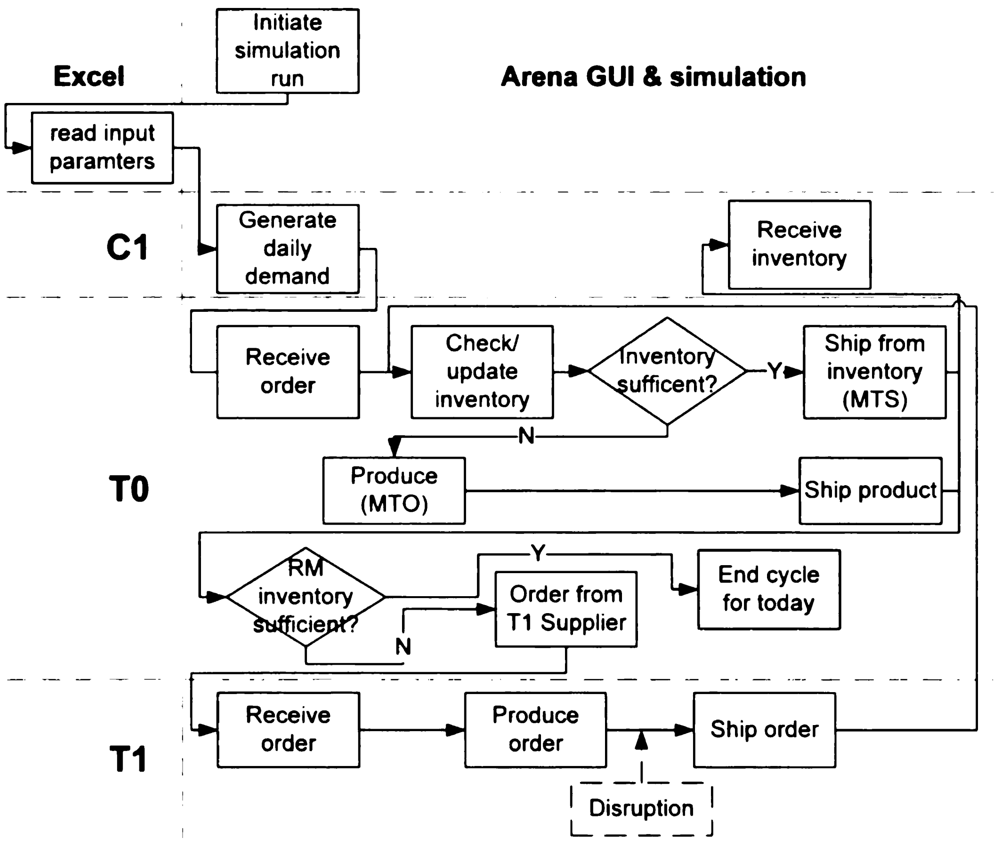
- Closely matched strategic stances on the decision dimensions of each SCRS archetype, and
- Were able to provide considerable access to data and managerial time as necessary to complete the study.

The selection process required availability of managerial time within the selected firms to understand and document details and characteristics of the product line chosen for the study and the related SCRS for the product line, and to provide feedback, discussion, and clarification before and during the process of developing, verifying and calibrating the simulation model. This information was used to develop and parameterize the simulation model.

4.7 Simulation model development

Figure 4.1 presents the general structure of the simulation model. The model is "driven" from demand generated by the immediate Tier One Customer (C1) for an important product line for each class of demand stream. Once daily demand is generated at C1, the demand signal (quantity) is sent to the focal firm at Tier 0 (T0). The focal firm (Firm T0) is LDV or HDV, depending on which scenario is being executed according to the experimental design.

Figure 4.2 Simulation model flowchart



At the next step, Firm T0 schedules the order if a make to order (MTO) policy is used (as is the case for LDV), or checks the demand quantity against available inventory if a make to stock (MTS) inventory policy is used (as is the case for HDV). For MTS, production at T0 occurs when inventory policies trigger replenishment. Raw materials are drawn when production occurs, and raw material orders are placed with the Tier 1 Supplier (T1) when raw material usage triggers replenishment strategies per T0 raw material inventory practices and ordering policies. Shortages and backorders, per class of demand stream and customer policies, are enforced and related costs are accumulated in the model.

To simplify the model and focus on the effects of SCRS, transport and production times are assumed to be constant (with the transport and production times set at their average values) because these factors are not central to the focus of the study. The next section identifies how supply disruptions are modeled.

4.7.1 Modeling disruptions in supply

Modeling disruptions in supply is affected by choice of SCRS in the simulation model, using a selectable parameter in the input spreadsheet that selects a modular or integrated SCRS depending on the scenario being run from the experimental design. As noted earlier, the difference is based on differences in *visibility* and *information sharing* practices between the two SCRS archetypes and *degree of geographical proximity* associated with LDV and HDV demand streams.

Specifically, differences in visibility and information sharing are implemented in terms of whether a focal firm can "see" the disruption when it occurs at an upstream tier (high visibility for integrated) or only when it affects final T1 shipment (low visibility for modular). This, in turn, triggers reaction strategies based on the degree of visibility and information sharing. High visibility triggers an immediate response, such as triggering emergency airfreight or production from T1 prior to shipment to proactively mitigate disruption effects. Low visibility does not trigger early response. This lack of visibility in the modular SCRS induces a performance "cost" to the firm.

An example would be HDV, where disruptions typically are not recognized until *after* freight shipments from Asia do not occur on time. At this point, any prior in-transit inventory from Supplier HDV was assumed already loaded onto a ship and en route. In this case, no production could be sent airfreight until the disruption ceased, but once the disruption ceased product could be sent airfreight to refill the supply chain pipeline and mitigate further customer disruptions until normal supply was resumed. The latter condition is an available reaction strategy for a low visibility condition.

4.7.2 Model verification and validation

There are a number of references and guidelines on simulation model development and verification/validation (cf. Banks, 1998; Law, 2006; Kelton, Sadowski and Sturrock, 2007). These guidelines were followed during model development, model runs, and output analysis. In addition, variance reduction techniques were employed, as explained in Appendix 4B.

One computer model was developed for both companies to reduce confounding effects, and the computer model was developed in a modular fashion along development stages similar to the execution steps for the experimental design. To start the simulation model development, the model was constructed in an iterative fashion for the modular case with no disruptions (scenario A1) using verification techniques discussed in Appendix 4B. It was then extended to include integrated practices involving information sharing and visibility (scenario A7), followed by the development of model code to incorporate various durations of supply disruption (modular scenarios A2-A6 and B2-B6; integrated scenarios A8-A12 and B8-B12).

During each stage of simulation model development, model verification and validation was conducted. In addition, variation reduction techniques were employed to improve statistical efficiency in output generation, whereby variance reduction techniques produce the expected statistical outcomes with lower variance of output from random variables (Law, 2006). These are discussed in detail in Appendix 4B.

4.8 Simulation model execution

After verification and calibration per the processes outlined in Appendix 4B, the simulation model is executed based on the scenarios identified in the experimental design. Each scenario in the experimental design was run for 200 replications to achieve statistical significance for fixed effects models and to provide sufficient statistical discrimination in output variables (McCulloch, Searle and Neuhaus, 2008) (see Appendix 4C for how the number of replications was determined).

The data generated by execution of the experimental design are subsequently analyzed per the analysis strategy below to test for statistically and managerially significant differences in firm financial performance by demand stream variation. In Appendix 4B, a more detailed discussion of related simulation issues is provided, including generation of demand data for the model runs, startup /initialization strategies, length of warm up period, steady state model performance, model verification and calibration, variance reductions techniques, and key simplifying assumptions employed in the models. With the process of data generation provided, the discussion now turns to the strategy employed in Chapter Five for data analysis.

4.9 Data analysis strategy

The data analysis strategy employed in Chapter Five involves two steps. First, prior to executing the simulation model, an analysis of the input data is conducted to select the appropriate demand distribution for each level of demand variation. Second, the output data is analyzed to test whether there is evidence to support or reject the null hypotheses.

4.9.1 Input analysis

Input analysis of demand data obtained in the case studies is used in Chapter Five to identify an appropriate demand distribution to drive the simulation model for each class of demand stream. Demand data is used in the simulation model to replicate the frequency of order arrival times and the quantities ordered. In Chapter Five, demand data obtained from the firms is analyzed to evaluate whether the demand distributions fit theoretical distributions or whether an empirical distribution provides the best-fit distribution to the demand data.

4.9.2 Output analysis

The major dependent variable in this study is differences in firm financial performance. To evaluate the relationships at the heart of this study, it was decided to use a repeated measures linear mixed regression. (Kutner, Nachtsheim, Neter and Li, 2005; Norusis, 2008). This approach was selected over the repeated measures ANOVA or MANOVA and the general regression approach for several reasons.

First, using the general linear model, ANOVA and regression produce similar statistical results, with the difference that the regression approach provides estimates of βi for regression coefficients. MANOVA was another candidate for analysis, but the relationships between independent variables in this study are, in some cases, nonlinear and discontinuous. For example, due to shipment and timing differences during disruptions and corresponding differences in policies on backorders, linearity between dependent variables cannot be assumed. Thus these cases violate the standard assumptions of MANOVA.

Second, repeated measures regression allows for correlation of independent variables, which is desirable since the underlying processes being measured are the same and correlations may exist. The regression equation for the linear mixed model in Equation 4.2 was used in implementing this approach.

Equation 4.2 Regression equation for linear mixed model

$$Y_{ij} = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \sum_{j=2}^{200} \beta_j X_{ij} + \varepsilon_{ij}$$

where:

$$X_{i1} = \begin{cases} 1 & \text{if integrated SCRS} \\ 0 & \text{if modular SCRS} \end{cases}$$

$$X_{i2} = \begin{cases} 30 & \text{if disruption duration is 30 days} \\ 20 & \text{if disruption duration is 20 days} \\ 10 & \text{if disruption duration is 10 days} \\ 5 & \text{if disruption duration is 5 days} \\ 1 & \text{if disruption duration is 1 days} \end{cases}, \; X_{i2} \text{ is categorical}$$

$$X_{ij} = \begin{cases} 1 & \text{if response is from subject } j\text{-}1, \text{ for } j = 2,\ldots,200 \\ 0 & \text{otherwise} \end{cases}$$

for $i = 1$ (LDV), 2 (HDV)

This regression model is used in the statistical analysis in Chapter Five to test the fixed effects by class of demand stream for statistical differences in firm financial performance by SCRS (*Xi1*), after controlling for the effects of disruption duration (*Xi2*), and for random effects for the number of simulation runs for each scenario (*Xij*). These results will be evaluated by level of demand variation (LDV and HDV) as a control factor to directly compare performance using a modular SCRS and integrated SCRS. As noted previously, *differences in firm financial performance* (*Yij*) is the dependent variable.

A test for interactions will also be conducted in Chapter Five between SCRS and disruption duration. The hypotheses are tested in Chapter Five at the p<.05 level, which is consistent with the literature. Model fit is evaluated using the AIC criterion (Bollen, 1989), in the smaller-is-better form, since repeated measures linear mixed model regression does not produce results comparable to R^2 in linear regression. This concludes the discussion on research methodology. Next the Chapter is summarized.

4.10 Chapter Summary

In this Chapter, the conceptual model in Chapter Three was translated into operational terms, including operational definitions that were used in developing the experimental design. The experimental design provided in this Chapter was focused on evaluating the effects on firm financial performance by firm choice of SCRS and disruption duration. This was followed by a discussion on how data would be generated for this study using a simulation model. The development of the simulation model was discussed, including key aspects of the simulation model, selection criteria for firms used to parameterize the model, model development, and model execution.

After the data generation process was discussed, the data analysis strategy was presented. For input analysis, a discussion on how demand data by firm is analyzed in Chapter Five was presented. This was followed by a discussion on the use of a repeated measures design for output data analysis. In addition, three Appendices were provided. Appendix 4A provided a discussion on the background of the two firms selected to participate in the study, as well as parameter settings used by class of demand stream for the simulation model and a comparison of the SCRS strategic stances observed in the two companies against the predicted stances from the SCRS framework.

Appendix 4B provided additional detail on several simulation issues and tactics in this study, including discussions on verification and validation. Appendix 4C provided a discussic

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discussion on the how the number of simulation model runs was selected using an analysis of the statistical power of the test in this study and an evaluation of the statistical discrimination necessary to detect differences in firm financial performance.

In Chapter Five, results of the statistical analysis are provided, including presentation of statistical and managerial significance by SCRS archetypes and by disruption duration. These are provided for H1 (differences in SCRS archetype), H2 (differences in robustness by SCRS) and H3 (differences in resilience by SCRS). In addition, to support the analysis of H2 and H3, a graphical comparison of the marginal means of firm financial performance is provided in Chapter Five to help in evaluation of potential differences in robustness and resilience by firm.

CHAPTER 5

5 EXECUTION OF RESEARCH METHODOLOGY AND RESULTS

5.1 Chapter Objectives

The objective for this chapter is to draw upon and execute the research methodology from Chapter Four. Specifically, this Chapter focuses on input analysis of the demand data to drive the simulation model, execution of the experimental design by using the simulation model to generate data for analysis, and statistical analysis of the data generated. Then the results are placed within the context of the hypotheses. This Chapter begins with a brief overview of the analysis of input data used to generate demand data for the simulation model.

5.2 Input Data Analysis

The input data obtained from the case studies of the two participating companies were analyzed and compared to a number of theoretical distributions to determine an appropriate demand distribution to drive the simulation model. The demand data from both companies did not fit any of the theoretical distributions, and therefore empirical distributions were selected to run the simulation model runs according to the experimental design. More extensive details of the analysis of input data are provided in Appendix 5A.

5.3 Simulation Model Implementation

Chapter Four provided a discussion on the general structure of the simulation model, where one model was used to reduce confounding effects. The simulation model was implemented in accordance with the procedure and recommended practices outlined in Appendix 4B in Chapter Four, with extensive verification and calibration of the model conducted at each step in the modular development of the simulation model.

5.4 Method of Data Analysis

As noted in Chapter Four, analysis of the data generated by the simulation model was conducted using a repeated measures linear mixed model regression (Kutner *et al.*, 2005; Norusis, 2008). The method of estimation used was restricted maximum likelihood (REML), which produces unbiased variance and covariance parameters for linear mixed models (Patterson and Thompson, 1971; McCulloch *et al.*, 2008). The statistical analysis was conducted in SPSS version 16 and verified using SAS version 9.2.

5.5 Statistical Results

The analysis and presentation of statistical results follows the method prescribed in Chapter Four. A baseline of financial performance was established for each class of demand stream using a modular SCRS, which was used to compare differences in firm financial performance with the other scenarios in the experimental design within-demand stream comparison.

From analysis of this data, statistical results by demand stream are reported below for financial performance differences resulting from choice of *SCRS* and *disruption duration*. Statistical tests include *tests of fixed effects*, *estimation of fixed effects*, and *measures of model fit* by demand stream. This is followed by a test of significance for the interaction term *SCRS*disruption duration* by demand stream, and graphical analysis of the marginal means for LDV and HDV by disruption duration. After presenting the statistical results, they are discussed in the context of the hypotheses.

5.5.1 Results by Demand Stream

5.5.1.1 Test of fixed effects

The tests for fixed effects for LDV and HDV are provided in Table 5.1. For LDV, the F-test of fixed effects (β_i) for *SCRS* is 0.000, with a p-value that is highly insignificant at 1.000. The disruption duration and the intercept were highly significant at p<.001. For HDV, both SCRS and Disruption Duration are highly significant at p<.001.

Table 5.1 Tests of fixed effects by Demand Stream

Type III Tests of Fixed Effects[a,b]

			LDV		HDV	
Source	Numer. df	Denom. df	F	Sig.	F	Sig.
Intercept	1	199	57711.97	.000	2.62	.107
SCRS	1	2194	.000	1.000	135.51	.000
DisruptionDuration	5	2194	103231.56	.000	125.24	.000

a. CompanyID = LDV, HDV

b. Dependent Variable: Normalized Gross Profit.

5.5.1.2 Estimates of fixed effects

The estimates of fixed effects for LDV and HDV are provided in Table 5.2.

Table 5.2 Estimates of fixed effects for LDV and HDV[1]

Estimates of Fixed Effects[b,c]

	LDV							HDV						
						95% C.I.							95% C.I.	
Parameter	Est.	Std. Err.	df	t	Sig.	Low. Bd.	Up. Bd.	Est.	Std. Err.	df	t	Sig.	Low. Bd.	Up. Bd.
Intercept	-80.13	0.16	502.6	-507.3	.000	-80.4	-79.8	-.35	.071	228.9	-4.98	.000	-.49	-.21
SCRS= mod.	0.00	0.08	2194	.000	1.000	-0.1	0.1	-.18	.015	2194	-11.64	.000	-.21	-.15
SCRS=integ.	0[a]	0	.	.	.	.	.	0[a]	0	.	.	.	.	.
DisrDur=0	80.13	0.14	2194	580.8	.000	79.8	80.4	.44	.026	2194	16.86	.000	.39	.49
DisrDur =1	76.42	0.14	2194	554.0	.000	76.2	76.7	.44	.026	2194	16.79	.000	.39	.49
DisrDur=5	65.76	0.14	2194	476.8	.000	65.5	66.0	.39	.026	2194	14.97	.000	.34	.44
DisrDur=10	52.81	0.14	2194	382.9	.000	52.5	53.1	.16	.026	2194	6.10	.000	.11	.21
DisrDur=20	26.57	0.14	2194	192.6	.000	26.3	26.8	.55	.026	2194	21.01	.000	.50	.60
DisrDur=30	0[a]	0	.	.	.	.	.	0[a]	0	.	.	.	.	.

a. This parameter is set to zero because it is redundant.

b. CompanyID = LDV, HDV

c. Dependent Variable: Normalized Gross Profit.

5.5.1.3 Statistical results for LDV

For LDV, the estimates of fixed effects for the intercept and all disruption durations are statistically significant. The estimate of fixed effects for SCRS is zero, as expected given the insignificance of *SCRS* for LDV in Table 5.1. The coefficients for the disruption durations are positive, higher for shorter disruption durations, and statistically significant at all levels of disruption. Note that for LDV in Table 5.2 the *Intercept* and the scenario where *DisruptionDuration=0* are equal in absolute value terms, and that firm performance degrades for longer disruption disruptions, as expected.

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[1] The format of Table 5.2 is a default format common to SPSS 16 and SAS 9.2, where the estimate of fixed effects of the final cell of each experimental treatment is set to zero, such as the case for *SCRS=1 (integrated)* and *DisruptionDuration=30* [see Norusis (2008) for an example]. The format of these tables is not user adjustable.

5.5.1.4 Statistical results for LDV

For HDV, the estimate of fixed effects for the baseline modular *SCRS* is -0.18, relative to the integrated SCRS, with a highly significant p-value = .000 (Table 5.2). Each of the individual disruption durations and the intercept were highly significant at $p < .001$. Using a 95% confidence interval (95%CI), for HDV there appears to be no statistically significant difference between the estimates of fixed effects for disruption durations of 0, 1, and 5 days. There is evidence of a statistically significant difference, using a 95%CI, for disruption durations of 10, 20 and 30 days. The estimates for disruption duration for HDV are not linear as disruption duration increases, as they are for LDV. Part of the explanation for this effect will be presented in the subsequent discussion on graphical analysis of the marginal means for HDV.

5.5.1.5 Model fit for LDV and HDV

Table 5.3 shows the model fit results for LDV and HDV, in smaller-is-better form. This study employs the AIC criterion for measuring model fit (Bollen, 1989; Norusis, 2008), indicating a good model fit for both LDV and HDV, although the model fit for HDV is better. Alternative measures of model fit measures as shown in Table 5.3 are also small.

Table 5.3 Model fit for LDV and HDV

Model Fit - Information Criteria[a,b]

	LDV	HDV
-2 Restricted Log Likelihood	10484.326	2953.308
Akaike's Information Criterion (AIC)	10488.326	2957.308
Hurvich and Tsai's Criterion (AICC)	10488.331	2957.313
Bozdogan's Criterion (CAIC)	10501.886	2970.869
Schwarz's Bayesian Criterion (BIC)	10499.886	2968.869

The information criteria are displayed in smaller-is-better form.

a. CompanyID = LDV, HDV

b. Dependent Variable: Normalized Gross Profit.

5.5.2 Tests for interactions

5.5.2.1 Test of fixed effects for interactions

In addition, conducting a test for interactions is appropriate since there may be a potential moderating relationship between *SCRS* and *disruption duration*. The test of fixed effects for interactions was conducted separately for LDV and HDV (Table 5.4). The test for interactions included computing the marginal means for *SCRS*disruption duration* and plotting the interaction effects.

The F-test for fixed effects for LDV in Table 5.4 shows no statistical significance for the interaction term *SCRS*disruption duration*. For HDV, the tests of fixed effects for *SCRS, DisruptionDuration*, and the interaction term *SCRS*DisruptionDuration* were all highly significant at $p<.001$, indicating a direct relationship as well as a nonlinear interaction between the variables.

Table 5.4 Test of fixed effects for interactions, LDV and HDV

Type III Tests of Fixed Effects[a,b]

Source	Numerator df	Denominator df	LDV F	LDV Sig.	HDV F	HDV Sig.
Intercept	1	199	57711.9	.000	2.62	.107
SCRS	1	2189	.000	1.000	227.48	.000
DisruptionDuration	5	2189	102996.3	.000	210.24	.000
SCRS * DisruptionDuration	5	2189	.000	1.000	298.83	.000

a. CompanyID = LDV, HDV

b. Dependent Variable: Normalized Gross Profit.

5.5.2.2 Test of fixed effects for interactions

Since the results for LDV provided no statistical evidence of interactions (Table 5.5), the estimates of fixed effects with interactions were conducted only for HDV. For HDV, the estimates of fixed effects for the intercept, direct effects, and the interaction term are highly significant at p<.005 for HDV. The *main effects* for HDV are each statistically significant, but statistically indistinguishable from each other for disruption durations of 0, 1, and 5 days. However, there is evidence of statistically significant differences in main effects for disruption durations of 10, 20, and 30 days. The effect estimates for the interaction term, *SCRS*DisruptionDuration*, are each statistically significant, but the differences in estimates of effects for disruption durations of 0, 1, 5, and 10 days are statistically indistinguishable. However, the differences are statistically significant for disruption durations of 20 and 30 days.

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Table 5.5 HDV – Estimates of Fixed Effects with Interactions

Estimates of Fixed Effects[b,c]

Parameter	Est.	Std. Error	df	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	-0.5029	0.0712	231.8	-7.061	.000	-0.643	-0.363
[SCRS= modular]	0.1234	0.0286	2189	4.322	.000	0.067	0.180
[SCRS= integrated]	0[a]	0	.	.	.	.	.
[DisruptionDuration=0]	0.5029	0.0286	2189	17.607	.000	0.447	0.559
[DisruptionDuration=1]	0.5009	0.0286	2189	17.540	.000	0.445	0.557
[DisruptionDuration=5]	0.4534	0.0286	2189	15.877	.000	0.397	0.509
[DisruptionDuration=10]	0.2212	0.0286	2189	7.745	.000	0.165	0.277
[DisruptionDuration=20]	1.2008	0.0286	2189	42.044	.000	1.145	1.257
[DisruptionDuration=30]	0[a]	0	.	.	.	.	.
[SCRS= modular] * [DisruptionDuration=0]	-0.1234	0.0404	2189	-3.056	.002	-0.203	-0.044
[SCRS= modular] * [DisruptionDuration=1]	-0.1234	0.0404	2189	-3.056	.002	-0.203	-0.044
[SCRS= modular] * [DisruptionDuration=5]	-0.1234	0.0404	2189	-3.056	.002	-0.203	-0.044
[SCRS= modular] * [DisruptionDuration=10]	-0.1234	0.0404	2189	-3.056	.002	-0.203	-0.044
[SCRS= modular] * [DisruptionDuration=20]	-1.3020	0.0404	2189	-32.236	.000	-1.381	-1.222
[SCRS= modular] * [DisruptionDuration=30]	0[a]	0	.	.	.	.	.
[SCRS= integrated] * [DisruptionDuration=0]	0[a]	0	.	.	.	.	.
[SCRS= integrated] * [DisruptionDuration=1]	0[a]	0	.	.	.	.	.
[SCRS= integrated] * [DisruptionDuration=5]	0[a]	0	.	.	.	.	.
[SCRS= integrated] * [DisruptionDuration=10]	0[a]	0	.	.	.	.	.
[SCRS= integrated] * [DisruptionDuration=20]	0[a]	0	.	.	.	.	.
[SCRS= integrated] * [DisruptionDuration=30]	0[a]	0	.	.	.	.	.

a. This parameter is set to zero because it is redundant.

b. CompanyID = HDV

c. Dependent Variable: Normalized Gross Profit.

5.5.2.3 Model fit results for interactions

The model fit results in Table 5.6 for the interaction terms for HDV are very good, using the AIC criterion, and are an improvement over the earlier HDV model fit results for direct effects only that were shown in Table 5.3. With this result, the change in model fit was eva

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was evaluated for statistical significance. The change in model fit between the *direct effects* model and the *direct plus interactive effects* model for HDV is calculated as follows: Using a chi-square distribution with *df*=4 and a critical value of 18.47 at p=.001, the change in -2LL (Norusis, 2008) of (2953.308 - 1836.308) = 1117, indicating a statistically significant change in model fit.

Table 5.6 HDV – Model fit results for interaction term

Model Fit - Information Criteria[a,b]

-2 Restricted Log Likelihood	1836.308
Akaike's Information Criterion (AIC)	1840.308
Hurvich and Tsai's Criterion (AICC)	1840.313
Bozdogan's Criterion (CAIC)	1853.865
Schwarz's Bayesian Criterion (BIC)	1851.865

The information criteria are displayed in smaller-is-better forms.

b. CompanyID = HDV

c. Dependent Variable: Normalized Gross Profit.

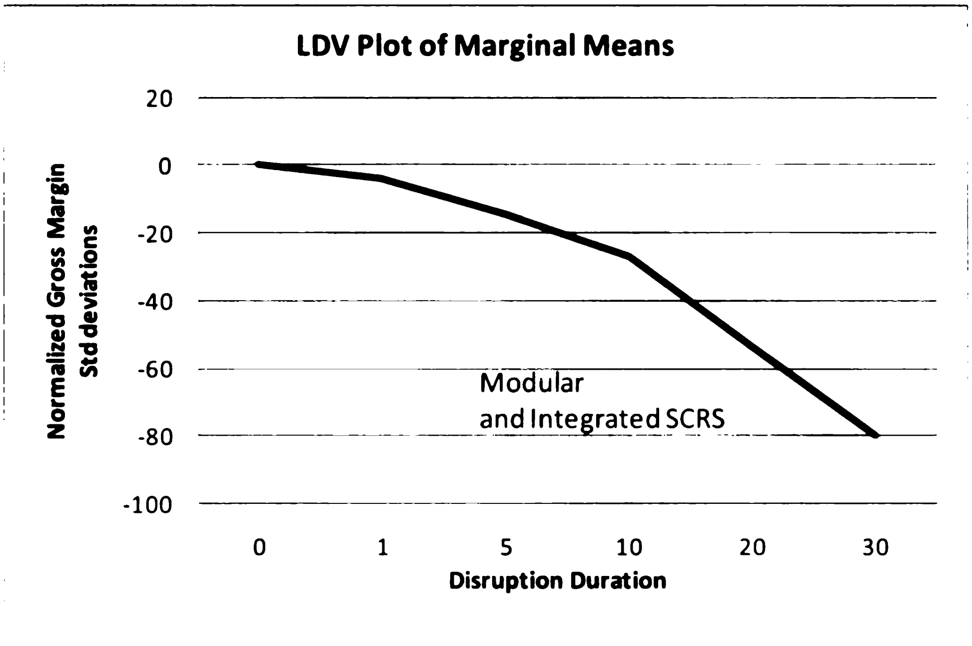
From here the discussion proceeds to a graphical of marginal means by class of demand stream to visually evaluate potential interactive effects by demand stream using graphical analysis.

5.5.3 Graphical analysis of marginal means

Graphical analysis of the marginal means is shown for LDV and HDV in Figures 5.2 and 5.3, respectively.

5.5.3.1 *Marginal means for LDV*

Figure 5.1 LDV – Marginal means for modular and integrated SCRS, by disruption duration

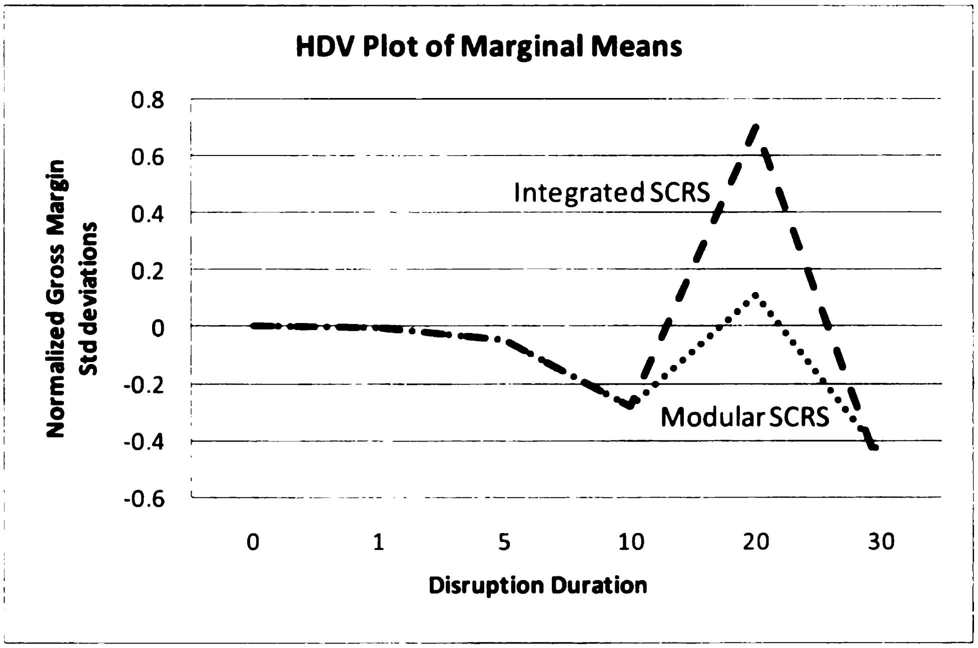


From a visual review of Figure 5.1, there is no evidence that LDV exhibits an interactive effect between *SCRS* and *DisruptionDuration* on firm financial performance; both the modular and integrated SCRS induce immediate performance degradation. The evidence suggests that both the modular and integrated SCRS's respond similarly for all disruption durations. From Figure 5.1, there appears to be no distinction between firm performance under conditions of disruption for the modular and integrated SCRS cases for the tightly coupled supply chain of LDV.

5.5.3.2 *Marginal means for HDV*

For HDV, in Figure 5.2 a clear difference is observed in firm financial performance by SCRS under conditions of supply disruption, where the integrated SCRS significantly outperforms the modular SCRS at a disruption duration of 20 days and slightly underperforms the modular SCRS for a disruption duration of 30 days. For disruption durations under 20 days, the two SCRS cases performance similarly.

Figure 5.2 HDV – Marginal Means for Modular and Integrated SCRS's



5.5.4 Statistical results for LDV and HDV simultaneously

For completeness, a combined analysis of LDV and HDV simultaneously was conducted to see if additional insights may be gained from the combined statistically analysis and to test for improved model fit. As recognized in Chapter Four, this was not expected to be the case since the underlying companies and their respective supply chains are fundamentally different and the moderate sample sized per cell in the experimental design may not be sufficient to detect statistically significant differences between LDV, which has small variances in demand and inventories, and HDV, which has large variances in demand and inventories. The combined analysis did not demonstrate the higher level of statistical discrimination that the separate analyses by demand stream provided, and the model fit using AIC was considerably worse that either single demand stream evaluation. Details of this analysis are provided in Appendix 5B.

5.5.5 *Results for hypotheses*

From here, the focus turns to evaluating the statistical results in the context of the research hypotheses. The findings from this study are summarized in Table 5.7.

Table 5.7 Summary of findings

Hypothesis	LDV	HDV	Outcome
H1: test for significant differences in firm performance due to SCRS	Not supported	Supported	Partial confirmation of H1
H2: observable properties of robustness	Not supported	Supported	Partial confirmation of H2
H3: observable properties of resilience	Supported	Supported	Evidence supports confirmation of H3
Test for interactions of SCRS * DisruptionDuration	Not supported	Supported	Contingent outcome, choice of SCRS made no difference for LDV
Additional observations from the study	SCRS dimension of tight geographical proximity dominated effects of SCRS visibility and information sharing	Safety stock algorithms played an unexpected and influential role in performance	Additional insights into SCRS dimensions and influence of transactional processes

5.5.5.1 *Hypothesis 1*

The statistical results are discussed in this section in detail by hypothesis. First, results for Hypothesis 1 are examined.

$H1_O$: *There will be no significant differences in firm performance directly attributable to firm choice of SCRS.*

$H1_A$: There will be significant differences in firm performance directly attributable to firm choice of SCRS.

5.5.5.1.1 <u>Results for LDV</u>

For LDV, there was no evidence observed that the choice of SCRS, as evaluated through the implementation of *visibility & information sharing practices* and *tight geographical proximity* in the simulation model, induced any difference in firm financial performance (Table 5.1). As noted previously in Chapter Four, this result was expected. For LDV, there was a direct relationship observed between duration of disruption and effect on firm financial performance. A closer examination of the data generated by the simulation model suggests that the tight geographical proximity of LDV with its suppliers and major customer resulted in very short transportation times and inventory levels during periods of normal supply. These low inventories and short transportations times provided no inventory buffers or time buffer, such as from potentially expediting freight, to mitigate the effects of even short supply disruptions.

5.5.5.1.2 <u>Results for HDV</u>

For HDV, there was strong statistical evidence that the choice of SCRS mattered to firm financial performance. Yet the relationship to firm financial performance was less clear than for LDV. For example, as noted previously for HDV there was no statistically significant difference observed in firm performance between disruption durations of 0, 1 and 5 days. In these cases, the primary financial effect for these disruption periods wa

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was lower inventory carrying costs that resulted from lower safety stocks for the short disruptions.

In contrast, the financial effects for a disruption duration of 10 days were statistically significant and different from the results for shorter disruptions. Upon further examination of the data for a disruption duration of 10 days, some instances of supply shortages occurred on some simulation runs when periods of higher than average demand preceded the disruption onset and therefore safety stocks were lower than expected prior to the disruption.

For a disruption duration of 20 days sufficient time was available to expedite replenishment inventory at a time when safety stocks were generally consumed, thus providing sufficient inventory to cover sales with very little inventory carrying costs. For a disruption duration of 30 days, the expedited inventory shipments that were initiated to avoid stockouts had arrived and were used to supply customers and replenish some inventory levels. This caused HDV to incur higher freight costs at a time when HDV was also incurring financial effects from inventory replenishment costs (on a "cash" basis) because previously shipped inventory that had been "on the water" was also arriving. This degree of underlying complexity in product and financial flows during periods of supply disruption is masked when focusing on gross financial profit as the firm performance measure, and will be discussed further in Chapter 6.

5.5.5.2 Hypothesis 2

Hypothesis 2 was stated as:

$H2_O$: There will be no difference in firm robustness due to firm choice of SCRS.

$H2_A$: There will be differences in firm robustness due to firm choice of SCRS.

5.5.5.2.1 Results for LDV

For LDV, there were no periods of robustness evident from firm financial performance reported in Table 5.2, where for each progressive duration of supply disruption firm performance degraded further. In this case, each duration of supply disruption was statistically different from other durations when using a 95%CI. In addition, the graphical plot of marginal means for LDV in Figure 5.1 exhibited no evidence of differences in firm financial performance by SCRS for any disruption duration.

5.5.5.2.2 Results for HDV

For HDV, firm financial performance did not show a statistically significant decrease until a disruption duration of 10 days, then performance improved for a disruption duration of 20 days due to receipt of expedited replacement inventory to avoid shortage costs. This suggests that HDV was robust firm financial performance effects from supply disruption for durations up to 5 days. As noted previously, looking further into the data there were a number of simulation runs where the firm was robust in performance for up to 10 days. But in some of the simulation runs for a disruption duration of 10 days, periods of higher-than-average demand preceding the onset of disruption and resulted in lower financial performance due to occasional stockouts in some of the replications.

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In addition, for HDV there was a notable difference in the marginal means by SCRS for a disruption duration of 20 days, as shown in Figure 5.2, indicating a significant difference in firm financial performance using an integrated SCRS due to HDV "invoking" visibility and information sharing practices to mitigate the effects of the disruption. The degree of geographical coupling did not appear to influence robustness for HDV.

5.5.5.3 Hypothesis 3

Hypothesis 3 was stated as:

$H3_O$: There will be no difference in firm resilience due to firm choice of SCRS.

$H3_A$: There will be differences in firm resilience due to firm choice of SCRS.

Results for LDV

For resilience, a decrease in performance and then a return to stable performance was predicted for both tightly (LDV) and loosely (HDV) coupled systems, particularly for longer disruption durations. For both companies, evidence of the first step in resilience was observed in the form of a statistically significant decrease in firm financial performance (from Table 5.2, Figure 1, and Figure 2). Once the disruption ceased, supply recommenced and in all cases of disruption duration firm financial performance returned to stability in a short period of time after cessation of the disruption. Thus resilience in firm financial performance was observed for both firms under all scenarios of supply disruption.

5.5.6 Summary of findings for modular and integrated SCRS

Overall, the findings for the effect of SCRS on firm performance for the LDV case were not statistically significant for differences in firm performance due to SCRS (H1) or to robustness due to disruption duration (H2), but were significant for resilience due to disruption duration (H3). Restated, the results for the LDV case did not demonstrate that additional visibility and information sharing in a very tightly coupled system was of financial benefit to firm performance due to differences in SCRS. For this case, the firm exhibited no robustness in performance for any duration of supply disruption (other than zero days). Yet, for all durations of supply disruption, the firm exhibited resilience – firm performance returned to a stable state after the disruption ceased as tested under the conditions of this study. For H1 and H2, the effects of relationship coupling dominated the marginal effects of additional visibility and information sharing, where the tight coupling induced effects on the focal firm almost immediately regardless of SCRS.

For the HDV case, the effects of SCRS on firm performance were clearly demonstrated. For H1, the integrated SCRS outperformed the modular SCRS due to the marginal value of additional information and visibility of supply disruptions, where there was sufficient time and availability of expedited transportation to invoke reactions strategies that limited the financial impact on the firm. For H2, the HDV case demonstrated periods of robustness in firm performance from the date of disruption onset, and after robustness ceased the firm exhibited resilience in performance (H3) – the firm returned to steady state performance after the disruption ceased. In addition, support was observed for an interactive effect between choice of SCRS and disruption duration, indicating a nonlinear interaction between these variables.

As noted in Chapter Six, before making any final conclusions from this study, further research is needed to better understand how these results may change when incorporating additional factors, such as incorporating supplier switching costs during periods of environmental uncertainty and the effect that these costs may have on firm performance.

5.5.7 An unexpected finding

In addition to testing hypotheses H1, H2 and H3 as well as testing for interactions between *SCRS* and *DisruptionDuration*, an unexpected finding from HDV was identified during the analysis. This had to do with short but unplanned and unexpected disruptions occurring during the "normal" conditions employed in the base case of modular SCRS under normal conditions of supply.

Under this "normal" scenario, no disruptions were induced and no shortages of shipments to Customer HDV were expected, yet they occurred on an infrequent but recurring basis under a number of the replication runs the baseline scenario. After *extensive* debugging and verification, this phenomenon was traced to the use of a safety stock algorithm that HDV employed. This algorithm was employed in this study and it contributed to the cause of these unexpected shortages in supplying HDV.

During the initial case study phase, instances of this infrequent stockout phenomenon had been reported by HDV managers, but the respondents at HDV were not able to exp

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explain its cause. From a more in-depth analysis, the properties of this shortage-inducing safety stock algorithm for HDV were traced to the use of 13 weeks of past history for calculating safety stock levels. As a result, this algorithm induced negative performance effects on the firm under certain demand conditions. A more detailed explanation of these properties induced by safety stock algorithms is presented in Appendix 5C. The discussion now turns to a summary of this Chapter.

5.6 Chapter Summary

This Chapter started with an analysis of demand data by demand stream to identify appropriate demand distributions to "drive" the simulation model. Next, a brief discussion was provided on how the simulation model was implemented according to the guidelines provided in Chapter Four, followed by a discussion of the analysis method and statistical software employed in the data analysis. This was followed by a presentation of the statistical results from the study, which were subsequently placed in the context of the hypotheses from Chapter Four. The final topic in the body of the Chapter was identification of an unexpected finding related to the use of a safety stock algorithm employed by HDV.

The Appendices for this Chapter include additional details on the analysis of the input data to generate appropriate demand distributions (Appendix 5A), an analysis of simultaneous statistical results for LDV and HDV demand conditions (Appendix 5B), and a more detailed discussion on the properties observed from the safety stock algorithm (Appendix 5C).

In Chapter Six, a summary of this study and the relevant findings are provided, along with a discussion of managerial implications, limitations of the study, and future research.

CHAPTER 6

6 CONCLUSION

This Chapter has several objectives: First, to highlight the findings and identify the contributions of the study. Second, to discuss the contingent nature of the findings and how they may affect managerial practice. Third, to discuss an additional contribution through the development of a simulation model to test the financial effects of alternative supply chain relationship structures on firm performance. Fourth, to identify limitations of the current study. The final objective is to identify areas of future research.

6.1 Findings and Contributions

The statistical findings of the study were summarized in Table 5.7, which identified results by demand stream for each hypothesis and included additional observations from the study. The findings are framed here in the context of the hypotheses, and then discussed in an overall context. To briefly summarize the statistical findings, Hypothesis 1, which tested for significant differences in firm performance due to differences in visibility and information sharing practices by SCRS, was not supported for LDV but was for HDV. Hypothesis 2, which focused on observable properties of robustness, also was not supported for LDV but was for HDV. Hypothesis 3, which focused on resilience, was supported for both LDV and HDV.

6.1.1 Clear support for Hypothesis 3

The clearest conclusion from the study is the full support of Hypotheses 3 – there is statistical evidence of resilience in firm financial performance after supply disruptions were observed for both firms. The method used in this study provides a technique for evaluating these effects from an academic and a practitioner perspective. One insight from employing this technique is that it is possible for managers to more accurately evaluate the potential cost of supply disruptions and make better informed decisions about investments in resources and time to mange or mitigate the potential effects.

6.1.2 Partial support for Hypotheses 1 and 2

Less clear, but consistent with the conundrum identified in the literature review, is the contingent nature upon which the results from the first two hypotheses can be explained. To do so, it is necessary to decompose the contingent effects of two influential factors identified in this study.

The first influential factor identified were the financial effects of tight geographical proximity on firm performance. In the first two hypotheses, statistical support for Hypothesis 1 and Hypothesis 2 was not observed for LDV, but was for HDV. Since LDV was tightly coupled, and more specifically tightly coupled in terms of geographical proximity, LDV relied on very small buffers and multiple shipments per day in the normal course of business. Under these conditions, even high levels of visibility and information sharing did not make any difference in improving firm performance during any unexpected disruptions. In these cases, the supply disruptions consistently affected firm performance almost immediately. This was due to very low inventories in the supply chain and no ability to "expedite" additional materials to the focal firm during supply disruptions, as HDV was able to do. Thus the fragility previously identified in lean systems in the context of supply disruptions (Zsidisin *et al.*, 2005) was observed in this study, and the effects of this fragility dominated LDV's financial performance during supply disruptions.

The second influential factor that influenced the contingent results is the presence of interactive effects on firm financial performance during supply disruptions. This is evidenced by statistical support for an interactive effect between SCRS and disruption duration, in addition to the main effects. This suggest that the relationship between choice of SCRS and firm financial performance under conditions of supply disruption exhibits linear and nonlinear effects, making the identification of the relationship more challenging when using traditional linear statistical methods. It also presents one possible reason why there have been confusing contradictions in the literature as to the most appropriate approach for firms to use in developing supply chain relation structures. It is hoped that these observations help to clarify some of the confusion.

6.2 Summary of differences due to modular and integrated SCRS

As noted in Chapter Five, there were differences observed in this study due to choice of SCRS, but not in all cases. From this study, initial indications are that SCRS provides partial explanatory power for firm performance differences under conditions of supply disruption. For H1 for the LDV case, there were no significant differences in firm performance due to choice of SCRS, but there were differences for the HDV case. For H2, in the LDV case the firm was fragile to disruptions, exhibiting decreased firm performance for even short disruption durations, while in the HDV case the firm was robust to performance degradation for shorter duration supply disruptions but was not robust for longer duration disruptions. For H3, both the LDV and HDV cases exhibited resilience in performance, returning to a stable state of performance after the disruption ceased.

From these findings, the following conclusions are made. For the LDV case, the choice of SCRS did not matter relative to firm financial performance since the strong effects of tight geographical proximity and tight organizational coupling dominated the effects of differences in information sharing and visibility due to choice of SCRS. For the HDV case, the effects of information sharing and visibility were important factors in firm performance, and the integrated SCRS outperformed the modular SCRS in terms of its effect on firm financial performance. It is recognized below that this is not a complete assessment of the conditions under which choice of SCRS matters, since a number of important factors need to be investigated in extensions of this study. From this initial study, it is concluded that supply chain design does matter, but these results highlight the contingent nature of firm performance.

6.3 Contingent Nature of Performance

It appears that the value and influence of visibility and information sharing practices in firm financial performance becomes more important when tight geographical proximity between firms is absent, as evidenced by the statistical support for HDV in Hypothesis 1. One of the interesting questions for future research is how much influence each of the four "proximities" for relationship structure identified by Fine (1998) affects firm performance. This contingent relationship needs further investigation to build a better understanding of the influence of these relationships on firm performance.

For HDV, which did not have tight geographical coupling, there was strong statistical evidence that visibility and information sharing practices influence firm performance under the range of normal and adverse operating environments for supply of components of products. In this case, firm choice of SCRS appears to have a significant influence on firm financial performance.

This contingent nature has important implications for managerial practice. For firms that participate in tight geographical coupling in their supply chains, investments in visibility and information sharing practices are one of the important mechanisms that make the tight relationship coupling process work effectively. For these companies, the trade-off is in *how much* to invest in visibility and information sharing practices, since some minimum level of investment is part of the relationship structure. As noted, this raises the question of whether there are upper limits on the value of information sharing in tightly coupled systems, as least those that are also tightly coupled geographically.

For firms with moderate or low levels of visibility and information sharing, and for which tight geographic proximity is not part of the structure of the supply chain, there may be considerable potential improvements in overall firm performance available through increased use of visibility and information sharing practices, as evidenced by the lower fixed-effect coefficient for HDV for a modular SCRS. But these findings are the result of a limited initial test into the effects of firm choice on SCRS, and should be interpreted with caution. It is not suggested that these results are generalizable, but rather that they provide initial insights and require further study.

6.4 Additional Contribution: A Test Model

One additional contribution from this study is the development of a discrete event simulation model that provides sufficient granularity to capture the transactional and financial flows in firms competing in supply chains, including the ability to generate data and through subsequent analysis identify nonlinear interactions between important variables that escape observation using simpler models. The model has the flexibility to increase or decrease granularity in observed variables and relationships, depending on the interest of researchers and practitioners.

While the model took considerable time to develop, verify and validate for the study, it provides a research platform from which to investigate additional aspects of firm performance in supply chains, including:

a) potential relationships between supply chain performance metrics and firm level operational metrics,

b) further understanding of the timing effects of the onset of supply disruptions and onset of performance degradation, and

c) extensions to incorporate costs and benefits of switching suppliers and accommodating environmental uncertainties, such as changes in market demand.

The next section focuses on identifying limitations of the current study.

6.5 Limitations

The statistician George Box noted "Essentially, all models are wrong, but some are useful" (Box and Draper, 1987, p. 424). So the model in this study is wrong as well, but hopefully useful. Yet there are a number of limitations of the study, several of which are identified here.

Obtaining data. While data was available for demand, costs, and internal transaction decisions such as ordering and inventory policies, there were several dimensions of the SCRS framework for which the companies did not have data. Data was not available on the cost of investments in developing modular or integrated supply chain relationships, for example, so a full cost/benefit analysis could not be conducted for a particular SCRS choice. In addition, the data obtained is very sensitive and confidential to the firms and thus challenging to obtain.

Reaction plans for disruptions were not quantifiable. While LDV had some level of reaction plans for disruption, such as potential alternative suppliers (through the influence of Customer LDV), there was no clear data available to quantify the costs or time in

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time involved in deploying the reaction strategy. For HDV, no reaction strategy was in place, although they were in the very early stages of investigating this option.

Additional desired outcomes. In this limited test of the SCRS framework, only one desired outcome was considered. There are several additional desired outcomes to consider and study in future research.

Geographical proximity was fixed. Geographical proximity turned out to play an important role in the contingent nature of the observed performance, yet there was no apparent method by which to turn geographical proximity into scenarios for sensitivity testing. It was recognized in Chapter Four that each class of demand stream was modeled according to whether it had tight or loose geographical proximity to its customers, primarily because no data was available from either representative demand stream (company) as to how to extend this into experimental scenarios by "converting" the geographical proximity aspect of their supply chain structure and related parameters to other strategic stances on geographical proximity. Since any "researcher-inspired" adaptation for this would have been arbitrary and difficult to ground in real data, it was decided to model LDV and HDV "as is" for each company regarding geographical proximity through the use of appropriate demand stream specific parameter settings for inventory and transportation times.

Potentially confounding effects. In this study, importance was placed on a relatively high degree of simulation model fidelity to the real LDV and HDV systems under study. While this provided important insights into firm financial performance under various

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experimental conditions, it also captured certain aspects of the underlying systems that may induce confounding effects, such as the choice of safety stock and inventory levels for the systems under study. These effects produce interesting effects in and of themselves, such as those explored in Appendix 5C, but they may alter the overall impact of the modular and integrated approaches for SCRS that were employed in this study. These potentially confounding effects must be recognized and investigated further in future research so that a more complete assessment of the impact of visibility and information sharing due to differences in SCRS practices on firm performance can be conducted.

Other factors weren't considered. Elements of environmental uncertainty, such as demand changes or competitive challenges, were not considered in this initial and limited test. Other important factors, such as supplier switching costs and the costs to develop standards necessary to deploy a modular SCRS or costs to maintain an integrated SCRS, were not possible to investigate due to lack of data. The companies responded that they did not have accurate numbers or reasonable estimates of these costs. The next section identifies several promising areas of future research.

Inventory costs were not segregated by fixed and variable cost savings for the HDV case. This occurred due to data availability issues. The effect on the results is thus: when disruptions occurred, the reduction in inventory carrying costs did not account for the unavoidable fixed portion of fully allocated inventory costs that would not have been avoided. As a result, while the differences in financial performance between the normal and

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and disruption cases are statistically and managerial significant, the differences represent a lower bound on the true costs.

6.6 Areas of Future Research

In addition to the areas identified above that merit additional research, there are four specific areas of related research identified below. They are: time signature of supply disruptions, different locations of disruption in the supply chain, additional relationship-related capabilities in supply chains, and the effects on performance from investigating different desired outcomes.

The time signature of disruptions is a challenging but interesting area of research. While the ability to understand the "time signature" or profile of a disruption should provide additional insights into the effects on firms from disruptions and provide insights into how to better mitigate and manage the effects of disruptions, the currently available statistical toolkits appear to be lacking in how to quantitatively evaluate distributions that display non-normality with high serial correlation in dynamic environments.

Another area of future research is evaluating how the effects on firm performance are influenced by the location of disruption in the supply chain, and whether different locations provide differential opportunities for the effects of the disruption to be absorbed or exacerbated before affecting the focal firm.

Additional research into supply chain relationships provides opportunities to better understand how social networks, and more specifically supply chain relationships, may contribute to or hinder firm performance under normal conditions and conditions of environmental uncertainty. This is a promising area of research.

The final area identified in this study for future research is to expand the scope of the study by extending this study to incorporate other desired outcomes of the firm. The question arises as to how the development of capabilities to support desired outcomes such as innovation or flexibility, for example, affects firm choice of SCRS, and how these choices subsequently affect firm performance. These questions and research opportunities provide a rich set of extensions to the present study.

6.7 Chapter Conclusion

This Chapter started by identifying the findings and contributions of this study, including full support for identifying the effects of resilience (Hypothesis 3) on financial performance for the two firms under study. Statistical support for the effects of SCRS (Hypothesis 1) and robustness (Hypothesis 2) were observed for HDV, but not LDV. Further review of the data for LDV revealed that the effects of geographical proximity and corresponding reductions in inventory and transport time dominated any mitigating effects modeled for visibility and information sharing practices for LDV.

In addition, there was statistical support in Chapter Five for an interaction effect for SCRS and disruption duration for HDV, adding to the complexity of the observed results. These finding provide support for a contingency model of for the strategy-structure-performance model as it applies to supply chain relationship structures. An additional contribution of the study is the development of a test model of supply chain pe

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performance, whereby firms can develop similar models to test the effects of important SCRS decisions in a manner more appropriate for their environment and circumstances.

In addition, several limitations to the study were identified. The Chapter concluded with the identification of several areas of future research, including investigating the time signatures of supply disruptions, differing locations for supply disruption, additional relationship related capabilities such as the effects of business social network aspects of supply chain relationships, and the exploring the effects of different desired outcomes on firm performance in the context of firm choice of SCRS.

APPENDICES

APPENDIX 2A - CONSTRUCTS AND BUILDING BLOCKS IDENTIFIED IN CHAPTER TWO

Note: The constructs initially introduced in this Chapter will be more fully developed into constructs in Chapter Three, and are summarized here along with important "building blocks" of the constructs.

Constructs	Definition	Interconnections	Citations
Supply chains are outcome driven	Desired outcomes are strategic outcomes desired by the firm. The supply chain should be designed and managed to deliver one or more of six basic outcomes: cost, responsiveness, security, sustainability, resilience and innovation.	Desired outcomes drive the development of supply chain capabilities.	Melnyk, Davis, Spekman and Sandor (2010)
Capabilities	The systems, processes, routines, and skills that the organization develops through its supply chain to solve specific types of problems.	Desired outcomes drive development of capabilities, which drive performance	Melnyk, Davis, Spekman and Sandor (2010), Fine (1998)
Expected firm performance	Firm performance in this study is defined as financial performance, where differences in cost result in higher or lower financial performance.	This establishes the "performance" aspect of the strategy-structure-performance model for this study.	Beamon (1999), Craighead, Blackhurst, Rungtusan atham and Handfield (2007)
Desired outcomes-> capabilities-> performance	From a supply chain perspective, Fine develops the model that argues strategy drives capability development, which drives firm performance.	This is the initial strategy-structure-performance model introduced in this study for supply chains.	Fine (1998)
Decisions on SCD are used to develop capabilities	Melnyk et al. (2010) applies this to the desired outcomes framework, arguing that desired outcomes drive SCD, which drives capabilities, which drives performance.	This links desired outcome to SCD, which is linked to development of capabiltiies, which is linked to performance.	Melnyk *et al.* (2010)
SCRS is an important dimensions of SCD	The implementation and management of specific types of relationships between firms in a supply chain which are intended to help the firm achieve certain outcomes.	Desired capabilities are influenced by SCRS decisions	As defined in this study
There are no generic or "one size fits all" SCD.	SCD is highly contingent on the desired outcomes selected. The capabilities developed will be very different depending on the desired outcome.	This is the contingency construct: the development of capabilities and performance outcomes must be evaluated in context of desired outcome.	Melnyk, Davis, Spekman and Sandor (2010)
Supply chain properties	That which is proper to anything; a peculiar quality of a thing; that which is inherent in a subject, or naturally essential to it; an attribute; as, sweetness is a property of sugar.	Properties are the result of developing capabilities, and are systematic outcomes or behaviors (observed or hidden) that influence firm performance.	Webster's Revised Unabridge d Dictionary (1998)

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APPENDIX 4A – COMPANIES, PARAMETER SETTINGS, MATCH TO SCRS FRAMEWORK

7 GENERAL CHARACTERISTICS OF FIRMS SELECTED

In this section, a general background is provided of each participating company representing relevant demand stream variation (LDV, HDL) and relevant parameters that are used in the simulation model are presented.

7.1 LDV Company

7.1.1 Discussion on strategic stances

LDV is part of an extensive and highly integrated supply chain that has been in place for decades through efforts and investments made by Customer LDV (at Tier C1). Long ago Customer LDV, and Customer LDV's Customer (Tier C2, the automotive OEM) required suppliers to fully participate in the supplier-customer integration processes at multiple tiers in the supply chain. This integration extends at least four echelons in the supply chain (C2 → C1 → T0 → T1), and may extend another tier as well. LDV has been involved in this long term supply chain and associated integrative practices since LDV was founded within the last two decades, and is very successful in improving company performance by participating and contributing to the integrative practices.

LDV provided substantial documentation of the high degree of visibility between echelons in the supply chain, and outlined the information sharing practices between companies. There was regular interaction and communication between the companies, often several times per day on various subjects and aspects of the relationship. The communication and problem solving was generally driven by Customer LDV, but the CEO of LDV provided direct examples where LDV initiated problem solving participation from Customer LDV to resolve problematic interorganizational issues identified by Company LDV.

Although the relationship was tightly coupled from the four proximities of coupling identified by Fine (1998), occasionally clear differences of opinion did occur and were addressed through the systematic problem solving process. Both company operations (LDV and Customer LDV) employed lean production processes and there were very few slack resources in the actual production systems. Yet it was observed that there were sufficient slack resources available for interorganizational communication and problem solving. The evidence for this was in the form of first-hand observation of initiation and/or resolution of several minor problems over the course of several onsite visits.

Although the clock speed of technological change in the industry is lower, as predicted by Fine (1998), the time intensity was high. The evidence for this was in the fast and

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very efficient pace of production processes, with evidence of an intense focus on "no waste" from the CEO of LDV during multiple visits to the production floor, and a strong focus on initiating interorganizational communication quickly once a problem or potential problem was identified. Customer LDV required very high operational performance from LDV, such as advanced shipment notices for all shipments, which were scheduled in small batches seven times per day to Company LDV. Any performance issues were quickly transparent in this high inventory turnover system.

LDV employed advanced preventive and predictive maintenance techniques throughout the T0 production process. LDV produced one to two days ahead of schedule in case of minor production issues such as unscheduled equipment repair. This produced a very small buffer, which resulted in very high annual inventory turnover of finished parts. LDV provided extensive data access to any data requested, and if the data wasn't immediately available or answers to questions needed follow-up from other personnel, answers were subsequently provided as requested. Cost data was extensive and available from two echelons in the supply chain, and records were meticulously kept and readily available.

7.1.2 LDV – additional details

For LDV, full 'late penalties' are not incurred in the simulation model as they are in the real system (Warner Communications, 2006), since the penalties are highly industry specific and on the order of tens-of-thousands of dollars per minute. Implementing such high penalties would cause the model to be highly idiosyncratic to this one industry, but the high penalties are recognized as very important in the discussion of results in Chapter Six.

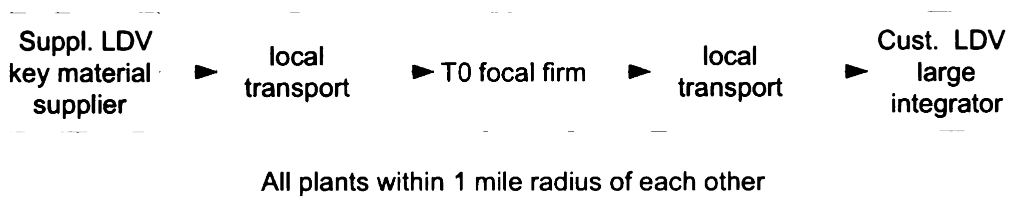
For LDV, backorders are allowed if necessary to get production back on schedule. Capacity limits are enforced at T0 in the simulation model during disruption recovery periods. The capacity limits are set to twice the normal capacity since LDV has sufficient excess production capacity in reserve to accommodate this difference.

Any disruption that would trigger the extremely high late penalties for an extended period of time goes beyond the scope of this study. For example, a fire or tornado could cause such an extended disruption. A power outage could also cause such a disruption, but LDV is located in the same power grid as Customer LDV, so this correlated disruption would likely stall both operations and negate any demand requirements by Customer LDV during the extended disruption period.

7.1.3 LDV supply chain

Figure 7.1 shows the supply chain as modeled for LDV. A key product (Product LDV) from LDV was chosen for the study via collaborative discussion with the participating company.

Figure 7.1 Observed integrated supply chain for LDV



The product line was chosen for several reasons:

- This product is typical of the majority of finished products produced by LDV,
- Supplier LDV provides approximately ninety percent of the material requirements for LDV, and
- Customer LDV is the largest and most important customer to LDV.

The supply chain for Product LDV is shown with the key material supplier, Supplier LDV, and the key customer, Customer LDV. All of the production plants in this simplified chain are within a one mile radius of each other.

7.1.4 Parameters for LDV

In this study actual demand data from Customer LDV to LDV is used, but due to confidentiality requirements only non-proprietary characteristics of the data are used in describing the parameters and discussing the published results. In Table 7.1 key simulation model parameters are identified for LDV.

Table 7.1 Parameters for LDV

Demand distribution	empirical
Coefficient of variation	Low (0 < cv < .25)
Sales volume	>10,000 units per month
Transport time (T1 to T0)	1 hour
FG Inventory safety stock	1-2 days
Customer forecast window	20 weeks
Order process type	MTO (make to order)
C1 order lead time	2 days
Tier 0 Costs	actual
Inventory holding costs	yes

LDV is characterized as a moderately high volume, quick inventory turnover, make-to-order company in a highly integrated supply chain. The coefficient of demand variation is low, demand is consistently above 10,000 units per month, transport times are very

quick, finished goods safety stock is quite low, the sales forecast window provided by Customer LDV is 20 weeks, the order process is make to order, finalization of orders are confirmed two days prior to production, actual costs are used, and inventory holding costs are included in the model. As stated earlier, Customer LDV may backorder quantities from LDV. This supply chain is a reasonable representative for many highly integrated automotive supply chains.

7.2 HDV Company

7.2.1 Discussion on strategic stances

HDV is in a much older company, having been founded many decades ago. Only in the last several years has HDV begun extensive outsourcing of finished products, primarily offshore. These offshoring practices have occurred in parallel with other firms in the industry, and HDV continues to develop techniques and practices to balance the needs of customer service with managing inventory levels, controlling costs, and handling variations in production and transport times in their extended supply chains. A significant percentage of their finished products are now produced offshore, yet they continue to refine and change their approach to the outsourcing process. HDV has recently adopted an initial total cost of ownership approach to sourcing decisions to further identify and quantify full outsourcing costs.

However, data availability has been primarily focused on direct production, sourcing, and transportation costs. Records of prior sourcing decisions were not readily available, and in many cases were sourced without formal analysis. Visibility was limited to sharing production forecasts from HDV to Supplier HDV, the main offshore source for HDV. HDV did not receive detailed production data and advanced shipment notices from Supplier HDV, but generally did receive shipment data several days after shipping containers were loaded in the port of origin and already in-transit. The communication and follow-up process did not appear to be highly systematic, other than processing paperwork for transactional requirements.

If problems occurred, email, telephone or fax communications generally initiated the communication process. Managers or the senior supply chain executive made trips to the sourcing country several times per year to the supplying plant. The company had many product lines sourced through this supplier, and detailed problem solving discussions generally ensued on problem parts only when the problems hadn't been resolved since the last overseas visit.

The investment intensity in the interorganizational processes and relationships were considered low by HDV, a view supported by observations of the researcher. There were virtually no investments in interorganizational information systems beyond standard telephone, email and fax communication. The clockspeed in this company and the industry is higher because the external appearance of many of the product lines is considered a fashion item. Several HDV products that were successful over time were still in the product mix, but the large "big box" retail customer, Customer HDV, required new product finishes and designs as part of the ongoing product mix to help draw customers in to see new products.

The time intensity was considered low due to the additional time it took to resolve problems and the laborious nature of the communication process, including half-day differentials in time zones and common multi-day delays due to the generally asynchronous communication. Thus in Table 7.3 (below) the problem stance was classified as ad hoc reactive problem solving, which was considered a weakness in the firm's problem solving process.

7.3 HDV – additional details

HDV sells to large retail chains in a competitive market. If HDV products are not on the retail shelf, there is a high likelihood that customers won't wait for replenishment since retail locations for Customer HDV order on a weekly basis. There are a number of easily substitutable products available at Customer HDV, so items that stock out are considered lost sales.

7.4 HDV supply chain

In Figure 7.2 the supply chain is shown as modeled for HDV. A key product from HDV was chosen via collaborative discussion for the study. This supply chain is multinational. Supplier HDV is located in Asia, HDV is located in the United States, and Customer HDV's retail locations are located across the U.S and Canada. Each of Customer HDV's retail locations order directly from HDV on a weekly basis. HDV almost always uses ocean freight, and has a policy to eliminate air freight for expedited products. This supply chain is a reasonable representative for the companies competing in this industry.

Figure 7.2 Observed modular supply chain for HDV

The product line was chosen for several reasons:

- This product is typical of finished products for HDV, and is a very high selling product,
- the finished goods supplier from Asia is a key supplier and supplies many products as finished goods to HDV, and

- the characteristics of this supply chain are representative of the supply chains in HDV's Asian sourcing strategy.

7.5 Parameters for HDV

In this study actual demand data is used from Customer HDV as sent to HDV, but again only characteristics of the data are provided in describing the parameters and discussing the published results due to confidentiality requirements. In Table 7.2 key simulation model parameters are shown for HDV.

Table 7.2 Parameters for HDV

Demand distribution	empirical
Coefficient of variation	high (1.25 < cv < 1.75)
Sales volume	1,000 to 5,000 units per month
Transport time	25 days standard, 7 days expedited
FG Inventory safety stock	20 days
Customer forecast window	n/a (HDV does internal)
Order process type	MTS (make to stock)
C1 order lead time	<7 days
Tier 0 Costs	actual
Inventory holding costs	yes

HDV is characterized as moderate volume producer with a high coefficient of variation. HDV uses an Asian supplier and ocean transport for almost all transportation requirements for sourced material. HDV calculates forecasts based in 13 weeks of prior sales for their make to stock inventory policy, and uses four weeks of production as inventory for demand and safety stock. Customer HDV provides HDV one week or less to replenish inventory at the retail stores. Actual sourcing and holding costs are included in the model. HDV doesn't backorder quantities for customers since sales are generally lost to competitors when retail stock is exhausted.

7.6 A match between predicted SCRS stances and actual firm stances

Here a discussion is provided of the match between the predicted firm stances from the SCRS framework from Chapter Three and characteristics of the firms selected for the study. The firms possess characteristics representative of each of the two SCRS archetypes, and implementation of their strategic SCRS decisions closely match the criteria provided in Chapter Three. The SCRS framework is applied to the companies in this study as shown in Table 7.3, and the simulation model is a simplification of relevant dimensions for the firms participating in the study.

Table 7.3 SCRS framework applied to observed SCRS strategic stances for LDV and HDV

	LDV	HDV
Strategic Decision	Integrated	Modular
Visibility & information sharing	high	low
Relationship coupling	tight	loose
Problem solving	reactive - responsive	reactive – ad hoc
Slack (technical) resources	higher	lower
Investment intensity	higher	low
Clockspeed	lower	higher
Time intensity	higher	low

In Table 7.3, the strategic SCRS decisions observed in LDV and HDV are presented, revealing a relatively close match between actual observations and predicted fit to the integrated and modular SCRS characteristics in the framework. The companies match up well on visibility and information sharing, relationship coupling, slack resources, investment intensity, clockspeed, and time intensity. However, there are differences in Table 7.3 between the theoretical SCRS framework predictions and actual practices on problem solving.

As predicted for an integrated supply chain, LDV employs a highly reactive problem stance to identify problems early and use collaborative actions to resolve problems in a systematic manner within an integrated SCRS. However, In Chapter Three, it was predicted that firms employing modular SCRS's would adopt a proactive problem stance to overcome the inherently lower levels of coordination and communication.

Yet it was discovered that HDV has what can best be characterized by an *ad hoc reactive problem solving* stance, one which is not very structured and which incurs significant time delays during the resolution process. This appears to be more related to a weak problem solving stance with HDV and its suppliers than a deficiency in the framework. This observation is based in part on HDV's recognition that their problem solving process had not performed well.

In addition to the fit of representative demand stream stances on the seven SCRS dimensions, details on other firm differences obtained from the empirical case studies for LDV and HDV are provided in Table 7.4.

Table 7.4 Observed empirical differences, LDV and HDV

	LDV	HDV
Nature of demand	low variation	high variation
Order process type	make to order	make to stock
Inventory policy	JIT (holds 1-2 day safety stock)	safety stock + normal stock = 20 days
Geographical proximity	<1 mile	Asia to U.S.
Deliveries	7 local deliveries per day	by ocean container
Margin characteristics	low margins, very high turnover	moderate margins, moderate turnover
Shortage policy	backordered	lost sales (retail environment)

These differences facilitate generalization of the study on a small scale by including aspects of differing demand functions, order policies, inventory policies, geographical dispersion, delivery frequencies, margin characteristics, and shortage policies. To the extent that differences in some of these characteristics may also influence financial performance in ways beyond the scope of this study, as noted in Chapter Six, they provide a rich basis for future research.

APPENDIX 4B – SIMULATION ISSUES AND TECHNIQUES

8 INTRODUCTION

In this Appendix, a number of simulation issues are addressed, including generation of demand data for the model runs, startup /initialization strategies, length of warm up period, steady state model performance, model verification and calibration, variance reductions techniques, and key simplifying assumptions employed in the models. There are a number of references and guidelines on simulation model development and verification/validation (cf. Banks, 1998; Pidd, 2004; Law, 2006). These guidelines were followed during model development, model runs, and output analysis.

8.1 Demand data for the models

8.1.1 LDV

Demand data for the models was provided by the participating companies. LDV provided data on two important product lines, and from these product lines one representative sample product was chosen. This product had been introduced in the prior year at full production rates for a new car model. 157 daily data points were provided of actual demand for the product during the period of mid- to late-2007, representing almost 32 weeks of production on five day per week basis. There is no observable seasonality to the demand of this or related products.

8.1.2 HDV

HDV provided relevant data on a significant number of product lines, and a large volume and important product for the company was chosen for detailed analysis. For this product HDV provided detailed C1 demand data and T0 orders to the T1 supplier. The data covered daily customer demand for a 40 week period from late 2006 to mid-2007. The demand from Customer HDV consisted of approximately 8,000 data points comprising independent local store demand over this period from dozens of large retail stores in the United States. Individual C1 store demand was consolidated into total daily demand for the product at HDV. There was no identified or observed seasonality for this product.

In Chapter Five, the demand data is used to generate the input distributions by class of demand stream (LDV, HDV) for the simulation model. Relevant ranges of monthly production for LDV and HDV, as well as relevant statistics and histograms of the demand data used for LDV and HDV are presented in Chapter Five.

8.2 Start-up/initialization strategies

Start-up conditions for simulation models can produce atypical behaviors due to initial transient conditions as the models "warm up" to steady state conditions. In the case of supply chain simulations, initial transient conditions may include starting from zero inventory conditions at multiple echelons, which could produce transient stock-outs and backorders until enough simulated time periods transpired such that inventories were replenished to appropriate levels. There are two issues to address when reviewing initial transient conditions:

- length of the warm up period, and
- management of initial transient conditions to achieve steady state performance

8.3 Length of the warm up period

Evaluating the length of the warm up period to achieve steady state performance includes careful observation of model performance against expected behaviors, assuming that at some point the model achieves steady state behavior and indeed "behaves" as experts knowledgeable about the system would expect the underlying system to behave (Robinson, 2004b; Law, 2006). In this study, initial time series inspection of inventories and stockouts revealed issues with model warm up.

Using graphical and numerical inspection of multiple performance indicators in the computer model ("traces") and multiple runs of each model, it was clear that for HDV initial transient model performance disappeared after a maximum of 45 days of model run time. Beyond this date inventories were cycling within proper reorder points and inventory levels.

In contrast, LDV achieved stability in performance after a couple of days due to trivial inventories and very high inventory turnover. As a result, it was decided to identify model variables that exhibit transient behavior and, after examining multiple model replications, set these variables to some initial settings to "seed" the variables to reduce or eliminate the model warm up period. After evaluating the model and factors affecting the startup, it was decided to focus on establishing initial seeding for inventory levels since this variable was the only aspect of the startup that induced transient performance. Once this was done, no detectable difference was observed in initial model stability.

Steady state performance

The model for LDV achieved steady state performance in the first day during the initial evaluation runs due to very low safety stocks, short production times and excess capacity. This was evidenced by the very small T0 safety stocks being filled on the first day and being sustained throughout the simulation runs. Since capacity exceeds daily demand and raw material is readily available, there were no production discontinuities to prevent stable system performance. Additional graphical and numerical performance reviews of production, shipments, stockouts, backorders, and financial flows demonstrated no transient states.

The model for HDV exhibited the initial transient states noted above for a 45 day period. Further inspection revealed that this was directly related to the "pipeline fill" of products by Company HDV's supplier (Supplier HDV) production and ocean transport. Since the initial model runs started at zero inventories and the supply process required 20 days production lead time and 25 days of ocean transport, including customs clearance and domestic delivery time, the 45 day transient period matched this pattern.

As a test, temporarily changing the supplier production times and transport times resulted in a 1:1 change in the transient state time. As a mitigation strategy for no in-transit and supplier inventories at the start of model runs, inventories were seeded at start-up with average Supplier HDV production and ocean transport inventories. Additional graphical and numerical performance reviews of production, shipments, stockouts, backorders, and financial flows demonstrated no remaining transient states.

8.4 Model verification and calibration

There are a number of techniques that can be employed for model verification and calibration (Banks, 1998; Pidd, 2004; Law, 2006). Verification is the process of making sure the model performs as the designer intended in the initial model specifications. Calibration is the process of selecting appropriate parameters for the model to properly replicate known behavior of the system under study. Validation, after verification, is the process of matching model performance to the external system and comparing performance to ensure model performance under all possible conditions matches performance of the system under study.

Full validation is considered impossible for realistic systems (Pidd, 2004; Robinson, 2004b) since, for example, many real systems cannot be tested in all possible states for comparison to the model. Calibration is used in conjunction with verification methods to improve model fidelity and build confidence in the customers or users of the model that model performance is consistent with expected behavior. Several verification and calibration techniques (Law, 2006) are employed in developing the models for LDV and HDV:

- Matching input distributions to real system
- Code "walk-throughs"
- Modular development, with individual tests of inputs at outputs at each stage
- Full model tests of inputs and expected outputs under known conditions
- Face validity
- Traces, including visual and output

- Manual calculations, external to the simulation
- Debugging techniques
- Common model components for non-company specific aspects
- Reviews with companies

8.5 Variance reduction techniques

Variance reduction is important because it enables the researcher to reduce variance between replications without compromising the quality of the results. There are a number of variance reduction techniques available for simulation modeling (Pidd, 2004; Robinson, 2004b), most of which are used in this study:

- Use of the same company demand data under different SCRS and disruption scenarios.
- Statistically significant number of replications.
- Converting stochastic processes to explicit experimental scenarios.
- Common random numbers.

The use of the same demand data under different SCRS and disruption scenarios, in combination with random numbers discussed below, improves statistical discrimination in analysis of the final results.

In this study, the recommendations on statistically significant number of replications by Kutner, Nachtsheim, Neter and Li (2005) are followed to improve the statistical validity of the model runs and ensure sufficient statistical power. That is, runs of 200 replications were used to achieve statistical significance while enhancing improving statistical power to detect small changes in performance for the short duration disruptions (for details see *Power of the Test* in Appendix 4C).

Converting stochastic processes to explicit experimental scenarios involves using disruption durations as an explicit experimental factor that can be controlled to test for statistical and managerial significance in terms of firm financial results. This method was also employed to set transportation and production times to their average values to reduce unnecessary variation in model output.

For the use of common random numbers within this study, variance reduction was implemented in the computer model through the use of common random numbers for each simulation run. That is, for each of the scenarios in the experimental design, a specified number of runs was completed to achieve statistical significance and to reduce the effects of an idiosyncratic simulation run on the data generated. In the replication runs, each initial run (run #1, in this case) used the same random number seed from the probability distribution underlying the random number generator in Arena, regardless of which scenario from the experimental design was being run. Run #2 also used the same common random number seed for all second runs by scenario, although this random number seed was different than the one use for run #1. The remaining runs proceeded similarly.

This method allows for a reduction in variance in the subsequent statistical analysis, particularly when using a repeated measures analysis as was used in this study. In the repeated measures analysis, each simulation run was treated as a repeated measure from the same "subject" - the specific scenario from the experimental design - allowing for the partial correlations by subject to be parsed from the other partial correlations in the statistical analysis.

8.6 Key simplifying assumptions

The key simplifying assumptions are summarized in Table 8.1. It is important to recognize that all models involve certain explicit or implicit assumptions.

Table 8.1 Model assumptions

Assumptions	Notes and comments
Transportation and production times are treated as constant.	Since transportation and production times are not central to this study, they are treated as constant. This is done to reduce additional "noise" by focusing on only random variations in demand, differences in SCRS, and disruption duration rather than accurately replicating all possible sources of variation in the supply chain.
Demand is stochastic and independent.	Demand is based on empirical demand distributions specific to the company.
Disruptions are modeled as full disruptions for specified periods of time.	Since the focus is on the performance effects of disruption durations, rather that identifying and mitigating individual causes, additional detail on the exact cause of the disruption is not needed, thus simplifying the model structure.
Each disruption duration is modeled as a separate scenario of supply interruption (see Table 2), using multiple runs per scenario to generate data for statistical analysis.	The models do not run with stochastic probability of disruption on any given run. This allows a specific focus on firm performance effects when disruptions of specified duration occur. During the analysis phase this allows a closer examination of the effects of differing durations of disruption, a key area of interest to executives participating in the study.
Disruptions occur at the Tier 1 supplier level.	This has an almost immediate effect on LDV since daily customer orders are completely processed and shipped in the same day. It doesn't affect HDV for a period of time since HDV ships from stock without adding further processing for the product under study. Thus for HDV, the key performance driver is the level of safety stock and disruption duration.
Safety stock is explicitly modeled for both companies. The same level of safety stock is used for the native SCRS and the alternate SCRS.	While this is not realistic, there is no data available on how the firm might change safety stock under the alternate SCRS since managers from both firms do not know what these safety stocks would be under the alternate scenario, and setting them by researcher preference would be arbitrary. More importantly, pricing for LDV is specifically designed to recognize the high throughput and low inventories. Adding significant safety stocks to model the alternate SCRS would seriously affect financial flows since not data is available to provide corresponding inventory cost accommodation for LDV pricing to Customer LDV.
The model uses daily performance over a 260-work day year. The models are based on the total of four 13-week quarters with five work days each.	This simplifies accounting for holidays and other non-focal anomalies.
Firm performance results are reported on an annual basis.	Monthly or daily performance effects can easily be measured, but this induces issues of timing differences that are not the focal concern of researchers or executives participating in the study. For example, although the timing may affect quarterly performance result if the disruption occurred in June rather than July, the effects wash out in the annual outcomes that are of most interest to executives.

Table 8.1 continued

Assumptions (continued)	Notes and comments
Differences between firms in terms of demand characteristics, inventory policies, ordering policies, and other factors identified in the discussion on *parameters* above are explicitly modeled as separate model configurations for LDV and HDV. Other non-focal aspects of the simulation models, such as model code for data collection of firm performance, scheduling model runs, and specifying the number of replications use shared model code.	This modeling practice helps to keep aspects of the models consistent and to help ensure that differences in performance are attributable to intended and specified elements of demand and relationship structure, rather than due to subtle differences in non-focal aspects of the model code or unique "bugs" in sections of the code.
Order quantity minimums are not enforced.	LDV has no minimums, thus this rule does not apply to LDV. HDV has rather small minimums and is able to use partial shipments in ocean shipment containers due to sourcing a large number of different finished part numbers from the same supplier using the same Asian port. The effect on performance is very minimal on a daily basis, and the effects of not enforcing minimum order sizes are essentially unobservable over the annual time frame of the model.
For integrated SCRS's, disruptions signals are observed and reaction strategies enforced by the T0 focal firm the day following the occurrence. For modular SCRS's, disruption signals are observable when the shipment is due to ship.	Expediting for an integrated SCRS can be triggered on the day when the disruption occurs, but is not triggered under modular SCRS until time of shipment as explained above.
The amount of raw material supply is uncapacitated.	LDV has abundant supply from qualified primary and alternate sources. HDV loses any delayed or disrupted sales, so T1 capacity constraints to fill any backorders are not important in the model.
The Tier 1 production capacity is higher than all expected (empirical) order sizes from the Tier 0 focal firm.	Tier 1 capacity for LDV is negotiated by Customer LDV, and consistently exceeds LDV demand requirements. HDV negotiates orders with Supplier HDV, and does not place order sizes in excess of Suppliers LDV's capacity. Supplier LDV's capacity has not been an issue for LDV.

APPENDIX 4C – POWER OF THE TEST

9 NUMBER OF EXPERIMENTAL RUNS

This Appendix provides an explanation of how the number of experimental runs per scenario was determined for this study. The discussion starts with a discussion on evaluating the necessary statistical power of the test. Power of a statistical test is the probability of rejecting the null hypothesis when the null hypothesis is false, and is given by the formula:

$$Power = 1 - \beta = P(\text{reject } H_0 \mid H_0 \text{ is false})$$
$$where:$$
$$\beta = P(\text{type II error}) = P(\text{fail to reject } H_0 \mid H_0 \text{ is false})$$

Calculating statistical power for a single factor study the formula is given by:

$$\phi = \frac{1}{\sigma}\sqrt{\frac{n}{r}\sum(\mu_i - \mu.)^2} \quad \text{when } n_i \equiv n \text{ and}$$

where: $\mu. = \frac{\sum \mu_i}{r}$

$\phi =$ noncentrality parameter, a measure of how unequal the treatment means μ_i are,

$r =$ number of levels of the factor under study, and

sample sizes are of equal size n

For multiple factor studies such as this one the calculations are more complex. Guidelines for selecting sample sizes are provided in statistical reference manuals. For this study the guidelines by Kutner, Nachtsheim, Neter and Li (2005, p. 1342, Table B.12) were employed. For a multiple factor study with Power = $1 - \beta = .90$ at $\alpha = 0.05$ and conservatively using $\Delta / \sigma = 1$ where Δ is the minimum mean difference to detect and σ is the standard deviation, and using six factor levels for the first factor an initial sample size of $n = 34$ was obtained. This resulting sample size n was then used in the formula $b*c*n$, where b = the number of factor levels for the second factor and c= the number of factor levels for the third factor. This results in a recommended minimum sample size of 136.

Interestingly, changing the order of the factors for the calculations based on the lookup tables results in a minimum sample size of 408 (17 samples per cell). This study initially used 30 samples per cell * 24 cells = 720 experimental runs for the initial analysis, which significantly exceeds the minimum calculated sample size. But this sample size proved inadequate to detect important but small changes such as short duration disruptions as compared to a 260 day work year.

Comparing this to the sample size requirements per cell for a repeated measures linear mixed model (McCulloch *et al.*, 2008) resulted in a minimum of 100 samples required per cell. In conjunction with this insight, the sample size was increased since, as the authors note, judgment is needed to determine final sample size. The final factor in increasing the sample size was the necessity to have sufficient sensitivity to detect small changes in financial performance.

When using financial performance (FP) as an example the standard deviation of FP is approximately 7% of the mean for annual performance for HDV at baseline performance (no disruption case). In other words, with the minimum sample size and $\Delta / \sigma = 1$ a 90% probability was achieved to detect a 7% difference in sample means on annual financial performance. However in this study, as an example, if a disruption of short duration (such as one to five days) results in a small difference (0.38% for one day) in average financial performance as compared to baseline performance. It was desired to be able to detect this important difference.

With this in mind, the decision was made to use 200 replications per cell in the experimental design to provide for proper statistical discrimination. The larger sample size provides this improved discrimination between sample means, and is consistent with larger sample sizes advised for repeated linear mixed models.

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APPENDIX 5A – ANALYSIS OF INPUT DATA, MODEL PARAMETERS, AND COMPANY BACKGROUND

10 IDENTIFYING DEMAND DISTRIBUTIONS

This Appendix includes an analysis of the demand data by class of demand stream (LDV, HDV) to identify appropriate demand distributions to drive the simulation model.

10.1 Input data analysis

Initial analysis of demand data for the product lines selected for the study required an additional step prior to inclusion in the simulation model. This step involved inspecting the data for outliers and to evaluate whether the demand data fit any theoretical distributions that could be used as input data to 'drive' in the simulation model. Outliers were reviewed by company, and none were identified that did not correspond to actual and occasionally expected data points.

The input data for each respective company were evaluated for fit against a number of theoretical distributions using distribution-fitting software[2] (Banks, 1998; Robinson, 2004a). Distribution-fitting software uses modern computing power to automate this process via explicit distribution functions or extensive numerical computations to evaluate the best-fit probability laws that underlie data sets while providing estimation and goodness-of-fit measures to rank suitable probability distributions (Madgett, 1998). Advances in computing capability allow the use of distribution fitting software as an alternative to the use of manual distribution transformations (Box and Cox, 1964), where manual distribution transformations may result in a higher probability of input distribution errors (Banks, 1998; Law and McComas, 2002; Law, 2006).

10.1.1 Demand data for LDV

For LDV the demand data comprised 157 daily observations for a key product line. While the actual descriptive data for these daily demand observations are not disclosed due to a confidentiality agreement with the participating firm, the data points are relatively stable, with monthly demand above 10,000 units and a coefficient of variation in the range of 0.00 – 0.25. To assess independence of the unordered data, two techniques were employed (Banks, 1998; Law, 2006). First a phase plot was reviewed in the form of a scatter diagram, revealing no simple patterns of cycles or obvious trends (results in Table 10.1). Second, a lag correlation plot was employed to evaluate potential cycles in

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[2] In this study ExpertFit version 7 Professional Edition was used (Robinson, 2004a), using high precision analysis. ExpertFit is by Averill M. Law & Associates, www.averill-law.com.

the demand data with lags of period 2 through 20, which represents a statistical estimate of the correlation between two observations that are *j* observations apart in time, also with no discernable patterns or cycles evident in the data (Table 10.1).

Table 10.1 Evaluation of independence, LDV demand data

Method	LDV	HDV
Scatter plot (*x, x+1*)	no discernable pattern	no discernable pattern
Lag plot, periods 2-20	no discernable pattern	no discernable pattern

Next the data were evaluated using goodness-of-fit tests from forty theoretical distributions (Banks, 1998; Law, 2006, p. 353). The Anderson-Darling (A-D) test is considered more powerful in discerning goodness-of-fit, and was the first test used to evaluate the fit of LDV data to the log-logistic distribution (Table 10.2), the closest-fit distribution as identified in the analysis. As shown in Table 10.2, testing the fit of the distribution to the empirical data resulted in rejecting the log-logistic distribution as the underlying distribution. Based upon the clear rejection of the distribution fit, no further evaluation is necessary (Law, 2006).

Table 10.2 Evaluation of theoretical distribution fit - LDV

Goodness-of-fit test	Theoretical distribution: log-logistic[1]		Result
	test stat.	crit. value (p<.05)	
Anderson-Darling (K-S)	3.149	0.659	reject

Note 1: closest theoretical distribution was tested

Since the data did not pass the requirements for the goodness-of-fit tests, an empirical distribution was chosen to replicate the demand distribution for Company LDV. ExpertFit has a procedure for generating empirical distributions for a number of simulation software programs, including Arena (the simulation program used in this study), and was used to generate the empirical distribution for Company LDV.

10.1.2 Demand data for HDV

For HDV the data comprised 202 non-zero daily demand observations for a key product line, where each daily demand total is the compilation of numerous daily customer orders. More than 8,000 data points from hundreds of Customer HDV's stores (discrete customer orders) over this 202 day period were used to generate the daily demand observations. In addition, there is a small percentage of the time where no orders were placed (<1%), which is modeled directly in the computational model. In this case, the daily quantities vary considerably, with monthly demand within a range of 1,000 to 5,000 units and a coefficient of variation in the range of 1.25 to 1.75. To assess independence of the data, the prior techniques were employed. The phase plot revealed no simple patterns of cycles or obvious trends, and the lag correlation plot also revealed no discernable patterns or cycles in the data (see Table 10.1).

Next the data for HDV were evaluated using the same goodness-of-fit tests for the lognormal distribution, the closest fit distribution as identified in the analysis. As shown in Table 10.3, the A-D test results were rejected but borderline, requiring additional evaluation. The Kolmogorov-Smirnov (K-S) test also resulted in rejecting the distribution fit. Using the less conservative χ^2 test, the distribution fit marginally passed the criteria.

Table 10.3 Evaluation of theoretical distribution fit - HDV

Goodness-of-fit test	Theoretical distribution: log-logistic[1]		Result
	test stat.	crit. value (p<.05)	
Anderson-Darling (A-D)	0.85	0.749	reject
Kolmogorov-Smirnov (K-S)	0.986	0.892	reject
χ^2 (if A-D & K-S is borderline or fails)	48.297	54.572	marginal pass

Note 1: closest theoretical distribution was tested

Following the recommendations of Law (2006) for a distribution that marginally passed the χ^2 test , additional evaluation was conducted using graphical comparisons of density-histogram, frequency-comparison, distribution-function-difference, and P-P plots. This revealed important differences in theoretical and actual values, predominantly in the lower ranges (<1,000 units), all indicating poor fit of the theoretical distribution to the data sample.

Since the data did not pass the requirements for goodness-of-fit tests, an empirical distribution was chosen to replicate the demand distribution for Company HDV. Once these demand distributions were specified, construction of the computational models followed based on the structure of the experimental design.

APPENDIX 5B- COMBINED STATISTICAL RESULTS FOR LDV AND HDV

11 SIMULTANEOUS TEST WITH COMBINED DATASET

The next step in the statistical analysis was to repeat the analysis for both classes of demand streams (LDV, HDV) simultaneously using a combined dataset. The test of fixed effects in Table 11.1 demonstrates statistical significance for the *intercept* and *DisruptionDuration*, but the significance for SCRS is a very insignificant 0.832.

Table 11.1 Test of fixed effects - Company LDV and HDV combined statistical results

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	4792	5195.154	.000
SCRS	1	4792	.045	.832
CompanyID	1	4792	5118.490	.000
DisruptionDuration	5	4792	954.721	.000

a. Dependent Variable: Normalized Gross Profit.

The estimate of fixed effects for the combined data set (Table 11.2) for the modular architecture was lower than the integrated SCRS by a normalized coefficient of -0.0879, but this effect is statistically insignificant.

Table 11.2 Company LDV and HDV - Estimates of Fixed Effects

Estimates of Fixed Effects[b]

Parameter	Estimate	Std. Error	df	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	-25.3728	.5877	4792	-43.170	.000	-26.5250	-24.2205
[SCRS= modular]	-.0879	.4155	4792	-.212	.832	-.9026	.7268
[SCRS= integrated]	0[a]	0	.	.	.	.	.
[CompanyID=LDV]	-29.7331	.4155	4792	-71.544	.000	-30.5478	-28.9183
[CompanyID=HDV]	0[a]	0	.	.	.	.	.
[DisruptionDuration=0]	40.2833	.7198	4792	55.962	.000	38.8721	41.6945
[DisruptionDuration=1]	38.4291	.7198	4792	53.386	.000	37.0179	39.8403
[DisruptionDuration=5]	33.0781	.7198	4792	45.953	.000	31.6669	34.4893
[DisruptionDuration=10]	26.4862	.7198	4792	36.795	.000	25.0750	27.8974
[DisruptionDuration=20]	13.5583	.7198	4792	18.836	.000	12.1471	14.9695
[DisruptionDuration=30]	0[a]	0	.	.	.	.	.

a. This parameter is set to zero because it is redundant.

b. Dependent Variable: NormValue.

The combined model fit results (Table 11.3) indicate a poor fit relative to the results by individual demand stream.

Table 11.3 Company LDV and HDV model fit results

Information Criteria[a]

-2 Restricted Log Likelihood	39213.855
Akaike's Information Criterion (AIC)	39217.855
Hurvich and Tsai's Criterion (AICC)	39217.857
Bozdogan's Criterion (CAIC)	39232.804
Schwarz's Bayesian Criterion (BIC)	39230.804

The information criteria are displayed in smaller-is-better forms.

a. Dependent Variable: Normalized Gross Profit.

The model fit, in the smaller-is-better form, is a poor fit that is likely due to considerable differences in covariance structure between results for the two companies. The supply chains that the companies participate in and the underlying demand patterns appear to be quite different, as noted in the body of this Chapter. From these results, the combined results are rejected in favor of the demand stream specific results shown earlier in the Chapter.

APPENDIX 5C – PROPERTIES OF SAFETY STOCK ALGORITHM

12 UNEXPECTED FINDING

An unexpected finding in this study is the hidden properties of the safety stock algorithm employed by HDV. Occasionally negative performance effects were observed on firm financial performance in HDV even during normal supply conditions. This observation was discussed in the body of the Chapter and is further elaborated in this Appendix.

12.1 Transactional policies affect supply chain performance

There is evidence from this study that transactional policies such as calculations for safety stock algorithms can negatively affect SCRS performance even under conditions of normal supply. This was observed in HDV via the deployment of a safety stock algorithm that used the prior 13 weeks of demand as the basis to calculate current safety stock levels. Upon further investigation it was observed that the negative effects of the safety stock algorithm were most noticeable during and just after changes in demand patterns, such as the inflection point where current demand increased or decreased from a prior demand state.

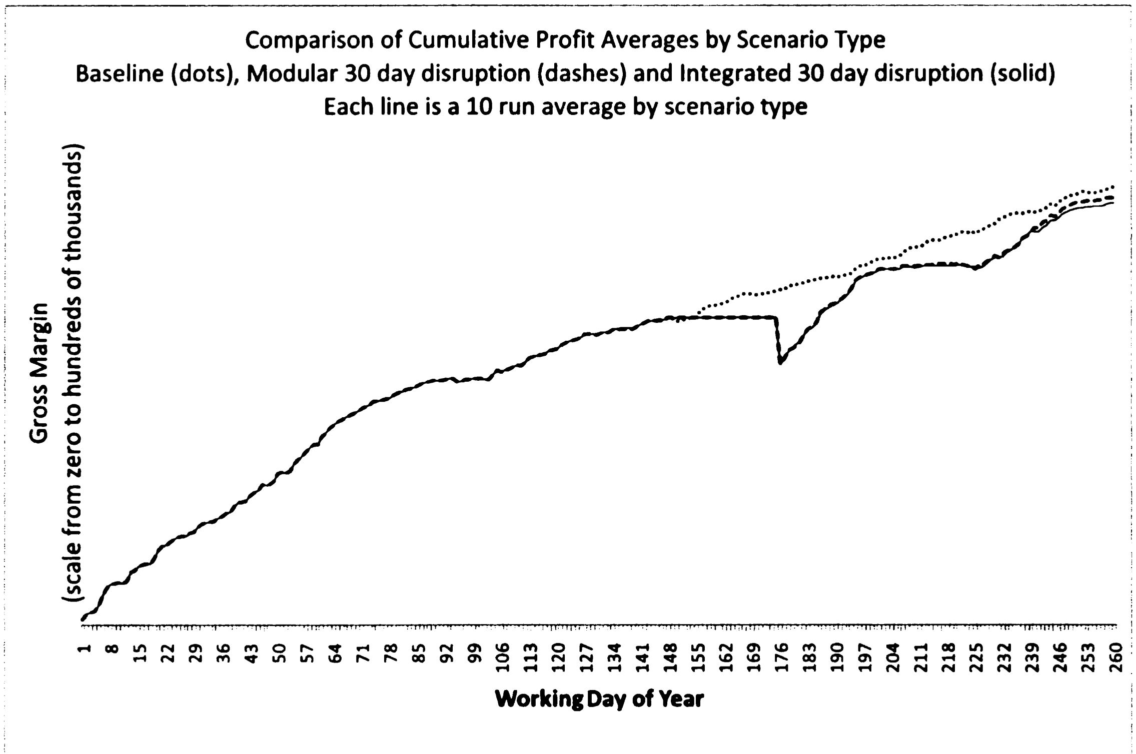
For example, when HDV experienced several weeks of higher than average demand, the safety stock algorithm employed by HDV calculated safety stock requirements using a 13-week average of prior (lower) demand at a time when the recent higher demand was now drawing inventory down, resulting in an amplification effect if inventory consumption analogous to the bullwhip effect. As a result, during these periods occasional and systematic stockouts occurred even when no disruptions were induced.

During the case study interviews and initial development of the computational model, there was recognition by managers in HDV that this occurred in the supply chain but there was no recognition as to the specific cause of these stockouts, given that the mangers expected the 4 weeks of safety stock to be more than adequate. They were unable to adequately explain in many cases why stockouts occurred that resulted in customer penalties even when the firm carried an average of four weeks of safety stock.

12.1.1.1 Discussion of the effect

This phenomenon is exemplified by Figure 12.1, showing cumulative profit averages for HDV. This graph was initially constructed using cumulative profit averages from ten model runs using three scenarios: a) baseline performance without any disruptions (dotted line), b) modular SCRS with a 30 day disruption (dashed line), and c) integrated SCRS with a 30 day disruption (solid line).

Table 12.1 Cumulative profit averages for HDV



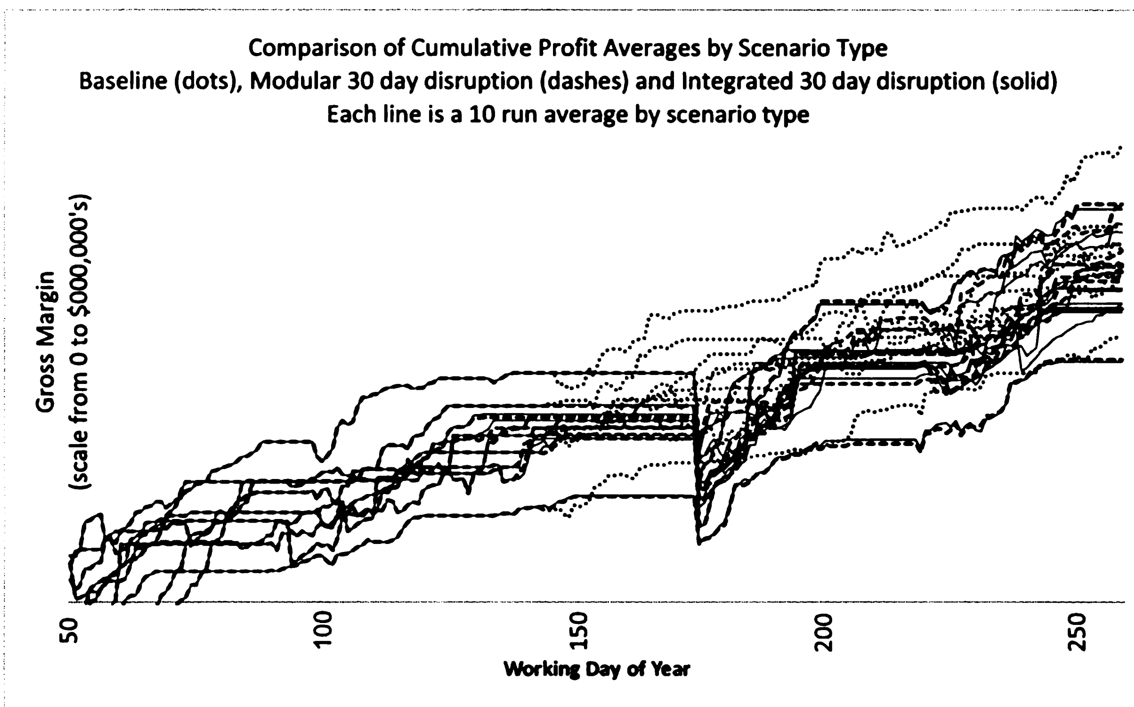
From the graph it can be seen that the initial performance is the same for each of the scenarios until the effects of the tier 1 disruption onset at day 100 produced a delayed impact on the focal firm. This occurs at around day 140, when financial performance is negatively affected due to inventory and pipeline stocks being depleted for HDV (blue/green lines) and customer shortages being incurred. At this point, sales for the product line have halted, resulting in a flat line for profits. Very quickly thereafter, customer penalties are incurred and financial performance degrades, as expected.

What was not expected from the results in Figure 12.1 is that at around day 200 cumulative profit performance from the disruption profiles appears to "recover" toward profit levels for the baseline performance, even though for HDV the sales are considered lost when a disruption occurs. In other words, while the *slope* of subsequent cumulative profits is expected to return to prior levels, the expected result should be a *persistent performance gap* equivalent to the cumulative lost profits between the baseline and disruption scenarios. Since these results are inconsistent with expectations, they were investigated.

At first glance, the baseline performance looks normal and cumulative profits accrue over time as expected, but this aggregate view is deceiving. A description of the underlying phenomenon is discussed next. After considerable review of model code and behavior of the system to eliminate the possibility of program "bugs" as the likely cause, it was recognized that this phenomenon is an unexpected and hidden "feature" of this supply chain configuration.

From this investigation, it was recognized that what is lost during the averaging process (of the 10 model runs in Figure 12.1) is insight into the detailed effects of each run which are masked by the averages constituting the cumulative profit lines in Figure 12.1. By decomposing the averages into individual daily profit performance for each run in Figure 12.2, it is revealed that firm performance after disruptions does not recover to baseline levels, but rather the initial baseline performance occasionally degrades over time (flat lines) due to other factors and lowering the slope of the line. Before discussing the detailed cause of the baseline performance degradation, a brief explanation is provided of how Figure 12.2 was constructed.

Table 12.2 HDV, comparison of detailed model runs by scenario type



In Figure 12.2 the data from Figure 12.1 are disaggregated into individual runs and the focal point of the graph is enlarged to show important details (days 50-260). To construct Figure 12.2, each of the ten model runs for cumulative profit performance for baseline performance is drawn separately in the dotted lines. Using the contrasting scenarios as a comparison example, the ten model runs for the modular SCRS disruption of 30 days were drawn in dashed lines, and the ten models runs for the integrated SCRS disruption of 30 days were drawn in solid lines.

The disruptions were induced at day 100, and HDV holds 20 days of safety stock and typically has 20 days of inventory "on the water" while in transit from the Asian supplier. Thus from day 140 onward the effects of the disruption are observed and continue for the 30 day duration of the disruption scenario – to around day 170.

From this rather "busy" graph, it can be seen that many instances of "flat line" profit performance for individual runs are observed during the non-disruption period (i.e., excluding days around the range 135-170) under each of the scenarios, including the normal-supply baseline performance. As noted previously, these are periods of stockouts due not to disruptions but stockouts due to artifacts of the dynamic safety stock algorithm. Since there are a number of these stockouts in individual baseline runs of both short and longer durations, and since the net effect of these stockouts in the baseline case is larger than the net effect of post-disruption stockouts for the disruption cases, the average slope of the baseline case is lower in the post-disruption period. This change in slope appears related to the mechanics of the replenishment policies and the timing of the disruptions, but this insight needs further research in future studies.

Thus the disruption alone does not account for all of the unusual system behavior, and in the case of the choice of safety stock algorithm by HDV, other negative effects are incurred by the system. These negative effects have eluded recognition by the management team of HDV, but should be of considerable interest to academics and practitioners.

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