

EXPLORING CREW BEHAVIOR DURING UNCERTAIN JOBSITE CONDITIONS

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ABSTRACT

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Construction projects are both time sensitive and dynamic in nature. Unexpected events pose a great threat to construction projects and their successful completion. The traditional method of tackling unknown unknowns in construction is based on a centrally controlling body - often the superintendent of the project. This research explores the nature of these unknown events and the crew behavior under these trying conditions. The study uses literature and an agent based model to achieve these objectives. The study also explores the effect of having autonomous and self-managed crews in making decisions regarding equipment breakdowns on construction sites.

Modeling showed that the decision making by the self-managed team outperformed the team that depended on external agents for making decisions. The delay caused by the same damage was on average 40% lower for the crew making its own decisions compared to the crew that depended on the superintendent. Considering that the model accounted for erroneous decisions made by the crew, the prima facie result shows that allowing crews to be autonomous is an effective strategy on the long run. As a result of the crews solving problems, the superintendent is also expected to have more opportunities to concentrate on improving the coordination and planning of work on site. It is also expected that conditions where crews are given autonomy to make decision will result in a healthier and more satisfying experience for the workers and the organization.

Dedicated to
My Father, Late Mr. Paresh D. Desai
My Mother, Mrs. Chanchal P. Desai and
My Sister, Ms. Anu P. Desai

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GO GREEN!

TABLE OF CONTENTS

LIST OF TABLES	ix
LIST OF FIGURES	x
CHAPTER 1: INTRODUCTION	1
A) Motivation	2
B) Problem Area	3
C) Goals and Objectives	5
D) Research Scope	6
E) Layout of the Thesis	7
CHAPTER 2: LITERATURE REVIEW	9
A) Introduction	10
B) Levels of Uncertainty	14
C) Introduction	18
D) Background on Unexpected Events	19
E) Methods Suggested in Literature to Mitigate Unexpected Events	21
F) Lean Construction	36
H) Autonomy in an Organization	59
I) Significance of the Research	63
J) Agent Based Modeling	64
CHAPTER 3: RESEARCH METHOD	67
A) Introduction	68
B) Model Development	72
C) Initial Model Setup	74
D) Model Execution	75
E) Model Output	76
F) Model Parameters	77
CHAPTER IV: RESULTS	79
A) Introduction	80

B) Research Overview	80
C) Research Goals and Objectives	82
D) Literature Review Results	82
E) Modeling Results	83
F) Research Findings	89
H) Conclusions	92
APPENDIX	95
A) Model Script	96
B) Excel Output from the model	107
C) Raw output from the model	110
REFERENCES	132

LIST OF TABLES

Table 1: The TFV Theory of Production (Lauri Koskela 1992)	39
Table 2: Evolution of models of Project Management (Laufer et al. 1996)	51
Table 3: Output from the AB model developed	107

LIST OF FIGURES

Figure 1: Certainty Matrix (Laufer et al. 1996)	13
Figure 2: Varying Classes of Uncertainty (Hastings and McManus 2004)	17
Figure 3: The spectrum of dynamism and unknowns (Collyer and Warren 2007)	25
Figure 4: Control Methods (Collyer and Warren, 2007).....	27
Figure 5: The three pillars to successful response to unexpected events (Geraldi et.al. 2009).....	30
Figure 6: John Boyd's OODA Loop.....	35
Figure 7: Lean Project delivery System (Ballard 200).....	41
Figure 8: The Last Planner® System (Ballard 2000).....	45
Figure 9: Crew Delay VS Superintendent Delay (For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.).....	84
Figure 10: The increase in knowledge of the crew	86
Figure 11: Superintendent (Damage VS Delay)	87
Figure 12: Construction crew taking decisions (Delay VS Damage)	88

CHAPTER 1: INTRODUCTION

A) Motivation

Construction Operations are both dynamic and time sensitive in nature (Abdelhamid et. al, 2009). The dynamic nature and the interactive complexity make construction projects susceptible to unexpected events. The unexpected events are often the source of project delays and budget overruns. In many cases these unexpected events are unavoidable and the construction crew has to be responsive in reacting to these situations. In a construction setting, change is seen more as a rule than as an exception (Kim and Paulson 2003). These changes can occur due to changes in design, supply chain issues, site conditions or unexpected operation delays (Sawhney and Walsh 2003). Even though the construction projects are governed by a master plan devised generally at the start of a project, the onsite activities show more of an emergent behavior.

The unexpected situations are also bound to arise because of the tight coupling of activities on the project master schedule. A small deviation from this master schedule can throw the project off its path and create cost and schedule impacts. In construction, it does not take much for deviations to occur given that activities are most often not conducted in a controlled environment. In fact, the production phases of construction are highly susceptible to external agents of variation such as the weather, the supply chain and lastly the economic environment. Thus it is not a question of if but rather when these events will take place.

The literature provides modest insights into the construction crew's behavior and decision making under these uncertain situations that we have come to accept as inherent on construction projects. The traditional way of dealing with these unexpected events is based on procedural

techniques such as executing a series of planned tasks to diffuse the situation (Pich et.al 2002). Use of pre-planned contingencies is another method often used to deal with the unexpected events. Most of the procedural methods are a means of reacting to the event and may or may not be successful in diffusing the situation at hand. By the time project managers or superintendents react to the situation, the project may have gone through considerable delays and cost overruns. The delays are compounded because of the ripple effect that results from the linear nature of a construction project.

Using an Agent-based Model (ABM), this research explores the behavior of construction workers under unexpected events. The behavior of construction crews that possess the ability to learn by making decisions (proactive) is contrasted with a construction crew that waits for the superintendent (reactive) to address the situation.

B) Problem Area

The hard bid type procurement in the construction industry has often shown that contractors do not completely understand the scope and/or the environment of the construction project in its entirety before the price is fixed. A short time after taking ownership of the site, contractors realize they knew less than they perceived about the project. Unexpected situations crop up pushing the schedule and the budget beyond its set limits.

Unexpected events, specifically the known unknowns type and not the unknown unknowns one, will cause delays in the project schedule because by definition that not foreseen and, hence, not included in the project plan. These delays have a significant cost attached to them which rise with the increase in delays. Strategies for combating unexpected events are developed in a

number of fields such as the military, IT and economy with noticeable results. The significance of these delays is more prominent in the construction industry as shown by the track record of construction projects being late and over budget frequently. A new strategy for combating known unknowns is needed. We expect the delays due to unexpected situations to decrease as the construction crews take responsibility and make decisions.

The research investigated the literature in the fields of mitigating uncertainties in a project environment. Methods and principles such as Last Planner®, Integrated Project Delivery and Lean Work Structuring show positive impact in combating unexpected situations or minimizing them on construction operations at the project and production strategic planning levels but not at the operational level of the crew. Through synthesis from literature and an agent based model, the effectiveness of a responsive team is measured against the traditional command and control environment. In conclusion, a learning method based on flexibility and responsiveness is propagated for the goal of better mitigation of unexpected events in construction operations. This method is only an early step to developing a strategy towards our goal.

The Florida Department of Transport (FDOT) did a review of 102 construction projects in the state of Florida in the year 1996 (Turcotte 1996). The aim of the review was to investigate cost overruns on the projects and establish accountability for these problems. The FDOT in 1996 maintained 12,000 centerline miles of highway in the state. (Turcotte 1996) Apart from highways, they also maintain airports and rail services in the state. FDOT is thus a construction savvy organization. In the review of the 102 construction projects, projects worth \$302.7 Million, FDOT faced cost overruns of \$28.6 Million or 9.5% of the total project value. The study classified these into avoidable (reasonably foreseen) and unavoidable costs- 5.2% of the

costs were avoidable and the other 4.3% were classified as unavoidable. . Overruns due to planning failures or design changes were deemed avoidable.

The FDOT study provided recommendations to remedy the avoidable costs but the unavoidable cost overruns were not discussed. These latter costs are often neglected in the planning process and there is no defined process to counter them once they do take place even though they could comprise 5% or more of a project's total budget. Kloppenborg and Opfer (2002, p. 21) found that 29 percent of 3,554 project management articles deal with planning, 23 percent with control, in comparison to only 1 percent which consider the implementation and execution phase of the project. This underscored the need to investigate construction crew behavior during onsite disruptions. This research focused on this need and is an attempt to better understand mitigation of unexpected events. It is important that we accept that unknown events will take place and build capability in the organization to tackle them instead of trying to stop them from taking place altogether (Abdelhamid et. al, 2009).

C) Goals and Objectives

The primary goal of this research is to understand crew behavior during onsite disruptions. This was accomplished through an in-depth literature review related to managing unknown events on projects. The research explored the various existing management techniques for unexpected events.

The literature review also compared the various techniques suggested in the literature to manage unknown events. Most suggested techniques were based on the degree of dynamism of the industry. The information technology industry, for example, is a highly dynamic industry in the

sense that the landscape of available techniques to accomplish tasks can change fundamentally during the execution of a project. The construction industry is dynamic because it is subject to constant execution whereas in other industries the tools and techniques that govern the execution are more stable. A higher degree of innovation is often required to implement these tools for effective and efficient execution of the tasks. This innovation often takes place at the site level between the construction crews. Using an agent based model, this research examined this dynamism in the construction industry by exploring construction crew behavior under unexpected circumstances. The model instilled autonomy in the construction crews allowing them to rectify events that come up without warning. The crews took decisions based on the knowledge that they possessed.

The research thus tests the hypothesis that a self-managed autonomous crew will perform better at mitigating unexpected events. This hypothesis is tested using an agent based model.

D) Research Scope

An owner survey conducted by Construction Management Association of America reported that between 40 and 50% of construction projects are behind schedule and/or over budget (CMAA 2006). The FDOT study cited earlier also reported approximately 5% of construction delays come from unavoidable situations. The literature has shown a distinct lack of management principles to manage unknown unknowns in construction, specifically at the crew level. Superintendents are generally charged with the management of these situations and are often overloaded. These unknown situations when mismanaged can spiral into a crisis and cause a disruption in the project. Using computer simulation, this thesis explored the methods to manage

unknown unknowns and tested a progressive approach by empowering construction workers to take decisions and solve issues.

Unknown unknowns for construction projects are things we cannot begin to predict will happen. These arise *out of the blue i.e.* we know they will happen, but we don't know when they will happen, and where they will take place. Neither do we know the magnitude of the disruption they will cause to the project. In today's world of increasing complexity and fast paced innovation, we need to manage this complexity to take advantage of it.

The scope of this research is to explore the current construction workers' behavior under these complex and uncertain situations and compare it to a scenario where they are empowered to take decisions.

An extensive literature review in relevant topics and an agent based model was conducted for this research. The findings of the thesis are expected to afford a better understanding of how construction workers should tackle these uncertain situations. Through literature and modeling, tools and principles have been extracted and summarized to help manage unknown unknowns in a more effective manner.

E) Layout of the Thesis

The thesis is divided into 5 chapters.

Chapter 1 gives an introduction to the issues faced by the construction industry when managing unexpected events and establishes the need for a study to examine uncertainty given the rapidly

growing and fast changing construction world . The chapter is the motivation to conduct this research.

Chapter 2 presents the literature review that was conducted in relevant areas to this thesis. A study of the current method to manage uncertainty in construction and project management practices is presented. A study into Lean Construction and the tools that can help us tackle uncertainty on construction sites is presented. The chapter helped outline the research methodology.

Chapter 3 presents the research methodology adopted. The research uses literature and an agent based model to study the current and suggested practices to manage uncertainty. The chapter goes on to explain the development of the components of the model and its outputs.

Chapter 4 outlines the hypothesis of the model. An explanation of the variety of uncertainties faced in the field is presented before further specifying the approach.

Chapter 5 presents the findings of the model and its relevance to the construction industry. A conclusion is drawn based on literature and the model outputs . An explanation is presented on how we can better ready ourselves to manage unknown unknowns on construction sites.

CHAPTER 2: LITERATURE REVIEW

A) Introduction

“There are known knowns; there are things we know we know.

We also know there are known unknowns; that is to say we know there are some things we do not know.

But there are also unknown unknowns – the ones we don't know we don't know.”

- Donald Rumsfeld (Former United States Secretary of Defense)

Unknown unknowns are by definition not known. Some are hopeless to even contemplate (Hastings and McManus 2004). However, as the secretary of state put it, we know they are out there, so we need to apply some thought on how to mitigate it.

Craft skills are usually taught by an experienced practitioner through observation, imitation and correction. Once sufficient skills have been attained by the learner, he or she has to continue learning by practice and adapt the skills to suit their respective practice (Wood 2004). The learner for some time may need support in the learning process but is largely left to adapt and innovate. The knowledge to be transferred in this practice is largely tacit. The teacher or facilitator of the learning process has to be comfortable with expressing his knowledge that is largely tacit.

Dealing with unknown unknowns in construction is a lot like craft skills. Each unknown unknown is a new problem and a unique problem. Subscribing to a process based approach to deal with these events is difficult due to the fact that we do not know anything about them. We will be much better prepared to deal with these events if we embrace that they will take place and teach our crews how tackle them.

The foreman and construction crew collectively have a large amount of experience on construction sites and dealing with issues. The centrally controlled environment in traditional construction project organizations does not allow them to put this experience to use. Through learning by doing, the construction foreman has immense tacit knowledge that can be utilized in dealing with the inevitable unknown unknowns we counter on the construction site.

This research does not undermine the need for planning a construction project. The planning stages in construction in fact need to be carried out more thoroughly and processes need to be designed during the early stages of the project. Principles of systematic planning outlined by Laufer et al. (1996) in fact play an important role in minimizing the occurrences of these unexpected events. The planning of construction projects through the design and construction phases bring order to the process.

The construction projects are managed to be as close to the planned sequence as possible and re-planned when they deviate from that sequence. This process of planning and re-planning of work is the base for management of construction projects in the production phases. The management process serves us well in certain situations that are predictable. When faced with the unknown, the sequence invariably fails the team. The centrally controlling entity (superintendent) works to solve the problem to the best of his/her ability and the project is re-planned.

When faced with an unknown unknown, it is necessary to foster an environment where innovation and creativity is encouraged. These issues are unique and it is difficult to create a process to tackle them. Geraldi (2009) notes that we need a certain degree of chaos to foster creativity and innovation. When there is overpowering reliance on order in an organization, it is hard to deal with uncertainty.

Hyundai motor company artificially create crisis in their organization to foster creativity and to keep their team ready for any unforeseen situations (Kim 1998). Literature has shown that good project managers rely on creating an environment where the operation crew manages their work and foster creatively to solve problems. The unexpected situations thus do not have to have negative impacts, they can be utilized to innovate and create added value for the user.

In most cases, construction project organizations are often over reliant on order. As a result, the knowledge and experience of the construction crews is underutilized in situations where creativity is needed on the construction site. Through an approach of having self-managed and autonomous construction crews, the construction project teams will be able to cope with the unknown unknowns in an efficient manner.

In traditional construction, we have always tried to eliminate the uncertainty on projects. We are better equipped to deal with unknown unknown when we embrace the fact that they are inevitable and prepare the project team to deal with these situations. In a tightly coupled system as construction, the effect of uncertainty is amplified. If left unattended, the event can spiral out into a crisis and put the entire project at risk.

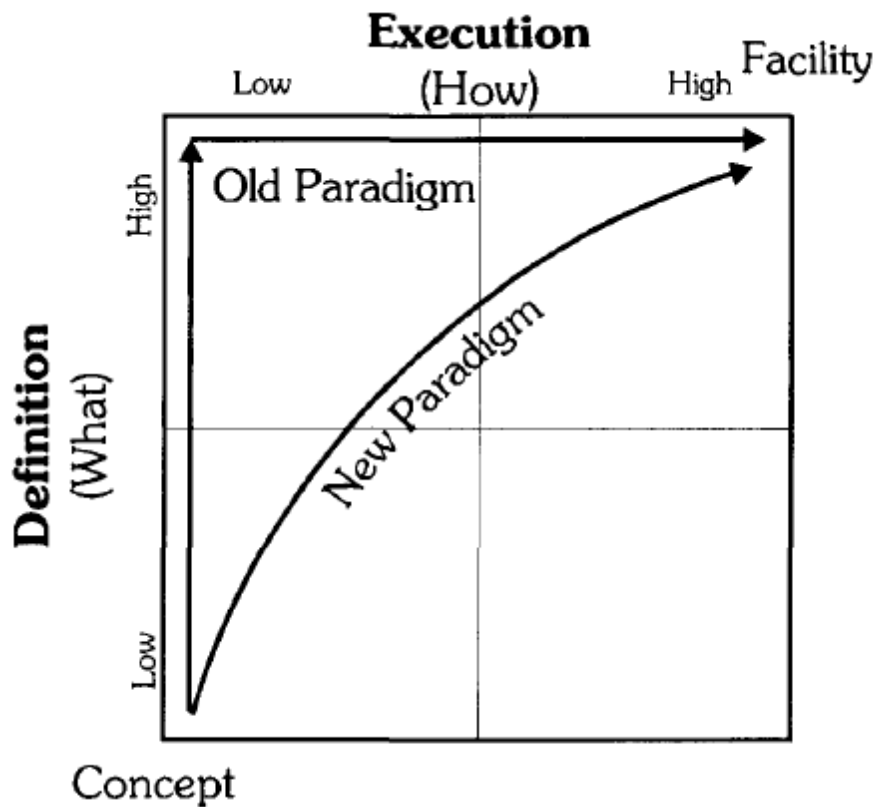


Figure 1: Certainty Matrix (Laufer et al. 1996)

Figure 9 from Laufer et al. (1996) shows us the relationship between the understanding of the project and the stage at which the project is in the execution phase. In the traditional (old) paradigm, when we get to the construction sites, the construction team assumes that they know everything there is to know about the construction project. The project management team has generally built contingencies into the project cost to cover any changes. Often, these contingencies are based on past projects data and the expertise of the planning team.

Starting the project with the assumption that there is nothing uncertain about the project is perhaps the most dangerous approach to managing uncertainty. There is surprise and panic when

things 'go wrong'. The project plans, budgets and schedules are decided in this approach by a project manager and pushed on to the construction team and subcontractors. Very little input is sought from the subcontractors.

In the new paradigm that Laufer et al. (1996) show, the construction team accepts that there is uncertainty about the project when starting the execution phase. This may be uncertainty in terms of the performance of a subcontractor or in fact the weather that year. As the construction team progresses with construction, they identify and resolve these issues thereby reducing the prevailing uncertainty.

These are two very distinct approaches. Literature and the experiences in construction have shown that it is a question of when and not if an unknown unknown will occur. Due to this, the construction team is better equipped to handle the unknown unknown if they accept the existence of the uncertainty. Uncertainty exists on construction projects in various degrees. The following section describes the different levels of uncertainty.

B) Levels of Uncertainty

Hastings and McManus (2004) studied the framework for understanding uncertainties and techniques for mitigating it. They even propose taking advantage of uncertainties when they are presented.

Many varying degrees of uncertainty exist on today's complex projects. There are methods to cope with some classes of uncertainty. For example, uncertainty is often tackled by building up redundancies in the system. The excess resources help to cushion the blow of the uncertain occurrence. The current environment of rapidly changing technologies, threats, needs and budgets has created a need for better understanding of these classes of uncertainty.

The need for designing a robust, flexible and evolutionary systems and designs is foremost in readying the organization to deal with these uncertainties.

McManus and Hastings (2004) note that uncertainties are things that are not known, or known imprecisely. Uncertainties are factual and measurable; things are known or not known or known to a degree.

The authors studied and classified the uncertainties based on the view point of a system architect or designer. Even though they study a system from a system engineering point of view, these classes apply very aptly to uncertainties existing in the construction industry.

Lack of Knowledge:

These comprise of facts that are not known or are only known imprecisely. These facts are needed to complete the design in the intended way. The missing knowledge may need to be collected or simply created based on customer needs and standards. The lack of knowledge will exist in the early development stages of the project. Many of these uncertainties are reduced at appropriate time as the designs progress.

Lack of Definition:

These again are specifics regarding designs that may not be known at the outset of the project. These uncertainties are eliminated as we progress in design and define the scope of the project. Care must be taken not to define too much of a system early in the project. This can lead to over specifying elements of work and/or bad specifications.

Statistically characterized (random) Variables:

These are elements of work that cannot always be known precisely. Specifications are set for these elements by setting standards within which the work is acceptable. The position of a foundation is needed to be within required tolerances. This forms a limit within which the foundation will be laid but the precise position is hard to attain till the work is executed. These uncertainties are harder to handle. The industry is always looking for ways to reduce these variations that act as sources of uncertainty.

Known Unknowns:

These are things that we know are unknown. These are best managed qualitatively. Change orders in construction fall under this category. We know there will be changes, but cannot begin to predict where they will arise from. Contingencies and redundancies are built into the project plan to deal with these unknowns.

Often risk management plans are based on identification of known unknowns and dealing with them ad hoc.

Unknown Unknowns:

These are by definition unknown. We cannot begin to understand where and when they will occur. However, we know they will take place and therefore need to put some thought into how we can best mitigate them when they occur. We build in high safety factors in to the structural designs of bridges. This is done to cover the occurrence of an unknown unknown that can potentially have devastating repercussions on the structure.

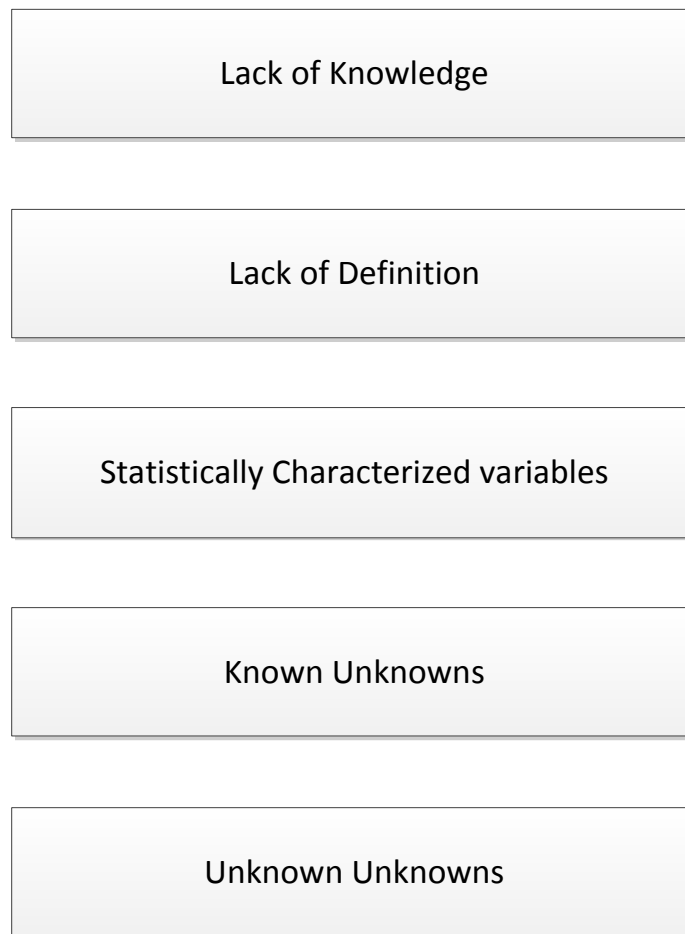


Figure 2: Varying Classes of Uncertainty (Hastings and McManus 2004)

This research aims to explore the strategies to mitigate the unknown unknowns on construction projects. An extensive literature review is conducted to study the existing strategies to mitigate the unknown unknowns in construction and in project management. An agent based model is developed to study the effects of self-managed and autonomous crews on mitigating the occurrence of an unknown unknown event.

The current practices of risk management deal with the known knowns. The base of risk management strategies lies in defining the known knowns and placing them into statistically defined variables. Sometimes design options are assessed in this light (Hastings and McManus 2004).

Hastings and McManus note that a strategy based on building systems that are flexible, evolve and have capability to interpolate are best suited to mitigating unknown unknowns.

C) Introduction

Chapter 1 laid out the motivation, needs and objectives of this research. One of the primary objectives of the research is to study and understand the current management practices to manage uncertainty in projects. An extensive literature review of the relevant topics in the industry was conducted and outlined in this chapter. A study of the prevalent tools and techniques put forward by Lean Construction are studied and presented as a means to manage uncertainty in the project planning and execution phases.

D) Background on Unexpected Events

J. Reid (2000) noted that unexpected events are inevitable due to human involvement. Secondly, unexpected events do not discriminate between the big and the small companies or the specialized and general companies. Each will meet his/her demise at some point.

Projects are inherently uncertain; they are prone to unexpected events, i.e., events that are predicted but are not expected to take place (Geraldi et.al. 2009). Geraldi (2009) uses the example of the Titanic sinking as an example. The ship was considered to be a great engineering success apart from being an extremely successful project. The event of the Titanic hitting an iceberg could well have been predicted but nobody expected it to happen. Similarly, we can predict that a backhoe will breakdown but we don't expect it to happen. This element of surprise can cause considerable delay to the project (as in case with the Titanic) before the issue is resolved.

When the unexpected event of the backhoe breaking down does take place, we have conventional means such as protocols, documents and processes to fall back on. Thus the strategies are based on reacting to the situation. The other approach that is commonly followed as a part of risk management is to try and avoid the unexpected situations all together (Geraldi et.al. 2009). However such an approach can be dangerous as Loosemore (1998) argues that this strategy can create over-reliance on the anticipation of events. The need to be resilient and responsive to these within the organization is ignored causing long reaction times and subsequent delays to follow. Due to the tight coupling of activities on a project and projects in an organization, the unexpected event in the worst case scenario can spiral out into a crisis (Perrows 1999). Hallgren (2007) says that a crisis is anything that affects stability, security and vitality.

Thus in this tightly coupled system, the unexpected event can easily transform into a crisis if mismanaged. The construction sector has the highest rate of business failures among all sectors at 20.3% (Equifax Business Failure Report 2011).

There are numerous events that can disrupt a construction project. Hallgren and Wilson (2007) conducted case studies on construction projects and their deviations from the project plan. The authors concluded that not all events had negative impacts on the project progress. The events that had the luxury of possessing float did not cause much delay to the overall project. The impact only occurred when the deviations are large enough to make non-critical activities critical. They considered the effect of the activities losing their float to be hidden from sight, suggesting a loosely coupled system. The consequence of using a central planning practice and procedures to deal with the unexpected introduces tight coupling in activities. Dealing with these activities from a procedural stand point can often result in a short term solution.

Hwang and Lichtenthal (2000) identified two kinds of crisis in an organization. The first kind is the *abrupt crisis* that can be associated with a particular event that took place and catches the management off guard. The second kind of crisis is labeled a *creeping crisis* that develops and accumulates stressors before eventually erupting. This can be related to construction in that if the unexpected event delays the critical path, it is an abrupt crisis and would have a higher chance of delaying the project. The creeping crisis can be compared to the event that disrupts a non-critical path but can go unnoticed and develop into a full crisis if the situation is not mitigated.

The superintendent on a fairly large construction site is generally the central controlling entity. He/she is responsible for the daily coordination and management of work, make ready planning, preparing weekly work plans, maintain a high percent plan complete and problem resolutions.

There could be as many as twenty different crews working on a construction site at a particular time. This puts pressure on the superintendent during unexpected events due to the use of a central control paradigm. Traditionally, crews will call upon the superintendent to assist them in resolving problems. At the same time, the crew is autonomous and self-managed, i.e., they will also frequently attempt to make a decision to resolve the situation at hand and learn from it. This research explores the behavior of construction crews during unexpected events using Agent Based Modeling.

E) Methods Suggested in Literature to Mitigate Unexpected Events

There is a lot of literature that talks about general project management, risk management in the various industries (Geraldi et. al. 2009). There are few studies conducted to analyze and develop strategies to deal with these unexpected events. Literature in the construction industry provides little insight in how the crew or the organization behaves during these events. The aim of this study is to explore this gap through an agent based model where agents as construction crews are exposed to these uncertain events. The effect of these crews making decisions in contrast with the crews waiting on the superintendent is studied.

Related literature in construction is mainly that dealing with crisis management. Loosemore (1998 a,b) found that important aspects such as mutual trust are missing during unexpected events. Hallgren and Wilson (2008) studied the responses to these events as practiced by an international construction company and had findings to the same effect. Suggestions for a strategy based on sociology and philosophy are made to tackle these unforeseen events. They

treated a project as something people do rather than a structure of activities bound within an organization.

There are various external factors that have bearing on the progress and outcome of a project. These external factors can easily cause a case of an unexpected event. Hallgren and Wilson considered 15 unexpected events faced by an international construction company that dealt mainly with power generation. They handled over 100 projects per year. The company possessed in house design, engineering and legal capabilities. The company maintained a rigorous planning approach. One of the steps in the planning process was to identify and prevent potential risks to the project. During the construction phase, construction related events were recorded in monthly reports. The reports provided some learning for the project team from previous experiences.

Of the fifteen events recorded, 9 arose out of contract disputes, 3 out of miscellaneous causes, 1 each from a guerilla attack, fatality and transport problems. The events were evenly distributed between creeping (8/15) and abrupt (7/15). The company utilized a dual structure to manage projects, i.e., one site team and one corporate team. The line between the responsibilities of the two teams was often fuzzy. Hallgren and Wilson identified responsiveness as one of the most important criterion to prevent an unexpected event from spiraling into a catastrophe. The conclusion drawn from the study, as stated by the authors was: “It was the task and not some structure that kept the team together. Thus, it seems unlikely that a common approach to crisis management is useful. There are situations that need immediate responses from all necessary and available resources”

Pich et. al. 2002 found that there are instructionist, learning and selectionism methods to mitigate complexity and the unknowns in a project. These methods are selected based on the state of the

world or the external aspects that affect a project's progress and outcome. Pich notes "Where levels of risk are considerably low, the project managers often deal with risk simply by including slack or time and cost buffers in the projects." Hence, projects which are well understood and there are few unknowns are well managed by using a procedural approach to unforeseen events. The authors suggest an instructionist or a procedural approach for the projects where the environment is known and well understood. A learning approach is suggested for a project that requires the project team to be flexible and be proactive to the situation at hand. The learning approach is simply put, an extension of the instructionist approach where the team learns from the past and incorporates in the present project to better the response philosophy. Unlike the instructionist approach, the learning approach requires flexibility in terms of its personnel rather than contingencies.

A selectionism approach is suggested for projects that undergo radical changes in its life cycle rendering the previous learning ineffective. The nature of the unknown unknowns is radically different from prior ones and will be different for the next. The project team thus puts forward a reasonable policy and observes the outcome. The authors go on to conclude that given a fairly complex project, the instructionist approach is more likely to fail. Learning and selectionism strategies seem to outperform the instructionist approach to cope with complexity and ambiguity.

Strictly using selectionism is not suitable for all construction projects. Construction projects are well grounded in terms of technology and methods used on construction sites. Selectionism is more suitable for projects where there is a radical change that can occur in those aspects. Learning as a tool can be used as a strategy to combat the unknown events. The agent based

model developed in this research tested the outcome of the learning ability of the construction crew under unforeseen conditions.

Collyer and Warren (2008) mention that a dynamic project in terms of project management is one which is influenced by changes in the environment in which it is conducted. The authors mention that these projects that are conducted in highly uncertain environment are a key unresolved issue in project management. Unknowns are an inherent character of a project. The rate of resolving these unknowns has to be faster than the emergence of the events. This cycle is especially critical in a linear operation such as construction (personal opinion). The authors go on to present the following methods to tackle these projects and the uncertainty inherent in them:

1. Environment Manipulation
2. Planning approaches for dynamic environments
3. Scope control for dynamic environments
4. Controlled experimentation
5. Lifecycle strategies
6. Management controls
7. Culture and communications for dynamic environments
8. Categorization
9. Leadership style

Most of the mentioned measures are aimed at and extremely useful in minimizing the occurrences of these unknown events. However, it is well accepted that in spite of the most stringent measures, the dynamism and the complexity of the projects are bound to cause events

that are hard to foresee. Moreover, no two projects are alike. This holds true in construction where no two buildings are alike and will have the same purpose.

In complex projects, the managers may lack the experience required to establish accurate controls (Collyer and Warren 2008). The establishment of strict controls may offend workers and cause low morale and stifle creativity in the organization. Collyer and Warren also note that burdening the workers with heavy processes and no incentives will discourage adaption to the ever changing environment.

Figure 1 shows how the unknowns increase on a dynamic project as compared to operational work. The dynamism in these projects is best tackled by giving the workers autonomy of action rather than restricting them with procedures.

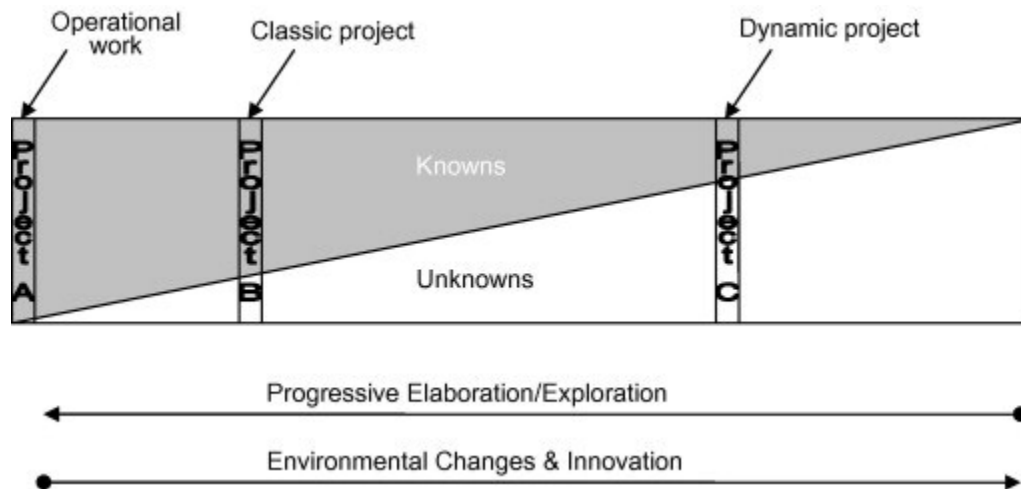


Figure 3: The spectrum of dynamism and unknowns (Collyer and Warren 2007)

Snell (1992) describes three types of project management controls; behavior, output and input. In project management, a process or a plan is developed to carry out the tasks. The key is to adhere to this process and any deviations from the same are monitored. This works well only if the project and the processes are well understood and a stable process can be created (Collyer and Warren 2008). In dynamic environments, strict behavior control measures can stifle creativity; offend workers thereby creating low morale. A central controlling body, the manager, can setup control measures that are counterproductive and result in unexpected behavior. Managers often lack experience and knowledge to setup effective controls. If the process is flawed and the employee can see it is flawed, it may be difficult to correct.

Snell (1992) also presents output or outcome control as a viable option for management of complex changing environments. In this approach, clearly defined targets are set to provide direction and discretion to the staff (Snell 1992). Snell advocated this approach for projects or industries where behavior is difficult to define or expensive to monitor. Incentives are setup based on reaching the defined targets.

The danger with output control however is deviations are harder to identify early. The mistake may not be realized till the output is produced and measured.

Snell (1992) also presents an input control method for management of complex and changing environments. This method is helpful in projects or industries where both behavior control and measurement of outputs is difficult. The input in the systems can be controlled in terms of the employees' 'knowledge, skills, abilities, values and motivation.' This is achieved by holding trainings, more involved staff selection and fostering interaction between employees. The method relies on building capability within the team and then giving them freedom to achieve.

The input control method is the most suitable method for tackling unknown events on construction projects. The process for mitigating these events is difficult to define and the outcomes are not measurable. Building capability and then trusting the employees with experience and knowledge to come up with a solution is an effective way to tackle unknown events.

Ouchi (1979) explains that it may be viable to control the behavior of a warehouse picker, it would require a very complex system to describe the behavior of a foreman's job due to the subtlety involved. He says a better approach will be to pick the foreman based on previously demonstrated commitment to the organization's objectives. The same can be applied to project work. A team committed to the project and that has shown ability should be picked. Figure 2 shows the methods suggested by Snell (1992), Ouchi (1979) and Collyer (2007). Ouchi and Collyer (2007) suggest that careful selection of the type of control can mean less control for managers but it is better to optimize than focus on a 'single unrealistic approach.'

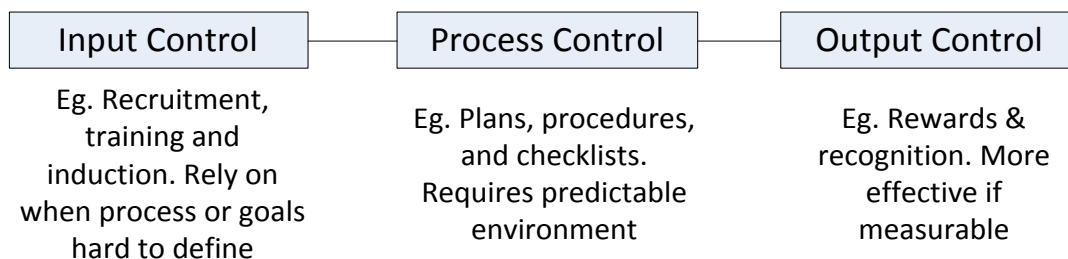


Figure 4: Control Methods (Collyer and Warren, 2007)

In line with Ouchi, Collyer suggests choosing a foreman who is experienced and has previously demonstrated a high level of commitment to the organizations objectives and giving him/her

autonomy of action under those situations. Simons (1995) suggests that innovation should be allowed between pre-defined boundaries. The boundaries can include codes of conduct and safety measures. These are especially helpful in projects with high level of dynamism because they afford flexibility to the team within reasonable boundaries.

Geraldi et al. 2009 studied unexpected events and associated responses in project management to find out what makes a response successful during unexpected events. The authors concluded that the successful responses were mainly based on three important pillars:

1. Responsiveness and functional structure: The authors note that quick and appropriate responses to the unexpected events were a key ingredient in successful responses to these events. The majority of the interviewed project managers mentioned quick decision making and implementation of these decisions to be important to diffuse unforeseen situations. Successful responses depended heavily on empowerment of the workforce rather than micro management and excessive control by the higher levels of management. Lack of autonomy caused slow response times and sometimes the team had to make several responses before the resources were deployed. These severely affected the ability to respond to the unexpected events successfully.

It is also important to note the difference between flexibility and responsiveness in the organization. Flexibility of an organization in this case is its ability to change within its existing pre-defined parameters. Responsiveness on the other hand refers to a team's ability to purposefully and quickly respond to a change or an event in the environment. Agility is also a desirable quality in an organizational makeup. Agility refers to a team's ability to rapidly re-configure its self-according to new parameters (Geraldi et al. 2009).

2. Good interpersonal skills: Respondents in the study conducted by Geraldi et.al. (2009) identified engagement with stakeholders as a key to successful responses to unexpected events. Making sure that all sides involved were committed to enable enough resources to solve the problem. Some participants complained of support system based on top down management system. This sort of management is heavy on reporting on a daily basis. The authors identify that this kind of management method often does not provide timely response to the situation at hand on the contrary it uses up a lot of time and resources that could be instrumental in solving the problem at hand.
3. Competent People: The mutual trust between the workforce and the judgment of the management team emerged as an important aspect contributing to successful responses to unexpected events. Events where people did not panic were better resolved.

Successful Response to Unexpected Events



Figure 5: The three pillars to successful response to unexpected events (Geraldi et.al. 2009)

Figure 5 shows the authors suggested three pillars approach to successful responses to unexpected events.

The authors note that the ideas that emerge and the three pillars that contribute to the successful responses to unexpected events point towards a post bureaucratic form of management system. Post Bureaucratic form of management replaces the centralized, hierarchical form of governance with a flat, de-centralized organization that emphasizes flexibility and responsiveness rather than rule following.

Raelin (2010) investigated whether managerial control has outlived its due course. While this might be true for some industries, the construction industry still has need for managers and facilitators. The study however presents insights into Post Bureaucratic forms of management that are very relevant to managing unexpected events in construction.

Raelin (2010) observes that our traditional and at first thought, rational view of management relies on a degree of predictability of the outcome. This can work well for certain tasks but how can we know whether a lawyer is going to win his/her case or whether a software engineer will produce a better code? The post bureaucratic form of governance has been proposed as a method to increase employee empowerment, autonomy and self-reliance.

There is a call for ‘soft control’ measures or informal control or culture control norms in project management rather than through hard direction (Grey & Garsten, 2001). Raelin writes, management by core cultural values to produce a highly motivated workforce has been a vital tool for corporations. These soft control practices encourage team work, clan control rather than central control and decrease the amount of surveillance required. The reduced workload on the

managers or the superintendent in the case of a construction site will afford him/her to concentrate on activities such as weekly work planning and coordination of work.

William McKnight, chairman of the board of 3M Corporation from 1949 to 1966, is known for his management theories that served as guiding principles at 3M (1948), he once said:

“Mistakes will be made. But if a person is essentially right, the mistakes he or she makes are not as serious in the long run as the mistakes management will make if it undertakes to tell those in *authority* [italics added] exactly how they must do their jobs.”

Geraldi (2009) presented a doctoral thesis aimed at exploring how multi-project companies reconcile order (efficiency, control and clarity) and chaos (creativity, trust, uncertainty, ambiguity). A lack of order in the organization can cause chaos and stifle efficiency of the organization. Whereas, a lack of chaos can stifle the much needed creativity and trust needed to innovate and solve problems.

Geraldi (2009) was employed at a large German construction company as a Research Assistant. Her main goal during this time was to find how the company balanced chaos and order in the organization. Geraldi notes that in order to deal with the heterogeneity, the company need to reconcile order and chaos. More and more companies in search of greater productivity are foregoing the chaos necessary in the organization. Geraldi notes that over 70 percent of project managers complain of bureaucracy of processes (Geraldi 2011). This changes the function of the project managers from managing of risk, process and creativity to managing of papers and forms.

Through this research, Geraldi found empirical data to confirm that organizations have and need both order and chaos within them. The coexistence of order and chaos was at all levels from

project phases to higher levels of the enterprise. She found that companies tend to avoid coexistence of order and chaos. They tilt either more on the order and compensate with low chaos or vice versa. We opine that most construction companies tilt towards order. Most processes are centrally controlled and a lack of chaos is guarded against yet it still exists in an unbounded fashion.

One of the key findings of Geraldi's work was that companies subject to external inflexibilities need to build flexibility within the organization. The organizational flexibility helps absorb the external inflexibilities that can be caused as a result of unexpected events or stakeholder demands.

Geraldi concluded that even though order is deemed as fundamental to success of companies, her findings pointed at excess of order does more harm than excess of chaos.

Abdelhamid et al. (2009) studied the management of unforeseen uncertainties with the help of decision making cycles. The OODA (observe, orient, decide and act) loop of Col. John Boyd was proposed as a suitable decision making cycle for tackling uncertainties. Figure 4 shows the cycles in the OODA loop. The OODA loop is a continuous decision making cycle with four stages: Observe, Orient, Decide and Act.

The observe phase of the OODA loop is when the person takes note of the issue at hand and contrasts it to the surroundings. The orient phase is perhaps the most complex phase in the cycle. The orientation of the observer to the surrounding is based on their perception of the same. A person will see differently based on their culture, education and analytical capability. In other words, although it appears as the second phase in the OODA loop, the orient phase affects the

observe phase and will affect the following decide phase as well. The orientation can trigger further and different observation of the situation. This non-linearity or non-sequential nature of the OODA loop was intentionally designed by Boyd to account for the complexity of the decision making process. The decide phase is when the person takes a decision based on the perceptions and understanding of the environment, and orientation. Based on the decision, the person will act in the last phase of the loop. Again, the OODA loop is not a linear process. There is feedback and feed forward amongst the different loop phases.

The OODA loop places great emphasis on the criticality of rapid decision making. Business strategies based on the OODA loop consider quick decision making as an important method to get ahead of the competition. Conceived for combat situations, the OODA loop has found use in business transactions. The conclusion of the authors is that the OODA loop in conjunction with the Last Planner® System is a viable conceptual framework to tackle unforeseen uncertainties. These are in line with this research in the sense that the OODA loop emphasizes quick decision making with the people involved and subsequently leaning from these decisions to make better decisions in the future.

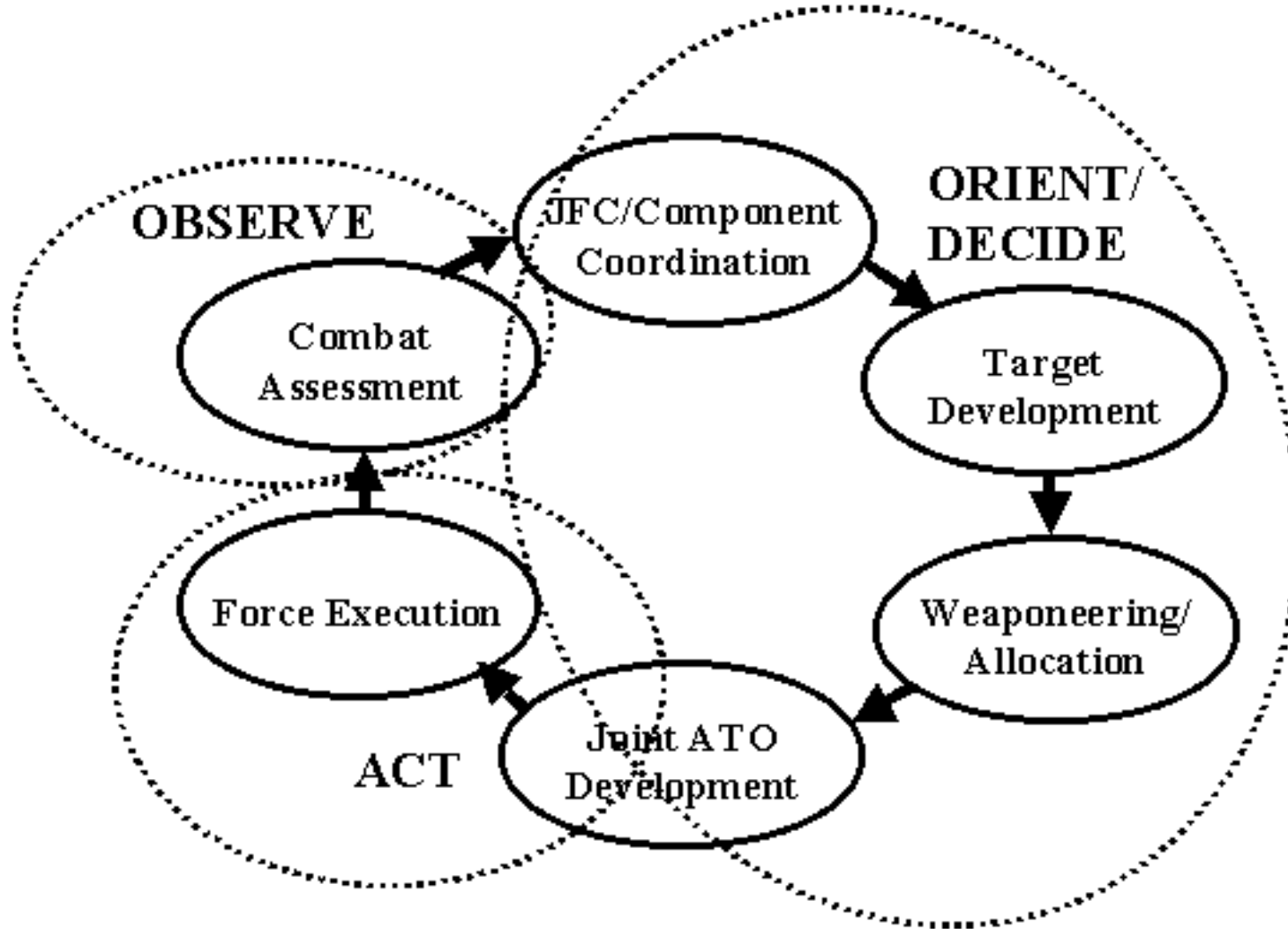


Figure 6: John Boyd's OODA Loop

The aforementioned studies indicate that attempts at theoretical constructs for avoiding and resolving unknown unknowns in project management are worthy endeavors. Insights into the construction industry and the behavior of construction workers under unexpected events remain under-researched. This research proposes to utilize the concepts of learning and the three pillars to explore and understand the behavior of construction crews in uncertain conditions.

The research explores the impact of independent decision making; self-managed teams on the construction site as compared to a conventional team dependent on the superintendent for directives. Of the three pillars, we have to assume that the team has inherent qualities of competent personnel and good interpersonal relationships. The responsiveness and its effects on the project are studied through an agent based model. Learning within the construction crews is a consequence of making decisions in the model. The tradition in the construction industry has been that construction workers are hired from the 'neck down', i.e., there is no value that they add to the job by the knowledge that they possess. This is considered a form of waste per Lean principles. Crews who are on site each day will have vast hands-on knowledge about the work they perform. They play an important role in predicting and mitigating unforeseen situations that arise on the construction site. An involvement on these terms would also result in greater satisfaction for the crew. The feeling that instead of carrying out a set of instructions, the team is there for a larger contribution improves worker satisfaction and productivity (Liker 2003).

F) Lean Construction

A well accepted definition of construction management has been 'the judicious allocation of resources to complete a project at budget, on time and with desired quality.' The theory of construction management has in the past been based on the Transformation view. The traditional

construction practices view construction as a transformation of inputs into outputs (Koskela 1992). The theory of construction management is really a theory of task management. However in a complex production system like construction, we cannot rely on a theory based solely on transformation.

Relying on task management theories in construction management is extremely dangerous because task management assumes certainty in the production system. In a complicated production system such as construction, the idealization error associated to transformation can become large (Koskela 1992). This is reflected in what happens in practice.

The transformation view of production tells us that production is a transformation of inputs to outputs. There are a number of principles that govern the transformation theory of production. For example the principles tell us that the production can be accomplished through decomposing of the total transformation into tasks and executing these tasks. To decrease the cost or the time required to complete the total transformation, we try to minimize the costs or time to execute these tasks.

The flow view of production was first suggested by Gilberths in 1922. The flow view of production formed the basis for what we know today as Lean production and Just-In-Time (JIT) systems. The production system is viewed as a flow of material and information through the system. The flow view of production advocates waste reduction from the flow processes (Koskela 1992). The flow view takes into account principles cycle time, lead time reduction and simplification.

The third view of production is the value generation view. The main aim of the production system is to generate maximum value for the customer. The value generation view of production is refined and used as foundation for quality movement in various industries.

To counter the problems caused by these assumptions, Koskela put forward the Transformation Flow and Value (TFV) view of production in construction. The TFV theory is thus based on task management, flow management and value management. Figure 5 shows a comparison of the three production management theories.

	Transformation view	Flow View	Value Generation View
Conceptualization of Production	As a transformation of inputs into outputs	As a flow of material, composed of transformation, inspection, moving and waiting	As a process where value for the customer is created through fulfillment of his requirements
Main Principle	Getting production realized effectively	Elimination of waste (non-value adding activities)	Elimination of value loss (achieved value in relation to best possible value)
Methods and Practices	Workbreakdown structure, MRP, Organizational responsibility charts	Continuous flow, pull production control, continuous improvement	Methods for requirement capture, Quality function deployment
Practical contribution	Taking care of what has to be done	Taking care of that what is unnecessary is done as little as possible	Taking care of that customer requirements are met in the best possible manner
Suggested name for practical application of the view	Task Management	Flow management	Value Management

Table 1: The TFFV Theory of Production (Lauri Koskela 1992)

Lauri Koskela's TFFV view of construction management has played a major role in forming the basis for what we know today as Lean Construction.

In the term Lean Construction, construction refers to the construction industry rather than the actual activity of construction. Lean Construction is a new paradigm that presents a collaborative model to project management. The project team including the owner, designers, construction manager, and specialty subcontractors form an alliance with the success of the project as an overarching aim.

Lean Construction is a complete delivery system, in the conceptual sense and not the contractual one. Figure 6 illustrates the various phases and tasks that are carried out in the LPDS, which is divided into the phases of Lean Programming, Lean Design, Lean Supply, Lean Assembly and Lean Use. Through these phases, Lean Construction provides fundamental concepts and tools for carrying out construction projects from inception through the design, construction and the use of the structure.

Lean Construction presents various tools to achieve the aims of construction project management. Many of these tools are very relevant to and help to prepare for unknown unknowns on construction sites.

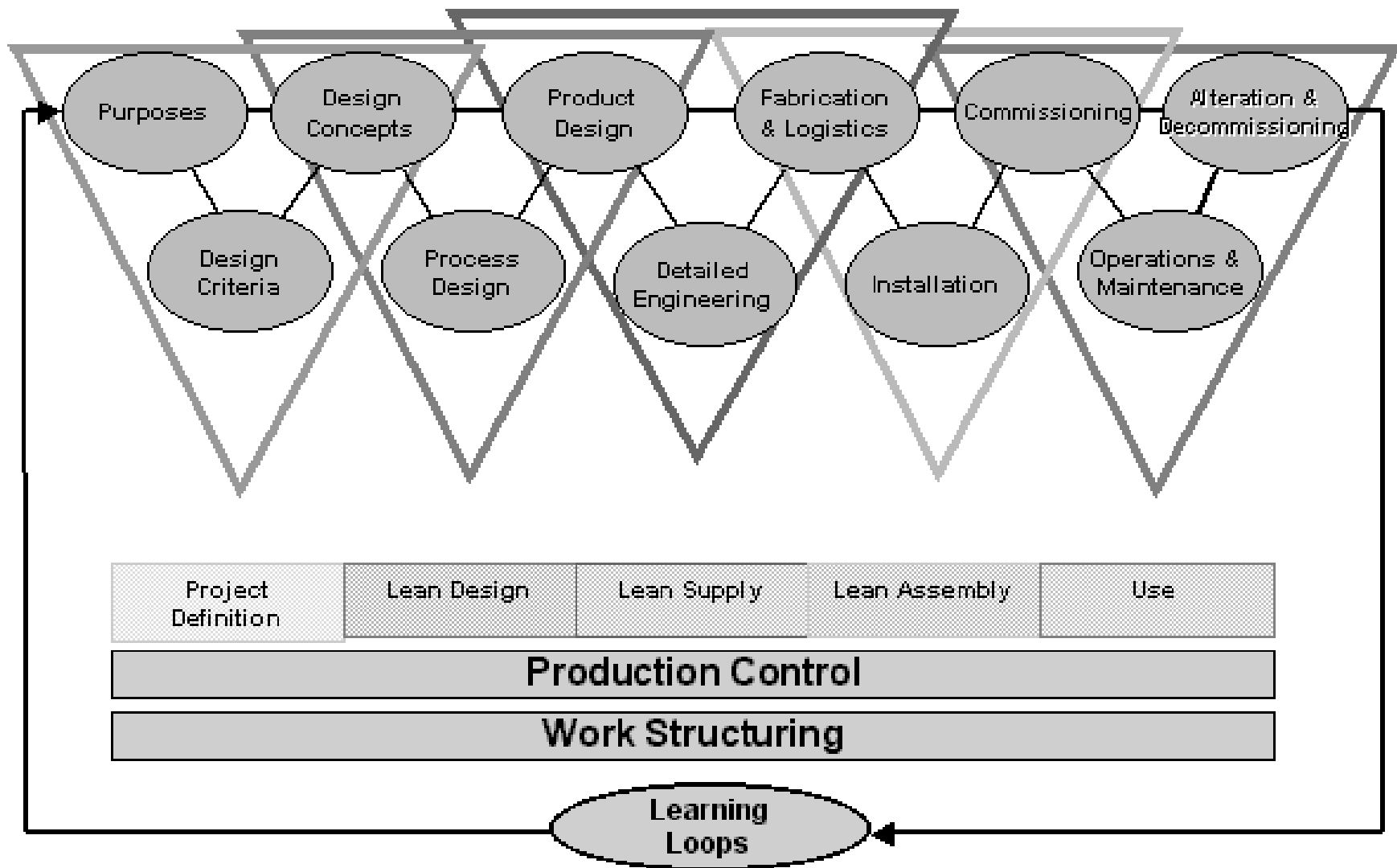


Figure 7: Lean Project delivery System (Ballard 200)

LPDS presents various tools and techniques that help to make the project work more reliably and with minimum of waste. The approach relies on involving the various project partners early in the project and working together to achieve the best possible solutions to the problems. Bringing the project partners together and solving issues results in a more certain and agreeable plan for the project. Some of the tools are discussed further.

G) The Last Planner[®] System (LPS[®])

LPS[®] is a production management module developed by Howell and Ballard (1994). Production Management can be divided into two functions; planning and control.

Planning activities establishes a goal and a desired sequence of activities to achieve this goal. The control activities initiate re-planning of activities once a plan undergoes deviations and the original sequence is not sufficient to reach the goals.

In a dynamic project environment such as construction, the planning activities cannot be outlined with accuracy much before the work is to be performed on a construction site. As a result, the next piece of work to be performed by a design team or a construction crew can hardly be managed by a master schedule developed at the beginning of the project (Ballard 2000). In spite of this reality, construction projects continue to be managed through a detailed CPM (Critical Path Methods) schedule that is developed early on in the project development stage. This usually works against successful production management. Howell and Ballard (1994) found that, on average, only 50% of weekly planned production activities were executed as planned by

construction crews. They attributed this failure to the inability to predict workflow on the construction site.

To solve this prevalent problem in the construction industry, Ballard and Howell (1994) began introducing the Last Planner System. LPS[®]. LPS[®] aims to make the construction operations flow more predictable by utilizing a series of planning events that consider the best available information from the construction site with respect to execution. Constraints preventing execution are pro-actively removed.

The LPS[®] uses a scheduling charrette, a gathering of all project players, with the following outcomes; Master schedule, Phase schedule, MakeReady plan and the Weekly Workplan. The work is planned based on different stages of readiness. Master and Phase schedule arrive at the work that *should* be done. The makeready plan actively takes the work that should be done to work that *can* be done and the weekly work plan is a listing of the the work that *will* be done (work that is committed to by the crews).

Master Schedule: The master schedule is generally a critical path schedule that is based on milestones and may be used to track the overall progress of the project. The schedule is based on owner milestones and is developed early in the project planning process. The schedule in most cases is a part of the contract between the owner and the contractor.

In most delivery methods for construction projects, the contractor is not brought into the design process. This leads to the master schedule being full of guess work rather than intended work plans by the contractors executing the work. The general contractor or construction manager may

not have enough knowledge about the design and the work to be carried out to accurately estimate the time and resources required to execute the project. The same master schedule cannot be used to manage production 6 months into the project. It is hard to gauge uncertainties like the weather half way into the project.

In the LPS®, the master schedule is used as a milestone schedule. The master schedule is further broken down into multiple phases.

Phase Schedule: A detailing of activities to take place between the milestones shown on the master or the milestone schedule. The phase schedule is formed through a process called pull planning rather than pushing dates on to the subcontractors. Phase Schedule (also called pull planning session or pull scheduling session) brings together all trade partners into one room to outline their plan for executing respective scopes of work. The durations, the resources and the pre-requisite work required are derivatives of the pull planning sessions.

In pull planning, the work is pulled from the end of the project to the beginning. The project team collaboratively fixes the activities and timelines for each phase. It is much easier to get buy in from the entire project team because of their involvement in planning the schedule. Once the phase schedule is fixed, the schedule is entered into scheduling software and communicated with the project team.

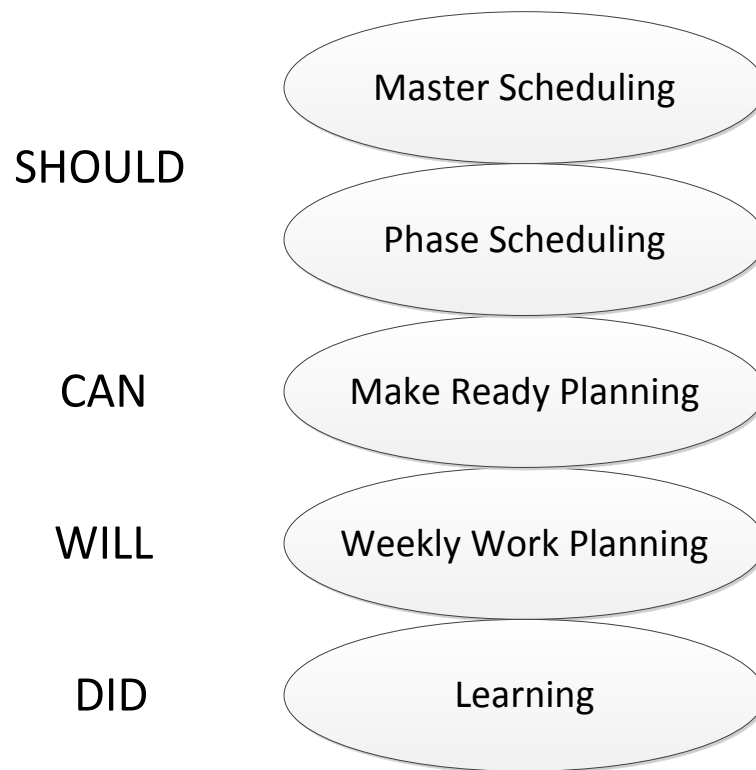


Figure 8: The Last Planner® System (Ballard 2000)

Make Ready Plan (or Look Ahead Plan): The master and phase schedules make up the activities that *should* be performed. The Make Ready plan tells us what we *can* perform at any given stage of the project.

The Make Ready plan or the look ahead plan is where we screen the activities on the phase schedule for constraints that will stop it from being performed on site. The plans are generally carried out using a 6-week window. The activities are screened for three fundamental constraints; directives, pre-requisite work and resources.

Directives: These are information, instructions, product data, quality assurance requirements or testing requirements that might be critical to the start of an activity. Lack

of these directives will result in the activity not starting on time or not being carried out to required quality.

Pre-requisite work: The activities on the phase schedule require pre-requisite work to get started. A steel column cannot be erected until the base plate is installed to requirements. The pre-requisite work has to be of required quality and quantity to avoid rework later in the project.

Resources: The activities on the phase schedule require resources such as material, labor and equipment. It is imperative to ascertain that these resources are available before the activities are put on the Makeready plan.

A lack of any of these will result in the failure to start the activity as planned. If the activity screening results in the conclusion that it is ready to start, the activity is placed on the Makeready plan as an activity that *can* be executed.

Weekly Work Plan (WWP): The Makeready plan is generally conducted on a 6 week look ahead on the project. The Makeready plan is further broken down into tasks that the construction crew can commit to be completed in the upcoming week. The WWP is what the construction crew *will* accomplish within the next week on the construction site. These commitments are made by the last planners on the projects, i.e. the foreman and crews that actually carry out the tasks.

The commitments by each construction crew are logged and tracked during the week. The work is committed to only a week in advance and therefore the judgment of the amount of work that *will* be done is more accurate than that on the phase schedule. The weekly work plan is accurate also because that the crew is committing to the work to be done and not a project manager from

the office. The fact that the work is planned and committed to by the last planners and only a week in advance increases the reliability of the commitment.

Percent Plan Complete (PPC): Once each crew commits to complete a number of tasks in the upcoming week, the project team updates the weekly work plan on a daily basis with the actual number of tasks completed. For the tasks to be counted as complete, they must be finished to satisfy all quality requirements.

The percentage of tasks complete at the end of the week against the tasks committed by the crew at the start of the week is the PPC of the week. The PPC is calculated for each crew. PPC is an indicator for the reliability of construction operations on a weekly basis. PPC forms a baseline each week from which the construction crew tries to better its performance.

During tracking of the work done, the project team cites reasons for any tasks that are not completed in the given week. These are often termed as variances due to which the tasks were not completed. An analysis of the reported variances leads to identification of problems on the construction site that the team needs to resolve.

The aim of the exercise is always to get as close to 100% PPC as we can. By removing the variances reported in the field, the team creates a more reliable workflow and better results. As a result, the project will fare better compared to the estimate and schedule.

The PPC is often made public on construction projects. This is an attempt to foster competition between the crews. The subcontractors that are performing below par are easily found out and are under pressure to better their performance so that the entire project is not held back.

As noted earlier, we cannot completely eliminate variations in the project plan. . The LPS[®] is production management tool that is aimed at minimizing variation on the construction site. It does this by combating the sources of variation, mainly those arising from known unknowns. The variations that remain in the system are those arising from unknown unknowns.

In traditional construction, the progress of the project may be updated on a monthly basis. Hence, the identification of any deviations from the planned schedule is at the least a month from the occurrence of the deviation. The measures that are taken to mitigate the deviations are therefore reactive. The source of the deviation itself is harder to identify. It is a greater possibility in this case that the deviation could cause a cascading event and cause delays on the projects.

Work Structuring

Work Structuring in Lean Construction is defined as ‘the development of operations and process design in alignment with the product design, the design of supply chains, the allocation of resources and design for assembly efforts.’ The goal of work structuring is to make workflow more reliable and quick while delivering value to the customer (Ballard 2000).

Work structuring in construction answers the following questions (Ballard 1999):

1. What units of work will be allocated to what workers?
2. How will the work be sequenced?
3. How will the work be released from one sequence of workers to the next?
4. Will consecutive groups of workers execute the work in a continuous manner or will the work be decoupled?
5. Where are the decoupling buffers needed and how should they be sized?
6. When will the units of work be done?

Work Structuring thus is a process that should be re-evaluated during the course of the project (Tsao 2004). Work structuring is by no means a new concept. Construction teams have been *structuring work* for as long as we have been constructing. However, the formal process of work structuring forms an integral part of designing a resilient project. Work structuring can play an important role in combating unforeseen situations as there is attention paid to the design of the operation processes. Situations that can cause an event that affects the project in operations are often unearthed and solutions are found to perform the operation better.

For example, it may be found that due to high ceilings, there is a safety risk in installing electrical conduits on the ceiling. The contractor may point out to the designers that this causes low efficiency, excessive need for equipment use and safety issues. The team may decide to lower the ceilings or design the process to eliminate as many of the issues as they can. As a result, some of the sources that can create an unexpected event are eliminated. The project gains as a whole.

Tsao et al. (2004) note the process of work structuring is fundamentally different from the traditional work breakdown structure in the construction industry. We understand from the TFFV theory presented by Koskela that construction management is not merely a transformation from inputs to outputs. The work breakdown structure used in construction is a process of breaking down the project into tasks. These tasks are assigned costs on estimates and time on the schedule. Work breakdown structures are thus tasks management tools. Through work breakdown structures we cannot understand the complexity caused by the interaction and overlap in processes of construction operations (Tsao et al. 2004). While the design of each separate part may appear to be sensible, the production process as a whole may be far from optimal. The

breakdown structure approach may amplify the errors made upstream in the production process and are only realized later in the downstream processes.

Tsao et al (2004) conclude that the solution is to design the production process in construction in line with, and in a fashion similar to, the product design. This eliminates much rework, unexpected situations and conflicts in design. One of the findings they refer to is that having more detailed designs at proposal stage is not the solution. A higher level of design early by the architect is often a constrictive practice and inhibits innovation and creativity. The solution is to have the contractors come into the design process early and contribute by identifying the issues with executing the design in the field.

Laufer et al. (1996) investigated how managers of capital projects successfully complete their job in today's uncertain and complex construction environment. They noted that the successful management practices they found in their studies deviated greatly from traditional management methods.

To understand the new management philosophies, we have to understand the evolution of management concepts over the years and decades. Laufer et al (1996) notes 4 distinct generations of management principles, each incorporating the traits of the preceding generation (as Figure 8 illustrates).

In the 1960s, the first generation can be traced back to CPM and PERT techniques. These techniques emerged in large defense and space contracts. The construction industry was quick to adapt this approach to project management as a method in its own. Construction as an industry dedicated substantial amount of financial and professional resources to further develop this

technique. This approach concentrates on the coordination of sequential and parallel activities and their control. The technique was very much like flight scheduling problems in major airlines. CPM and PERT proved to be effective tools for managing simple projects with low levels of uncertainty (Laufer et al. 1996). This approach was termed as *scheduling* by Laufer et al. (1996).

Central Concept	Era of Model	Dominant Project Characteristics	Main Thrust	Metaphor	Means
Scheduling (control)	1960s	Simple, Certain	Coordinating	Schedule regional flights in an airline	Information technology, planning specialists
Teamwork (integration)	1970s	Complex, uncertain	Cooperation between participants	Conducting a symphony orchestra	Process facilitation, definition of roles
Reducing uncertainty (Flexibility)	1980s	Complex, uncertain	Making stable decisions	Exploring an unknown country	Search for information, selective redundancy
Simultaneity	1990s	Complex, Uncertain, quick	Orchestrating contending demands	Directing a three-ring circus continuously switching acts based on the crowd's response	Experience responsiveness and adaptability

Table 2: Evolution of models of Project Management (Laufer et al. 1996)

In the 1970s, a *teamwork* approach was adapted for project management. There was a realization of the need for managing complex projects, projects consisting of dissimilar and highly interdependent components requiring many specialty skills. The challenge here was to interlace these components and integrate the work process across the teams. The manager in this case took charge of facilitating the process and defining roles (Laufer et al. 1996)

The two approaches based on scheduling and teamwork fit well into an environment with low uncertainty. It was soon realized that projects rarely have static goals. Ever changing goals, perpetual changes and unexpected events constantly disrupted the project schedules.

In the 1980s, the more resourceful project managers aimed at *reducing uncertainty* on projects. The main test in this technique was to make stable and long standing decisions that are relevant to the project. The managers collected as much information and experience as they could and made educated decisions. Flexibility was introduced by introducing selective buffers to ensure that the project stays in track.

The 1990's brought a need for faster execution of projects (Laufer et al. 1996). The project managers were managing more projects and time to market was the driving force behind most projects. The successful project managers managed tasks by integrating them and keeping them separate at the same time (Laufer et al. 1996). They resorted to a myriad of informal and formal procedures. The goals and methods were decided on simultaneously and interactively rather than separately and sequentially. This is termed as Simultaneity by Laufer et al. (1996).

Today, as the projects get more complex, the managers on projects face issues of large issues and small details. It is easy for managers to get stuck in one domain (Laufer et al. 1996). The more successful project managers swing back and forth in sync with rising and falling need – termed Simultaneous Management. As the projects get more and more complex, there needs to be a different concept to execute project management. Laufer et al. (2009) outline 9 principles to achieve better simultaneous management techniques to tackle the complexity in projects. The authors' nine principles are divided into three groups: Planning, leadership and integration, and systems.

Planning:

1. Systematic and integrative planning:

Laufer et al. argue ‘The need for speed should not be a reason to spare time and effort on early, integrative, and systematic planning.’ Systematic planning is a multi-phase design process. The phases in systematic planning include setting up objectives, deciding on the means and strategies for implementing and determining the resources needed to execute the project. The typical areas dealt with during the planning stage include project definition, budget, schedule, logistics, human resources and procurement of construction. The documents created during the planning exercise guide the project team through execution of the project, authorization activities, communications and control of the project.

Systematic planning is a pillar for successful project management. However, to translate the principles effectively into reality under complex and uncertain conditions, we need to have timely decision making (Laufer et al. 1996).

2. Timely Decision making:

Under conditions of uncertainty, managers often resort to stable decisions; they cannot look for the optimal decision. It is easier for managers to take a complete look at information and inputs in the early planning phases of the project. They can therefore afford to pay much greater attention to quality and completeness in the planning phases. The emphasis here is not only to react to information, it is to proactively decide on matters and identify missing information.

In early stages of planning, the importance of decision making assumes great importance. Successful project managers do not see their role as making the best decision. It is their duty to ensure that the best decision is made (Laufer et al. 1996). Managers should facilitate the decision making process. The early stages of planning are often seen as a production of decisions. It is the project managers duty to ensure the right decisions are made and to the right amount of detail.

3. Isolation and Absorption:

This principle is designed to produce the most robust plan capable of tackling the unexpected situations during the execution phase. This principle however does not deal with missing information or guidelines. The emphasis here is on the multiple interdependent and dissimilar elements of the project.

Laufer et al. (2009) note that under situations with high certainty, high interdependence of processes result in optimal utilization of resources. However, under environments with uncertainty, this is not a good practice. A few uncertain tasks can quickly result in a cascading effect in downstream tasks. Laufer et al. explain it is the same as one bad apple spoiling all the good apples in a basket. The independent and dissimilar tasks therefore need to be decoupled by employing redundant resources.

The probability of having a successful project diminishes by having a large number of uncertain activities. Therefore, it is a good practice to decouple the uncertain activities from the rest by using these redundant resources. This is an effective way to shield the project

from sources of uncertainty. Where there is high uncertainty on projects, the authors suggest using set based concepts i.e. using two parallel alternatives for development.

Leadership and Integration

4. Inward and Outward Leadership:

To have a successful project, the project manager should be brought in early in the design process and should remain a part of the project till the customer takes it over. The project managers have a large influence on the cost, schedule and the operations on the project. The main duty of the project manager however lies in integrating the various project partners. For a construction project, that may be the architect, the owner and the various subcontractors.

Leadership is an important characteristic for the project manager in turbulent times. The project manager thus need to exhibit leadership both within the organization by motivating and aligning the teams work towards the goals of the project. The complexity of the projects today makes them susceptible to influence from outside the project. The project management needs to be a leader in terms of tackling the supply chain for example.

5. Multi-Phase Integration

Multiple phase integration principles consist of important organizational and time related aspects to achieve speed and quality of decisions (Laufer et al. 1996). The construction project goes through various phases with different organizations taking responsibility for each. A typical construction project may comprise of the following phases: feasibility studies, conceptual planning, project definition, engineering design, procurement, construction and commissioning/startup. Traditionally, the first three phases are often more

design and owner oriented while the contractor takes responsibility of the later three. There is a need to bring the leaders of the later phases into the project at the latest by the feasibility studies stage. Similarly, the architects and the designers need to be included in the construction phases downstream.

Using the principles of multiple phase integration has three advantages. Firstly, due to the participation of the downstream members in the upstream discussions, the decisions are made with more experience and in a more educated manner. There are fewer surprises for the contractors downstream as they are involved in the decision making processes upstream. Secondly, the production teams downstream understand better the objectives and the intent of the designers. The construction teams will find it easier to align their efforts better with the efforts of the project. Thirdly, the communication between the upstream and the downstream participants will improve. The collaborative nature of the multi-phase integration produces a transparent, bi-directional and continuous communication process on project (Laufer et al. 1996). As a result, there will be less need for change later in the construction phases and a much better level of decision making productivity.

6. Multi-Disciplinary Teams

Laufer et al. (1996) explain that projects are executed by teams and not by a single project manager. Today's complex construction projects require an inter-disciplinary team to make decisions and execute work. The team is committed to aligning their interests with the interests of the project. The individual on the team should depend on one another on important decisions.

The project team as a whole work to create a sense of belonging on the project and pride in their respective specializations (Laufer et al. 1996). High performance project teams however realize that individual successes are inseparable from team successes.

The multi-disciplinary teams are generally tied together with loose guidelines and room for creativity and innovation. As the project progresses, there is a transition from unknowns to known and from creative discovery to planned activity (Laufer et al. 1996). These multi-disciplinary teams help to tackle the unexpected situations when they occur. The high level of creativity and varied knowledge is an asset to finding innovative solutions.

Systems

7. Intensive Communication:

Intensive communications are perhaps the central factor in making a project successful. This hold true for most projects much more so for today's complex construction projects. Laufer et al. (1996) note that the best remedy to reduce uncertainty in an ambiguous, clouded, changing and volatile world is in fact the creation and flow of information. When a project is undergoing fast developments, the information flow must keep up. There is a significant amount of information that is circulated during the duration of the project. The team is hard pressed for time to receive, scrutinize and impart this information to others.

Laufer et al. compare the information flow on projects to traffic in a metropolitan city. There is a large volume of it, it comes from many places and goes to many different places.

8. Simple Procedures:

Master project managers often resort to the simplest forms of processes. Although complex and indifferent in nature, the processes can be applied to today's construction projects in a similar way. A network of processes is the backbone of project management. Some companies however, have a tendency to use too many processes.

Laufer et al. note that in successful companies, the formal processes are often used as a means for horizontal communications. The processes are much less used for vertical and intra organization control. While designing the processes, it should always be kept as close to the ultimate value to the customer as possible. The processes should therefore be developed with constant input from the field staff. The procedures should show in detail the product to be attained rather than the way to get there. On the 'how' side, it should be much more like a general outline.

The result of this is a simple and flexible process that requires only minimal amounts of paperwork and approvals.

9. Systematic Monitoring

The traditional means of monitoring or 'control' is to make certain that we compel the events to conform to the plan. The project managers in simultaneous management measure the utilization of resources, the achievements of objectives and the validity of the objectives itself.

The principles of simultaneous management present concepts that are instrumental in eliminating the sources of uncertainty in the design phases and mitigating them in the production phase of construction.

H) Autonomy in an Organization

The study of project management literature in the construction industry and other industries to manage unexpected and dynamic events points us to maintaining flexibility and responsiveness of action in the organization. The flexibility can be achieved through autonomy in the organization.

From the studied literature, we have also learned that the unexpected events are best embraced and not avoided as they will inevitably happen. Since we cannot avoid them, we have to prepare the organization and the project teams to tackle them when they occur. In an autonomous and responsive team, these unexpected events often prove to be opportunities for organizational learning. Hyundai, one of the worlds' leading automotive companies creates internal crises in its organization at various levels to foster innovation and organizational learning (Kim 1998).

Polanyi (1966) identifies that there are two distinct dimensions to knowledge in an organization; explicit and tacit. Explicit knowledge is knowledge that can be codified and transmitted in form of texts, specifications and designs. Tacit knowledge on the other hand is embedded deep within human minds. Tacit knowledge is only expressed through action, commitment and involvement in a particular context. Tacit knowledge is only acquired through experience such as observation, action and practice.

Kim (1998) notes that the tacit knowledge in an organization is nothing but the core of its prior knowledge base. The organization may have some explicit knowledge in the form of manuals, instructions and procedures. The explicit knowledge however is useful only when tacit

knowledge enables its members to utilize them. Thus the performance of the organization is often a function of its tacit knowledge embodied within its members.

The transfer of this tacit and explicit knowledge within the organization is instrumental in sustaining learning in the organization (Kim 1998). The transfer of knowledge takes place in the following ways:

Tacit to Tacit (socialization): Tacit knowledge is transferred from an individual to the organization through training and workshops within the organization.

Explicit to Explicit (combination): Explicit knowledge is transferred when an individual takes discrete pieces of explicit information and combines it to form new explicit information.

Tacit to Explicit (externalization): Tacit knowledge is converted to explicit knowledge when an individual identifies the foundations of his/her tacit knowledge.

Explicit to Tacit (Internalization): The transfer from explicit to tacit knowledge takes place when new explicit knowledge is shared throughout the organization and members start using, expanding and reframing the knowledge.

All organizations are learning systems, they learn as they develop and deliver products (Kim 1998). The organizational learning and the intensity required to transfer knowledge depends on factors such as autonomy, flexibility and leadership among others. The autonomy and flexibility in the organization facilitate more efficient sharing of knowledge. More specifically, Kim (1998) notes that autonomy in the organization creates an environment that enables teams to function creatively. The creativity is an important trait to possess for mitigating unexpected situations.

Hallgren and Olsson (2008) conducted a study to find out how unexpected events are managed in practice. The authors resonate that unexpected events will occur on projects and they will inevitably cause delays on projects that substantially increase project costs. The authors note that the deviations on projects are managed by tools and methods that are reactive. These tools and methods do not describe what actually happens when a deviation occurs, i.e., they do not tell us actions, they only tell us what is considered to be the right procedure.

One of the main characteristics of a project is that it is unique (Hallgren and Olson 2008). This trait of the project in itself causes a degree of uncertainty on the project. The projects are planned assuming linear rationality. The work is broken down using a work breakdown structure (WBS) into tasks and assigned costs, time and responsibility. The changes to this project plan are managed by tools such as earned value, information systems, expert judgment, and formal and informal project management. The access to these different tools and techniques creates an illusion of the project being planned and executed in a controlled manner (Hallgren and Olsson 2008).

There will be unexpected events that occur even after the use of tools and methods to control the project. These unexpected situations are problematic and require a lot of effort on behalf of the project manager. A major part of the uncertainty is because of not knowing where the deviation will arise from. These events will occur sooner or later due to the lack of independence between the different components of work (Hallgren and Olsson 2008). The common answer to these unexpected situations has been to add contingencies and redundancies but neither is enough even in an extremely highly controlled environment (Perrow 1999).

Instead of looking at management of unexpected situations by tools and methods, we should look to understand the management of these unexpected situations from an organizing point of view (Hallgren and Olsson 2008). In an organizing point of view, the nonlinear form of the project can be understood. When things start falling apart on a project, the participants act not according to the planned procedure but rather based on improvisational pattern. Moreover, the management of unexpected events has proved to be a trial and error endeavor with some basic structures (Hallgren and Olsson 2008).

Hallgren and Olsson (2008) present a case study of a power plant construction project where they studied the occurrence and management of an unexpected event. They noted that most of the literature on the subject of unexpected events concentrates on what should be done rather than what is done. The literature describes procedures to follow when everything falls into place. Despite the efforts of project teams to eliminate the unexpected events, the events are persistent and they remain very expensive to projects. The study concludes that the project team handled the unexpected event by an informal process. The authors suggest participative observations as an effective way for the team to understand these unexpected situations and learn how to act when they occur.

The author's case study showed that the unexpected event of a piece of equipment not reaching on time did not receive much attention. Thus bringing out the emphasis on what is done rather than drawing up plans for what should be done.

Hallgren and Olsson also identify the occurrences of the unexpected events as an opportunity for learning by reflection. The project teams must hold individual and collective reflection. Through these sessions, the team members' prior knowledge is made explicit through participation

whereby new ideas and knowledge can be created. The knowledge created in the reflection cycles are instrumental in building capability of the project team in mitigating the next unexpected event that occurs.

Engwall and Svensson (2004) suggest forming *cheetah teams* to combat unexpected events. The cheetah teams are ad hoc teams of skilled members that are separate from the team carrying out the work. Cheetah teams are called up to solve unexpected events that threaten holding up the project and causing budget overruns.

Construction is a management intensive industry (Betts and Ofori 1992). A shift from the management intensive nature is key to mitigating unexpected events. It is essential to give the foreman and crew autonomy of action in order to act quickly to mitigate the event from spiraling into a crisis.

I) Significance of the Research

There are numerous principles and theories for dealing with these uncertainty and complexity (Pich et.al. 2002). Perrow (1994) argues that it is not a question of ‘if’ but ‘when’ the unexpected event will occur. Perrow states ‘no matter how hard we try there will be serious accidents because of interactive complexity (which allows the inevitable error to interact in unexpected ways and defeat safety systems) and tight coupling (in which small errors propagate into major ones) of most risky systems.’

Unknown unknowns thus pose a complicated problem in management. We know they will happen but cannot begin to predict where they will come from and when. However, the fact that

we know they will happen and will pose significant threats to the project forces us to study and develop an approach to tackle them.

This research considers contrasting self-managed autonomous methods against the traditional centrally controlled method to explore the behavior of construction crews under unexpected events. The effects on a construction project are the results of an agent based model. A better understanding of the current practices and the autonomous approach can provide insights to strategies to address unexpected events.

The construction industry is time sensitive in nature. Unexpected events can cause considerable delays on construction projects and subsequently cause cost overruns and delays. A better understanding of the behavior of construction workers facing unexpected events is a step in the right direction towards formulating a strategy to help embrace and tackle these situations on construction projects.

J) Agent Based Modeling

Agent Based Modeling (ABM) is considered as a system in which a simulation experiment is created around a set of autonomous agents that interact with each other and the surrounding environment to imitate the real world proceedings (Sanchez and Lucas 2002). ABM is used in various fields of social sciences, ecology, politics, economics, marketing and sales. In each of these fields, the agents are designed such that they sense and respond stochastically to the conditions in the local environment to replicate complex large scale system behavior. Each agent is developed as an individual decision making entity.

Though limited in numbers, ABM simulations have been used in the construction industry to simulate various facets of the construction process. Construction has been widely viewed in history as a centrally controlled process. One plan is created and it is assumed that the construction will be carried out according to the plan and the entities will have little impact on the process (Sawhney and Walsh 2003). Howell (1999) suggested that the dynamics of a construction industry could be better explained through a decentralized and autonomy based concept. At a micro level, the onsite construction activities show more “organic control” rather than central control system (Howell 1999). These behavior types are more easily modeled using ABM. Moreover, a construction project is subject to constant alterations due to changes in design, unexpected delays and interruptions, field conditions, etc.

Sawhney and Walsh (2003) cited that most current approaches to create a safe and congenial work environment on the construction site is focused on past indicators and not enough study of organizational, managerial and human factors have been incorporated. Much of this is due to the lack of availability of adequate modeling techniques and analysis tools. It is extremely difficult to model aspects of trust and support within a construction crew, safety rules and procedures and amount of time available to carry out the work, etc.

Another aspect that makes the construction industry unique is that some of the workers are more risk tolerant than others and readily take risks that others would not. Accidents can occur to both the risk averse and the risk taking workers but in different proportions. The work environment could also become more unsafe due to the actions taken by the workers and their interactions with the environment. These observations cited by Sawhney and Walsh were specific to the safety in construction but also can be applied to other aspects.

ABM simulations have been adapted to reduce the inefficiencies of the construction claim negotiation process, to simulate the processes in production home building, the response of crews to company safety cultures and to simulate dynamic interactions in the supply chain (Palaniappan et. al. 2007) among others. “Agent Based Modeling Simulations is a promising area that has the potential of providing answers to many questions that have remained unanswered in the construction discipline” Sawhney and Walsh (2003). The approach can be effectively used to study the emergent nature of the construction projects and the proactive application of human factors in construction. The complex nature of the construction industry makes ABM simulations a suitable tool for its analysis.

CHAPTER 3: RESEARCH METHOD

A) Introduction

Construction projects by their dynamic nature are susceptible to change and uncertainties. The conclusion from studies and literature is that uncertainties in construction should be embraced and accepted as a challenge rather than artificially ruling them out (Abdelhamid et al. 2009). The construction teams would improve their workflow reliability through meaningful discussions innovations. The probability of the occurrence of these uncertainties is low and is generally managed by a project contingency incorporated in the budget.

This research aims at unknown events not covered by this project contingency budget. Known unknowns in construction can be represented by owner scope changes, change orders, etc. We know that these exist and that they are bound to occur. Planning for these is often done through the introduction of time and cost buffers in the estimates. Unknown unknowns however cannot be anticipated and can be of varying nature.

The traditional planning and procedural methods to tackle these issues are often found wanting. The site superintendent is often put under enormous pressures when these events transpire. Hallgren and Wilson studied unknown unknowns for a construction company. Out of the fifteen events documented, eight events occurred abruptly and seven were of the creeping nature. Nine events arose out of contract disputes, one each out of fatality, guerilla attack and transport issues. The remaining three were identified as miscellaneous causes. This research will explore the behavior of construction workers and compares the performance of self-managed autonomous crew to a centrally controlled crew. As mentioned in literature, the dynamic nature of the

construction project should point to a learning strategy in contrast to a rule based hierarchy for better performance in managing uncertainty.

Under the traditional system, when an unforeseen situation arises (let us take the example of a scaffold breaking down for the purpose of illustration) the crew would stop work and wait for further directives. The superintendent/foreman is the central controlling entity. She/he is generally called upon to find a solution to the problem at hand. She/he might take a decision based on the perceived damage that he/she interprets. This diverts the superintendent from his primary objective on site that is looking over the make ready plans and coordinating work. The delay caused on the construction site due to this stoppage in work can cause a ripple effect throughout the project if it is at a critical stage.

This research proposes a decision making model where the last planners (the foreman) who perform the work take a decision based on their knowledge and foresight.

By giving the last planners the freedom to take decisions, it is possible that the situation which could have been resolved or prevented quickly goes unseen. It is easy for a crew to bypass a situation if they think they do not need to deal with it. The ‘not my job’ thinking is thus avoided on the job. Moreover, an event that is unattended could easily spiral out into a full blown crisis and cause catastrophic effects to the organization. Responsiveness has been identified as one of the three pillars for success in response to unexpected events (Gerali et.al. 2009)

In this research, an environment simulating a construction site setting and agents representing the construction workers on that site will be created. The environment is affected by various uncontrollable constraints like size, location, type of project and weather conditions and also

subject to other internal factors such as trenches, equipment, worker diversity, safety culture, etc. The environment is thus a complex combination of these factors. The agents on the other hand are subject to movements in the environment. The agents move progressively in the environment. The movement represents the completion of work. Thus when the agent starts in the environment, the work done is zero and when it exits, the work is deemed complete. The agents will have properties of age, culture, responsibilities and other personal attributes but more importantly, they will be given the ability to learn from making decisions in case they encounter an unforeseen event. The agents in the system will interact with each other and the environment and learn from each other through these interactions. Various decision making cycles can be tried out using this methodology. Decision cycles such as the OODA loop and PDCA are suggested in literature to encounter these events (Abdelhamid et.al. 2009). The crews can be trained in these decision making cycles to raise their respective individual competencies.

Geraldi 2009 mentions the three pillars for successful responses to unexpected situations. The three pillars are responsiveness and functioning structure at the organizational level, good interpersonal relations at the group level and finally competent people at the individual level. The three pillars are in line with the literature that was studied in this research.

The individual level requirement for competent people has to come from the human resources management. The employees should be hired and trained to execute their jobs more efficiently. Continuing education opportunities to hone their skills can be helpful to improve the individual competency.

The interpersonal relationships are an important part of any organization. Literature about simultaneous management (Laufer et al. 1996) also brings forward the importance of

communication within the organization. The communication assumes an extremely important role in project organizations. These organizations bring together teams skilled at certain tasks and a general contractor who manages these teams. The teams are together for a short time i.e. the duration of the construction project. Managing the communication between these teams therefore is a difficult task and needs skillful construction managers to execute. The superintendent is responsible for these teams and coordinating the work on construction sites. The responsibility for solving unforeseen issues on construction sites falls on the superintendent in traditional construction practices.

At the organizational level, Geraldi et al. mention the need for a responsive and flexible structure. The current organization structures on construction projects do not afford the team this flexibility and responsiveness needed to cope with unexpected situations. The superintendent takes charge of coordination of work and also managing the production activities. The superintendents are often overloaded with work. The management of these unexpected situations take away time from important activities like look ahead planning and weekly work planning. This in turn causes more unexpected events. The superintendent thus is the centrally controlling body on the construction site.

The agent based model compares the centrally controlled construction site with a construction site where there are autonomous and self-managed crews. The self-managed crews perform work and take decisions to mitigate any unforeseen events that may take place on the construction site. The superintendent will thus have more opportunities to manage the communication and coordination of the work on site.

The model utilizes the learning strategies as outlined in Pich et al. (2002). The crew actively makes decisions and this enhances their knowledge of the environment. As a result, they would be better contributors in the next event that transpires. The model also aims to incorporate the three pillars to success in meeting unexpected events as outlined by Geraldi et.al. (2009). The modeling of competent people in the organization and good interpersonal relations are assumed to be inherent. The responsiveness is tested by the model. The aim of including the responsiveness element is incorporated in the construction crews to study the effect of autonomous self-managed teams in tackling unexpected events. Thus the crew is autonomous and operates on a learning strategy to tackle unexpected events.

The interaction and decision making in the crews fosters an environment where the tacit knowledge is transferred within and between construction crews. The cumulative knowledge within a system increases and the crew will be better equipped to face the next unforeseen situation.

B) Model Development

The model is developed to analyze the workers' and the superintendent's behavior under uncertain situations and how they deal with them. The model is developed using python version 2.7. The model has the following agents

1. Construction Site:

The construction site is a two dimensional grid of '0' that represent the construction site. The grid acts as a platform over which all of the active agents iterate. The site changes depending

upon the situation of the other agents in question. When initialized, the site comprises of all '0's and one unknown occurrence randomly generated to represent the unforeseen situation.

2. Construction Crew:

The construction crews are perhaps the most active agents in the model. They iterate over the construction on each progressive step. As they move forward, they represent work performed on the site. The crews have attributes of name, knowledge and size. The name is initialized as '1'. Knowledge possessed by the crew is a value between 0 to 100 that determines the errors that they produce while taking decisions.

The crew proceeds on the construction site in an orderly fashion until they face an unforeseen situation. Each simulation step simulates the base case scenario, in which a traditional approach is retained, i.e., the superintendent is the central controlling entity. The construction crew stops work and call on the superintendent to solve the situation. A counter is started to keep track of the amount of time elapsed before the work can proceed again. Each simulation step also simulates the autonomous decision making crews' response to the event. The crew takes a decision without waiting for the superintendent to intervene. The superintendent is also called however to see if the decision taken based on the crew's knowledge is correct. In the second case, there is no wait time associated with the decision. The delay is caused solely by the amount of damage that has occurred.

3. Superintendent:

The superintendent is initialized as a dormant agent. It is called upon by the crew when they encounter an unforeseen situation. Once called, the superintendent iterates over to the location on

the site where the issue is and takes a decision to solve the problem. The decision taken by the superintendent in all cases is assumed to be the right one, i.e., the superintendent has 100% knowledge. In the case where the crew takes active measures, the crews' decisions are compared to the superintendent's decision to judge whether the crew made the right decision.

The Damage:

The damage is an unforeseen situation that occurs on a random location on the site. Damage has a random attribute between 5 and 100 that tells us the extent of the damage. The higher the number, the greater the damage. The damage is created when the site is initialized. The damage triggers a decision from the construction crew in the model.

Assumptions

1. It is assumed that the construction crews are all using the same equipment and there are equal chances for the equipment to malfunction for each crew
2. The cost of repairing and replacement is not considered in the model with the assumption that in comparison between the two scenarios, the costs cancel out.

The Superintendent's decision is absolutely correct

C) Initial Model Setup

The model uses an environment through which the construction crews (agents) iterate. The default site is a ten by ten grid of the character '0'. The size of the site is customizable. A ten by ten grid however is sufficient to obtain sizeable results and also manageable in terms of computer processing power required. The value '0' denotes a normal work condition in the

environment, i.e., the work proceeds smoothly without any negative impacts. The environment is an abstract representation of a crew's process on a construction project. It represents the procurement, set up, carrying out of the work, and demobilizing of equipment. If we consider a drywall crew, the first 10% of the iterations can be considered procurement and mobilization. The following 80% can represent the installing of drywall in a sequential manner. The remaining 10% can be seen as inspections and demobilizing activities. Most construction activities are linear in nature, i.e., they either progress in a horizontal or a vertical manner.

The agent objects are representations of the construction crew that would iterate over the environment. The name is the character that would be placed in the environment and helps to identify the agent during simulation.

When the program is run, the site is initialized with all values as '0' to denote normal conditions. Once the site is initialized, an unexpected event occurs at a random location with a random magnitude that represents damage. The crew starts moving from the first position on site and progressively forward until it encounters the unexpected event.

D) Model Execution

The agents or the construction crew iterates over the environment or the site as if going through the construction process right from mobilization to demobilization. The values '1' in the environment point out the current location of the agents. In each time step, the agents move to the next location if the next location has a normal working condition or a value of '0'. During the iterations, if the agent hits a cell with value of over '5' which denotes the location of the event,

the method superintendent is called in the base case to take a decision. In the autonomous crew's case, the agent takes a decision on its own based on the knowledge it possesses.

This method decides whether the agent will choose to repair the equipment or completely replace it. The method uses two comparisons for deciding which action to take. A randomly generated damage coefficient is checked to be less than 40. It would be impractical to replace the equipment if the damage was less than 40%. The other comparison is between the agents risk coefficient entered by the user and a randomly generated number. If both the conditions are satisfied, the agent decides to repair the equipment, otherwise the equipment is replaced.

If the repair method is selected based on conditions, the method calculates the number of days the project is likely to be delayed during repair. The method identifies the number of workers in the crew and the damage occurred as the factors to calculate delay. The two values are multiplied and delay is calculated.

The replace method has no factors affecting it since there is no cost considered in this model. The assumption is that it would take 3 days for the equipment to be replaced. Thus, the delay in replacing the equipment is calculated by multiplying the number of construction workers by 3.

The crews would each be delayed and the total delay of the project is calculated and printed.

E) Model Output

The entire process is repeated 100 times. The model exports results to an excel spreadsheet. The outputs are as follows:

1. The current iteration number (tick)
2. The amount of delay caused by the crew taking the decision
3. The amount of delay caused by the superintendent taking the decision
4. The magnitude of damage that occurred
5. Whether the decision taken by the crew was right or wrong
6. The learning in the iteration

The model can be altered to run any number of iterations. Running the model 100 times gives us a sufficient indicator of the results. The results stay consistent over greater amounts of iterations.

F) Model Parameters

The model has the following parameters:

1. The size of the grid

The size of the grid for this model is 10 X 10. This can be changed to test the hypothesis on various sizes of the construction environment. The increase in size causes the delay caused due to disruption to increase proportionately. A sensitivity analysis with the size of the grid found that the results stay consistent.

However, on a very small construction site, the improvement due to decentralization is negligible.

2. The decision parameter

The construction workers take a decision based on the magnitude of the damage. The parameter in this study is kept at forty (40). The parameter controls the criteria for the workers' decision. If

the parameter is kept at 40, the correct decision is to replace the equipment when damage is over 40%.

The parameter can have whole number values between 10 and 100.

3. Error rate of the workers

The error rate effectively controls the starting knowledge of the construction worker. In this model, the error rate at the start is kept at 4. The error rate is a number between 0 and 10. The error rate of 4 means that 4 out of every 10 decisions that the construction crew will take will be wrong. The parameter is dynamic and decreases every time the construction worker takes a wrong decision and 'learns' from it.

4. Learning factor for the workers

The learning factor controls the increase in the knowledge of the worker (or the decrease in the error rate) each time the construction crew takes an incorrect decision. The value can be a number between 0 and 0.99.

Each time the construction worker takes a wrong decision, the learning factor is multiplied by the error rate to decrease the error rate and effectively increase the knowledge of the agents.

CHAPTER IV: RESULTS

A) Introduction

Chapter 5 provides an overview of the research conducted, and the major findings. The relevance of the results to the construction industry is discussed. This chapter also discusses the limitations of the research.

B) Research Overview

This research focused on understanding the crew behavior under uncertain situations. A thorough literature review was conducted in the fields of construction and project management to investigate the current methods suggested to minimize and mitigate uncertainty on a construction site. An exploration into the crew behavior during these uncertain times provided a better understanding of how we can effectively tackle these events in the future.

Chapter 1 presented the need and the significance of the research. Studies have been conducted that have shown that the unexpected events indeed have a large impact on the construction operations. Chapter 1 also outlined the goals and the objectives of the research.

Chapter 2 provided a literature review of the current practices in construction and project management to tackle unexpected events. The chapter outlined literature in the fields of management of uncertainty, project management, Lean Construction and Agent based modeling. The literature review in these topics provided the needed background to carry out the research.

Chapter 3 described the research methodology for this research. The chapter explained the relevance of the studied literature in construction management and managing the unexpected in construction. An agent based model was developed to simulate the occurrence of an unexpected event on a construction site. The model helped understand the behavior of the construction worker under uncertain conditions. A parallel scenario was simulated where the construction teams were self-managed and autonomous, in which the construction teams decided to take decisions and rectify the issues they are faced with. As a result, the crews gained in knowledge as they took decisions. Through this agent based model and the literature reviewed, the behavior at the crew level was better understood when faced with an unexpected event. Chapter 4 presented the findings of the research and the relevance of the findings to the construction industry. This chapter will put forward the learning from the model and literature and state its relevance in today's complex construction industry.

C) Research Goals and Objectives

The overall goal of this research was to understand the behavior of construction crews under unexpected events. One of the primary goals of the thesis was also to document the current approaches to unknown unknowns in construction and the strategy to deal with them on the construction site.

To study the current practices dealing with unknown unknowns in construction, a literature review was conducted in the fields of construction management, Lean Construction, managing uncertainty in project management and Agent Based Modeling.

Agent Based Modeling was chosen as the research method to develop a model that allowed investigating the crew behavior on a construction site. Agent based modeling is a versatile tool that has been used in construction to study the safety and performance of supply chain among other things. This modeling approach allowed creating construction crews that interacted and took decisions. As a result of the interaction, there was learning that took place in the crew and they were better equipped to make the next decision.

D) Literature Review Results

The literature review brought forward the fundamental strategies to tackle unexpected situations. Studies propagate planning in greater details, planning of the production process, selecting a capable and responsive team among other measures. In construction, we are often faced with extremely dynamic and uncertain projects. To tackle these uncertainties, we need to embrace the fact that they will happen rather than trying to avoid them altogether.

The literature also showed the need for a responsive, flexible and autonomous production team to handle uncertainty. Geraldi (2009) explains the three pillars of successful response to unknown unknowns. On the construction sites, these pillars translates into providing the last planners with a degree of freedom to innovate and creatively solve problems. The construction crews should also be autonomous and be able to quickly decide and implement actions. At the group level, good communications need to be maintained. At the individual level, we need to develop competencies in the employees. The Human resources department at the companies has to draw guidelines which must be followed when recruiting new employees. Leaders should be developed from within the organizations who lead the team to deal with stressful situations.

These learning points from the literature were applied in the model to test the behavior of construction crews under traditional project organizations. These results were compared to the results of an autonomous and self-managed crew faced with an unexpected event. The results are presented in the next section of this chapter.

E) Modeling Results

The results from the model based on 100 runs were analyzed. The first measure of interest was the amount of delay caused while the crews made the decisions and the corresponding delay when the superintendent took the decision on how to proceed. The equipment damage (the assumed uncertain condition encountered) was constant for both simulated instances where the superintendent takes the decision and where the crews take the decision.

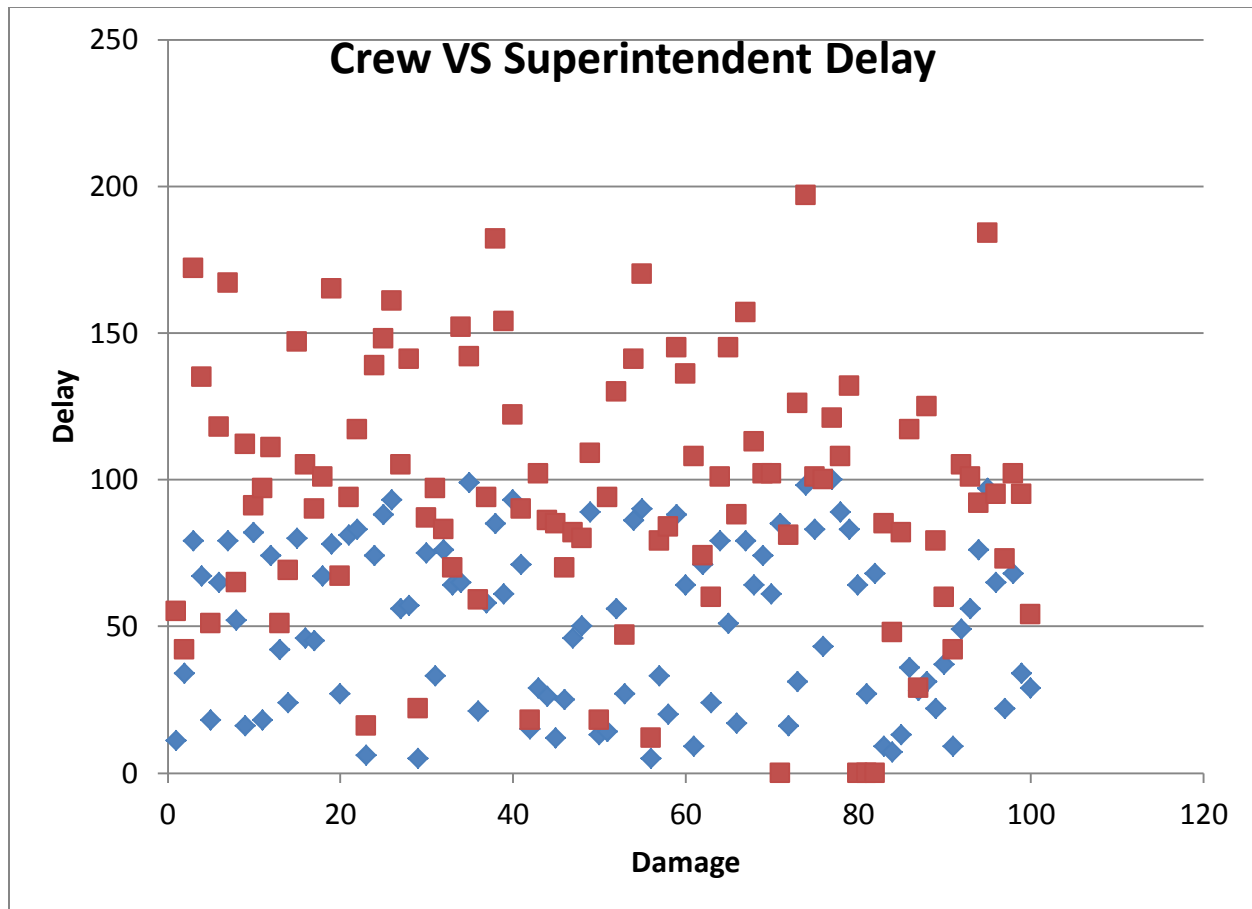


Figure 9: Crew Delay VS Superintendent Delay (For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.)

Figure 11 illustrates how the data compares when the delay caused by the damage is plotted against time. The blue plots represent the delay caused by the crew agent taking the decision and the red plots are the delay caused when the superintendent taking the decision.

The figures indicate that, as modeled in this research, the decision making by the self-managed team outperformed the team that depended on external agents for making decisions. The delay caused by the same damage was on average 40% lower for the crew making its own decisions compared to the crew that depended on the superintendent. Considering that the model

accounted for erroneous decisions, whether made by the superintendent or the crew itself, the prima facie result shows that allowing crews to be autonomous is an effective strategy on the long run.

The model assumed that the crew started off with a knowledge coefficient of seventy (70) on a scale of 1 to 100. Learning took place every time the crew made a decision. The knowledge of the crew increased each time they made decisions. This is based on the observations of Kim (1998). Kim observed that there are two kinds of knowledge in any organization.

The first kind of knowledge is the explicit knowledge possessed by the company -the manuals, training programs, and processes. The more subtle and perhaps more important kind of knowledge with regard to tackling known or unknown unknowns is the tacit knowledge owned by the organization. Tacit knowledge is much less accessible. Tacit knowledge is gained through experience, observation and practice. The construction team in the model learns through these principles. Tacit knowledge in the team increases every time they take a decision and solve a problem.

When a problem is solved incorrectly, the crew gains in knowledge. In the case of making a right decision, the crew gains knowledge only applying the tacit knowledge that they already possess. There is learning in this case among the team members but to a lesser degree. Figure 12 shows the increase in knowledge of the crews as they made decisions throughout the simulations. The reduction in the error rate over time (number of runs) matches real-life behavior, further giving support the model was reasonably realistic.

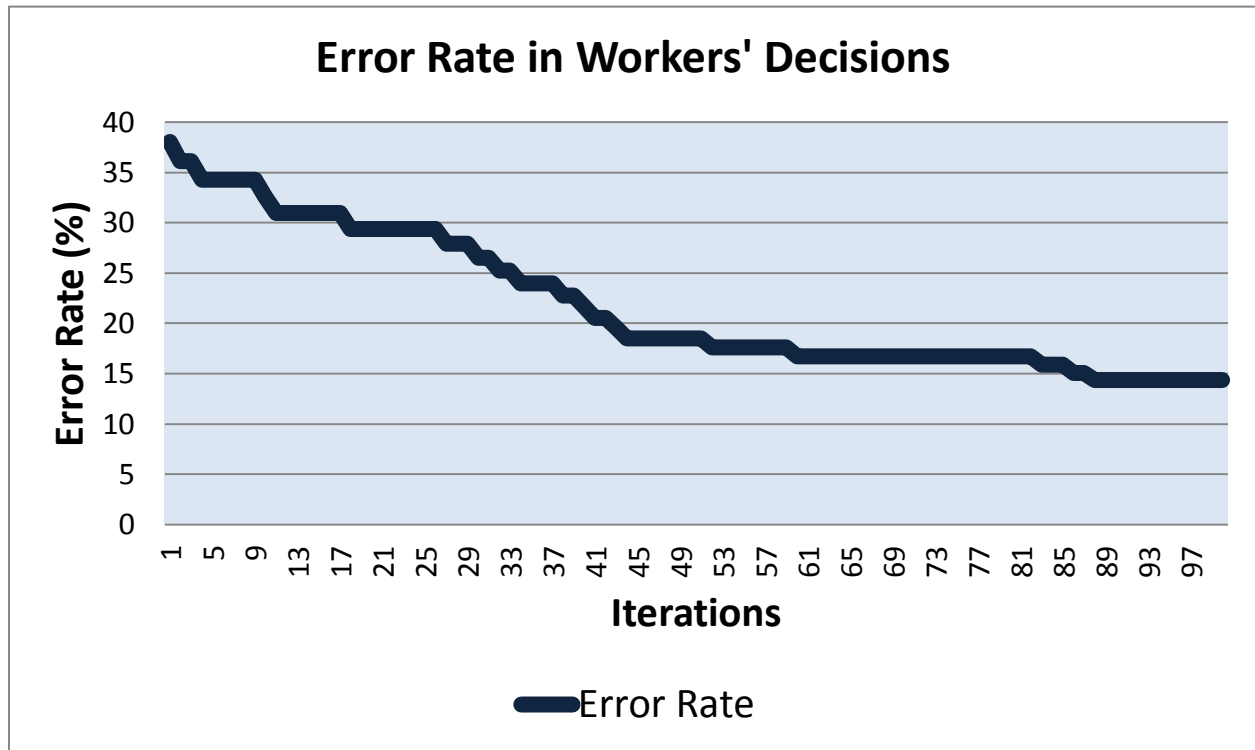


Figure 10: The increase in knowledge of the crew

A number of the lean methods and principles are aimed at reducing variation on the construction site. This helps make the project more predictable and easier to manage. Reducing variation is a fundamental concept in production planning (The Last Planner® System). Figure 13 shows the delay caused against the damage occurred for the superintendent taking the decisions. The data is very varied. For example, for a damage of magnitude 60, the delay caused can be anywhere between the range of 60 and 160 units which is an extremely large variation. The variation is mostly caused due to the location of the unforeseen situation with respect to the location of the superintendent. The superintendent takes time to iterate over to the location of the damage and subsequently solves the problem. This is a representation of reality to some extent where the

superintendent might be busy with other responsibilities. The unforeseen situation thus might not be top priority for the superintendent. The negative by product is also in that the superintendent who should be focusing on coordination of work and planning of work is sidetracked due to these situations arising.

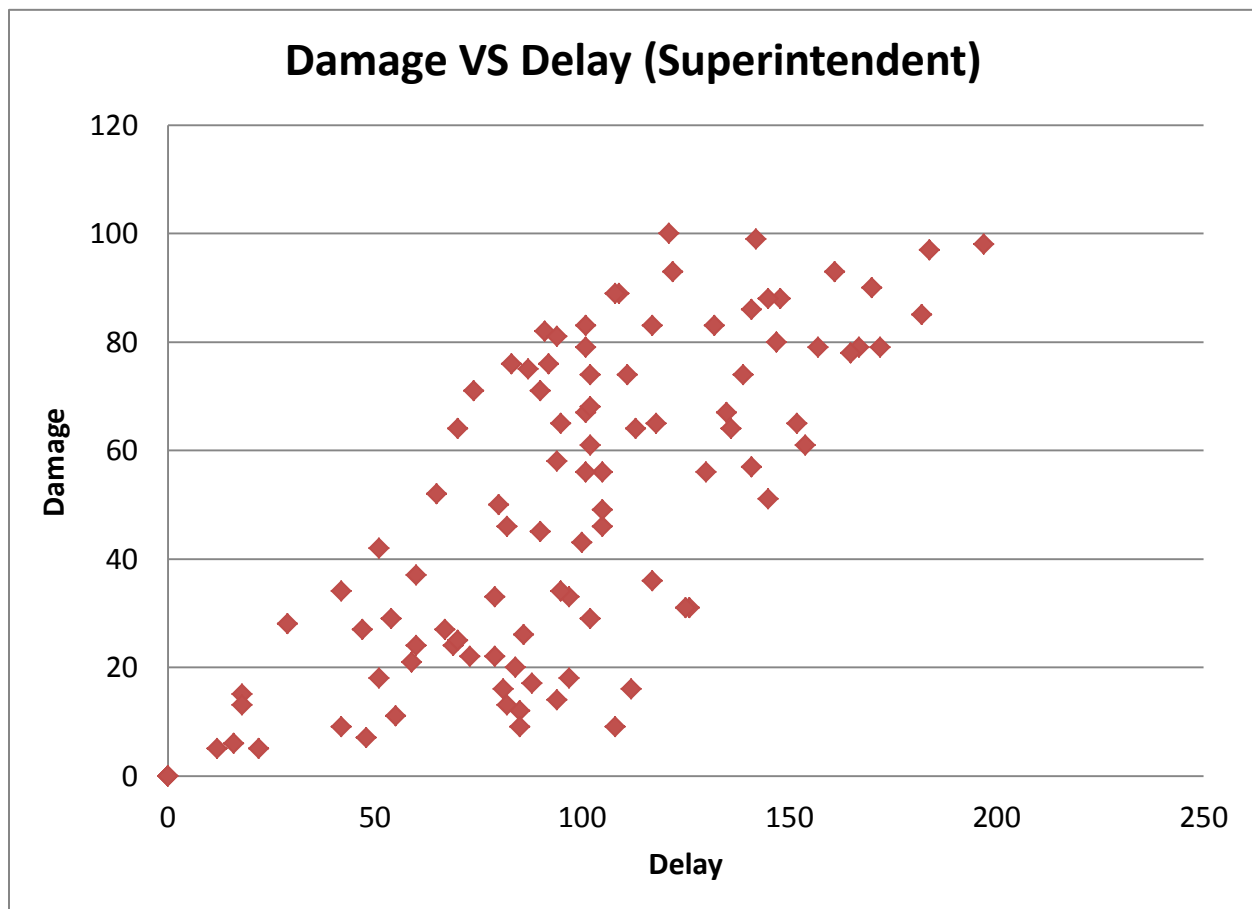


Figure 11: Superintendent (Damage VS Delay)

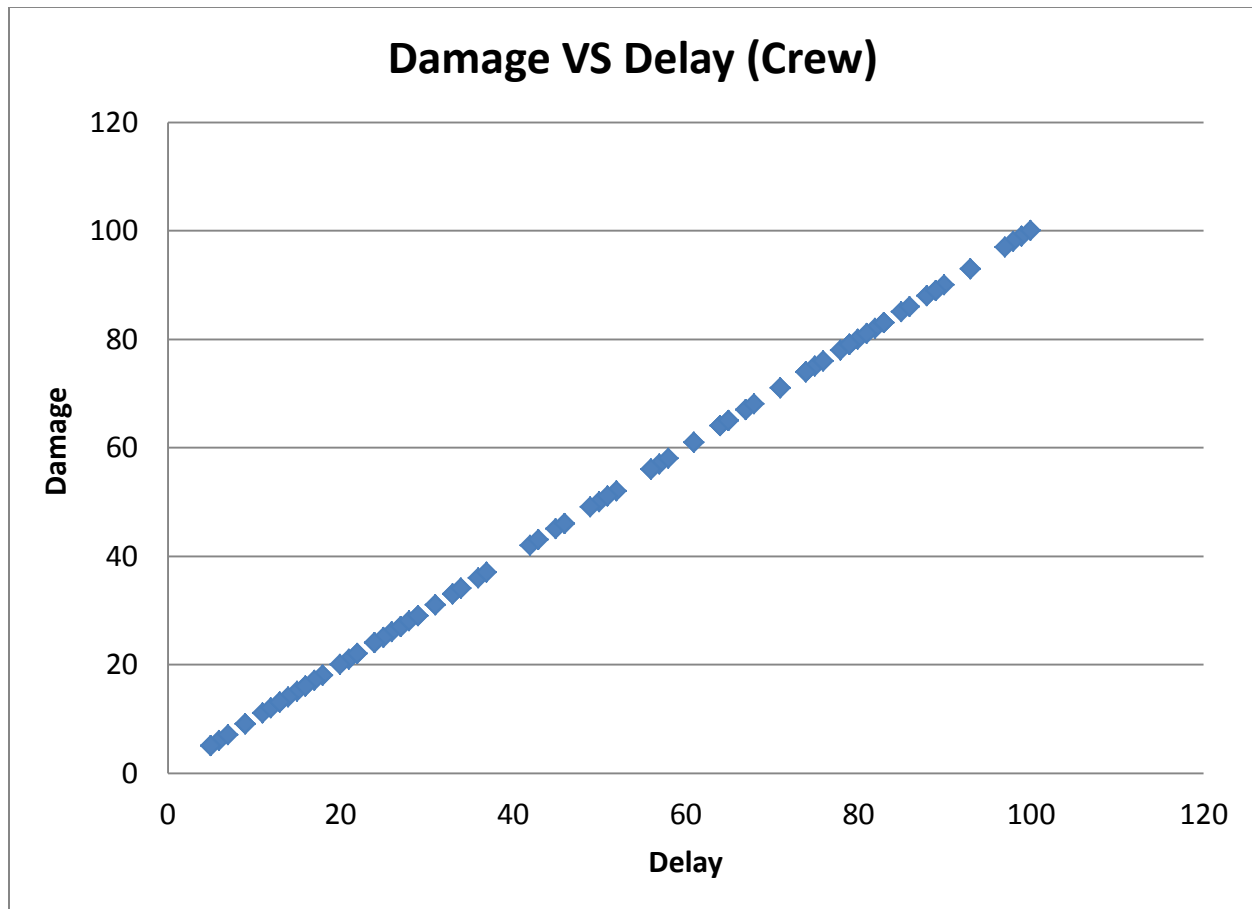


Figure 12: Construction crew taking decisions (Delay VS Damage)

Figure 14 shows the delay generated against damage occurred when the self-managed crew takes a decision. The plot is almost a straight line as derived from the model results. This is because there is no wait time associated with the decision making. The agents encounter the problem and instantaneously take a decision to rectify it. The decision has a possibility of being wrong causing a negative impact. The straight line is a modeling result and will not likely be observed in reality. It is however fair to conclude that the variation in this case is a great deal smaller than in the previous case. When the agent encounters the event, the foreman perceives damage and takes active measure to correct it. The decision adds to the agent's knowledge through learning and he/she is better equipped to tackle the next occurrence.

Thus we observe that based on model results, there is less variation in the decision making process amongst the self-managed crew and there is savings in terms of delay caused due to damage occurring. The error rate that exists is expected to subside dramatically at first as there are wrong decisions made more frequently and a lot of learning occurs. As time passes and more exposure is given to the crew, the knowledge in the agents will build up and error rate will fall.

F) Research Findings

A thorough literature review was conducted to understand the current practices used in handling unexpected events in construction. The findings from the literature review were as follows:

1. The occurrences of unexpected events is inevitable and we must prepare to combat them

The literature review has shown that unexpected events are inevitable due to the increasing complexity on construction projects today and the highly interactive nature of our construction projects. It is thus imperative that we build capabilities in our construction project teams to combat these uncertainties. These unexpected events when mismanaged can lead to far reaching damages to the project plan. The events also have the potential to cascade into a full blown crisis.

2. Lean Construction offers various tools that help to minimize the occurrences and impacts of unexpected events

Lean Construction offers various tools and techniques to ensure that the issues that could arise on construction projects are analyzed and eliminated early in the project. Elimination of these issues will help reduce unexpected events on site. Techniques such the Last Planner® System help improve the communication and organization on construction sites thereby exposing any issues

in real time and can be eliminated before they cause any disruptions. Lean Construction also propagates the use of the workers' knowledge and experience which is in line with what this thesis proposes.

The findings from the literature review were also used in the agent based model developed to test the two cases of interest in this research. Based on the assumptions of the model and after analysis of the model results, we find that:

1. A decentralized system appears to help the project to recover from unknown unknowns more effectively

A decentralized system where the crew and the construction workers are empowered to take decisions and help to mitigate encountered disruptions, as modeled in this research, appears to be an effective method to combat unexpected events. The modeling showed that the unexpected events are found and dealt with earlier in the decentralized system. The shorter time taken, compared to waiting for the superintendent to help, to resolve disruptions had a positive effect on the project completion time. The delay caused by the disruptions was found, in the model, to be approximately 40% lower when the system of decision making was decentralized.

2. A responsible and flexible organization is helpful in recovery from unknown unknowns

The model results indicate that an organization that is responsive in reacting to disruptions was more effective in its mitigation. Prior research in Lean Construction agrees that the flexibility of construction site operations can often be increased by using multi-functional crews that are capable and knowledgeable in various trades. The use of cheetah teams have also been found to be useful in mitigating unexpected events.

3. Superintendent was under much less pressure in a system where the crews were autonomous and self-managed

In the traditional approach modeled in this research, the superintendent was responsible for solving all issues that arose on site. In the decentralized system, every worker and crew was actively working to keep the operations on the construction site on track. It can be logically inferred here that this should reduce the workload on the site superintendent. In turn, this allows spending time on coordination of the construction activities and planning activities that are part of the Last Planner® System.

Again, based on the prima facie results of the agent based model implemented in this research, using a system where workers take responsibilities and decisions to help manage the project appears to utilize workers' knowledge and experience better. This may give the workers a sense of more involvement in the project as well as possibly aligning the crews' interest with that of the project.

G) Research Limitations

The research shows us through the model that disruptions on construction sites can in fact be better managed through maintaining a self-managed and autonomous construction team.

However, the research is subject to the following limitations:

1. Learning in the construction teams is non-linear in nature. The construction workers gain knowledge each time they make a wrong move. The learning in the model is a direct factor of the knowledge gain by the crew, which was assumed to be linear.

2. The research tested the behavior of a single construction crew at a time. The model tested the results for a single superintendent and a single autonomous construction crew. The model may be expanded to examine behavior emergence in case of multiple crews and superintendents.
3. The model does not consider other aspects that affect the crew behavior such as culture, traditions, etc. These are eliminated from the scope of the model to maintain parsimony of results and to analyze the effect of the unit of analysis (the crew making decision versus the superintendent making them).

H) Conclusions

Significant amounts of time and energy on construction projects is spent on managing uncertainty. Due to the tight coupling of activities in construction, the present means of planning and management do not help this cause. Projects are planned in advance using unrealistic schedules that are pushed on to the subcontractors. The Construction Management Association of America conducted an owner survey that notes that according to owners, between 40 – 50 % of construction projects are behind schedule and / or over budget (6th CMAA Owners Survey). This indicates that the current planning and management projects for construction projects is lacking.

A study conducted in Florida notes that 4.8% of the construction cost was overruns due to unavoidable conditions. There is little consideration given to these situations in construction management. Identifying and eliminating them will result in considerably more reliable projects. The burden of solving these issues is often placed on the site superintendent. This study focused on exploring how these events can be addressed.

This thesis advocated a progressive approach where the construction crews are trusted to make decisions and take responsibility for solving these problems as and when they occur. Through an approach of having a responsive and flexible structure, trust in the competencies of the workers and good leaders, we can tackle these situations effectively.

The strategy illustrated here is not to avoid changes and uncertainty but to embrace it and prepare a project team ready to tackle it. Through literature and an agent based model, a strategy of maintaining self-managed, learning and autonomous construction crews is advocated to tackle an unexpected event. The dynamic nature of construction makes it suitable for such measures rather than the traditional rule based strategy.

Empowerment of the workers to make decisions has been successfully used in various industries for quick and accurate executions, typically giving advantage over competitors or an adverse situation. Hyundai Motor Company fabricates crises in the organization as a means to build resilience against these unforeseen events. Through the literature review and the agent based model, we find that uncertainty was better tackled through an approach of autonomy and responsive decision making.

The model used in this research incorporated learning characteristics in the construction crews to analyze how they make decisions and how it affected delays under an unforeseen situation. The results show that when the construction crews make decisions based on their knowledge and within reasonable boundaries, the delay caused can decrease over time and there is more reliability in the process.

As a result of the crews solving problems, the superintendent is also expected to have more opportunities to concentrate on improving the coordination and planning of work on site. In closing, it is expected that conditions where crews are given autonomy to make decision will result in a healthier and more satisfying experience for the workers and the organization.

APPENDIX

A) Model Script

The following script is written in Python Programming Language version 2.6. Python is an open source programming language.

```
##### ANKUR DESAI, MICHIGAN STATE UNIVERSITY ### ###
```

```
##### MS CONSTRUCTION MANAGEMENT #####
```

```
##### MODEL TO EXPLORE CREW BEHAVIOR #####
```

```
##### DEEMBER 9TH 2011 #####
```

```
import numpy,random,copy,time,csv
```

```
totaloutput = []
```

```
tick = 0
```

```
knowledge = 4
```

```
wrongcount = 0
```

```
while tick <100:
```

```
    tick = tick + 1
```

```
    print "#####", tick
```

```
### Setup Construction Site ###
```

```
    size = 10
```

```
row = 10
```

```
end = 0
```

```
site = numpy.zeros ((size,size), int)
```

```
totaldely = 0
```

```
string = []
```

```
Delay = 0
```

```
class agents:
```

```
    def __init__(self, name, k, crew, knowledge):
```

```
        self.name = name
```

```
        self.k = k
```

```
        self.damage = 0
```

```
        self.dec = ""
```

```
        self.know = knowledge
```

```
    def __str__(self):
```

```
        grid = site
```

```
        return grid
```

```

def move_agents (self,agent):

    print agent.name

    tradestring = agent.name


    for i in range(size):

        for j in range(size):

            if site [i,j] == 0:

                site [i,j] = agent.name

            ##                print site, "\n\n\n"

            ##                time.sleep(0.75)

                site[i,j] = 0


            else:


            ##                site[i,j] = agent.name

                agents.met_damage(agent,i,j, site)

                damage = site.max()

                agents.decision (agent, Delay, damage)


def met_damage(agent, row, colum,site):

```

```

site[0,0] = super1.name

print site, "\n\n\n"

site [0,0] = 0

Delay = 0

for i in range(size):

    for j in range(size):

        if site[i,j] < 4:

            site [i,j] = super1.name

##            print site, "\n\n\n"

            ##            time.sleep(0.75)

            site [i,j] = 0

            Delay = Delay +1

##            print Delay

            end = 1

        else:

            ##            agents.decision(Delay, agent, e1)

            damage = site.max()

            agents.superdecision(agent, Delay, damage)

##    def know (agent):

##        knowledge = 4

##        newknowledge = newknowledge*0.9

```

```

##      print 'new knowledge =', knowledge


##      knowledge = agen1.knowledge

def decision(agent, Delay, workerdamage):

    wrongcount = 0

    if workerdamage > 40:

        agentdecision = "Replace"

        if random.randint(0,10)> agen1.know:

            dec = "Right"

        else:

            dec = "Wrong"

            agen1.know = agen1.know*0.95

        print "Construction Worker will REPLACE the damage"

        print "\nThe amount of delay caused is 0 but the decision is:", dec

        print "\nThe cost of the delay is: ", workerdamage

        agen1.damage = workerdamage

        agen1.dec = dec

    else:

```

```

agentdecision = "Repair"

if random.randint(0,10)> agen1.know:

    dec = "Right"

else:

    dec = "Wrong"

    agen1.know = agen1.know*0.95

print "Construction Worker will Repair the damage"

print "\nThe amount of delay already occurred is 0 but the decision is: ", dec

print "\nThe cost of the delay is: ", workerdamage

agen1.damage = workerdamage

agen1.dec = dec

```

```

def superdecision (agent,Delay, damage):

    if damage >50:

        superdecision = "Replace"

        print "The superintendent decided to REPLACE the damage"

        print "\nThe amount of delay already occurred is ", Delay

        print "The cost of the delay is: ", damage+Delay

```

```

    super1.damage = damage+Delay

else:

    superdecision = "Repair"

    print "The Superintendent decided to Repair the damage"

    print "\n The amount of delay already occurred is ", Delay

    print "The cost of the delay is: ", damage+Delay

    super1.damage = damage+Delay


##      while i>row:

##          for j in range(size):

##              if site[i,j] == 0 or site [i,j] == "1":

##                  site[i,j] = super1.name

##                  print site, "\n\n\n"

##                  time.sleep(0.75)

##                  site [i,j] = 0

##      for j in range(column):

##          if site[i,j] == 0 or site[i,j] == "1":

##              site[i,j] = super1.name

##              print site, "\n\n\n"

##              time.sleep(0.75)

```

```

##             site [i,j] = 0

##

def calculatedamage(self):

    pass

class superintendents:

    def __init__(self, name, k):

        self.name = name

        self.k = k

        self.damage = 0

    ##  def move_superintendent(superintendent):###PLACE SUPERINTENDENT AND
MOVE SUPERINTENDENT#####

    ##

    ##

    ##      for i in range(size):

    ##          for j in range(size):

    ##              random_row = random.randint(0,size-1)

    ##              random_colum = random.randint(0,size-1)

```

```

##         site[random_row,random_column] = super1.name

##         print site

##         site[random_row,random_column] = 0


def call_superintendent(row, column, k):

    ##random_row = random.randint(0,size-1)

    ##random_column = random.randint(o,size-1)

    ##site[random_row,random_column] = superintendentstring

    site [0,0] = super1.name

    print site, "\n\n\nSUPERINTENDENT IS NOW MOVING TOWARDS THE
DAMAGE\n\n\n"


    for i in range(size):

        while i<row:

            for j in range(size):

                if site[i,j] == 0 or site[i,j] == "1":

                    site [i,j] = superintendent.name

##                 print site, "\n\n"

                time.sleep(.75)

                site[i,j] = 0

```

```

class unknown_event():

    def __init__(self):

        self.damage = random.randint(5,100)

        print "Damage Magnitude = ", self.damage

        damagerow = random.randint(0,size-1)

        damagecolumn = random.randint(0,size-1)

        site[damagerow, damagecolumn] = self.damage

        print "\n\n\n\n\n\n\n", "DAMAGE HAS BEEN PLACED\n", site, "\n\n\n\n\n\n"

        agents.move_agents(agen1,agen1)

        self.damagerow = damagerow

        self.damagecolumn = damagecolumn


class Results:

    def __init__(self):

        pass

```

```

##### INITIALIZE
#####

agen1 = agents("1", 0.75, 60, knowledge)

super1 = superintendents("2", 1)

e1 = unknown_event()


output = (tick, e1.damage, super1.damage, agen1.damage, agen1.dec, agen1.know)

totaloutput.append(output)

knowledge = agen1.know


##### WRITE RESULTS
#####


w = csv.writer(open('output.csv', 'w'))

w.writerows(totaloutput)

```

B) Excel Output from the model

The model when run, exports the results into a Microsoft Excel worksheet. The table below shows the results for a run of the model for 100 such events. The starting error rate is kept at 40%.

Table 3: Output from the AB model developed

Iteration	Damage	Super's Decision	Workers Decision	Workers Decision	Error Rate	Error Rate %
1	13	65	13	Wrong	3.8	38
2	67	124	67	Wrong	3.61	36.1
3	36	103	36	Right	3.61	36.1
4	22	23	22	Wrong	3.4295	34.295
5	37	62	37	Right	3.4295	34.295
6	97	127	97	Right	3.4295	34.295
7	67	152	67	Right	3.4295	34.295
8	17	26	17	Right	3.4295	34.295
9	68	153	68	Right	3.4295	34.295
10	53	56	53	Wrong	3.258025	32.58025
11	68	121	68	Wrong	3.095124	30.95124
12	70	108	70	Right	3.095124	30.95124
13	26	99	26	Right	3.095124	30.95124
14	76	105	76	Right	3.095124	30.95124
15	97	101	97	Right	3.095124	30.95124
16	22	74	22	Right	3.095124	30.95124
17	47	87	47	Right	3.095124	30.95124
18	71	91	71	Wrong	2.940368	29.40368
19	97	141	97	Right	2.940368	29.40368
20	54	143	54	Right	2.940368	29.40368
21	90	186	90	Right	2.940368	29.40368
22	88	151	88	Right	2.940368	29.40368
23	41	81	41	Right	2.940368	29.40368
24	42	128	42	Right	2.940368	29.40368
25	35	113	35	Right	2.940368	29.40368
26	41	114	41	Right	2.940368	29.40368
27	61	134	61	Wrong	2.793349	27.93349
28	72	144	72	Right	2.793349	27.93349
29	25	72	25	Right	2.793349	27.93349

Table 3 continued

30	95	164	95	Wrong	2.653682	26.53682
31	56	123	56	Right	2.653682	26.53682
32	36	43	36	Wrong	2.520998	25.20998
33	73	117	73	Right	2.520998	25.20998
34	63	153	63	Wrong	2.394948	23.94948
35	51	108	51	Right	2.394948	23.94948
36	74	120	74	Right	2.394948	23.94948
37	10	60	10	Right	2.394948	23.94948
38	70	152	70	Wrong	2.2752	22.752
39	60	95	60	Right	2.2752	22.752
40	5	63	5	Wrong	2.16144	21.6144
41	71	165	71	Wrong	2.053368	20.53368
42	28	90	28	Right	2.053368	20.53368
43	47	114	47	Wrong	1.9507	19.507
44	38	56	38	Wrong	1.853165	18.53165
45	13	99	13	Right	1.853165	18.53165
46	24	65	24	Right	1.853165	18.53165
47	5	59	5	Right	1.853165	18.53165
48	50	114	50	Right	1.853165	18.53165
49	45	100	45	Right	1.853165	18.53165
50	82	122	82	Right	1.853165	18.53165
51	41	62	41	Right	1.853165	18.53165
52	68	77	68	Wrong	1.760507	17.60507
53	94	102	94	Right	1.760507	17.60507
54	33	131	33	Right	1.760507	17.60507
55	9	87	9	Right	1.760507	17.60507
56	10	69	10	Right	1.760507	17.60507
57	86	128	86	Right	1.760507	17.60507
58	97	160	97	Right	1.760507	17.60507
59	76	86	76	Right	1.760507	17.60507
60	13	50	13	Wrong	1.672481	16.72481
61	26	101	26	Right	1.672481	16.72481
62	30	104	30	Right	1.672481	16.72481
63	71	144	71	Right	1.672481	16.72481
64	45	81	45	Right	1.672481	16.72481
65	99	182	99	Right	1.672481	16.72481
66	53	144	53	Right	1.672481	16.72481
67	44	56	44	Right	1.672481	16.72481
68	75	111	75	Right	1.672481	16.72481
69	89	112	89	Right	1.672481	16.72481
70	11	45	11	Right	1.672481	16.72481
71	58	85	58	Right	1.672481	16.72481
72	41	73	41	Right	1.672481	16.72481

Table 3 continued

73	81	158	81	Right	1.672481	16.72481
74	18	57	18	Right	1.672481	16.72481
75	10	14	10	Right	1.672481	16.72481
76	85	121	85	Right	1.672481	16.72481
77	61	84	61	Right	1.672481	16.72481
78	93	139	93	Right	1.672481	16.72481
79	51	90	51	Right	1.672481	16.72481
80	16	110	16	Right	1.672481	16.72481
81	10	63	10	Right	1.672481	16.72481
82	59	94	59	Right	1.672481	16.72481
83	91	145	91	Wrong	1.588857	15.88857
84	19	0	0	Right	1.588857	15.88857
85	47	131	47	Right	1.588857	15.88857
86	97	0	0	Wrong	1.509414	15.09414
87	74	162	74	Right	1.509414	15.09414
88	45	134	45	Wrong	1.433944	14.33944
89	16	67	16	Right	1.433944	14.33944
90	47	71	47	Right	1.433944	14.33944
91	11	62	11	Right	1.433944	14.33944
92	88	183	88	Right	1.433944	14.33944
93	78	144	78	Right	1.433944	14.33944
94	17	48	17	Right	1.433944	14.33944
95	31	124	31	Right	1.433944	14.33944
96	82	102	82	Right	1.433944	14.33944
97	22	26	22	Right	1.433944	14.33944
98	52	149	52	Right	1.433944	14.33944
99	22	77	22	Right	1.433944	14.33944
100	64	132	64	Right	1.433944	14.33944

C) Raw output from the model

The following shows the results from the model running in the Python console. The results show the first 10 iterations of a run of the model.

```
##### 1
```

Damage Magnitude = 9

DAMAGE HAS BEEN PLACED

```
[[0 0 0 0 0 0 0 0 0 0]]
```

```
[0 0 0 0 0 0 0 0 0 0]
```

```
[0 0 0 0 0 0 0 0 0 0]
```

```
[0 0 0 0 0 0 0 0 0 0]
```

```
[0 0 0 0 0 0 0 0 0 0]
```

```
[0 0 0 0 0 0 0 0 0 0]
```

```
[0 0 0 0 0 0 0 0 0 0]
```

```
[0 0 0 0 0 0 0 0 0 0]
```

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 9 0 0 0]]

1

[[2 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 9 0 0 0]]

The Superintendent decided to Repair the damage

The amount of delay already occurred is 96

The cost of the delay is: 105

Construction Worker will Repair the damage

The amount of delay already occurred is 0 but the decision is: Wrong

The cost of the delay is: 9

2

Damage Magnitude = 21

DAMAGE HAS BEEN PLACED

[[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[21 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]]

1

[[2 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[21 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]]

The Superintendent decided to Repair the damage

The amount of delay already occurred is 50

The cost of the delay is: 71

Construction Worker will Repair the damage

The amount of delay already occurred is 0 but the decision is: Right

The cost of the delay is: 21

3

Damage Magnitude = 48

DAMAGE HAS BEEN PLACED

```

[[ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [48 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]]

```

1

```

[[ 2 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [48 0 0 0 0 0 0 0 0 0 0]

```

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]]

The Superintendent decided to Repair the damage

The amount of delay already occurred is 50

The cost of the delay is: 98

Construction Worker will REPLACE the damage

The amount of delay caused is 0 but the decision is: Wrong

The cost of the delay is: 48

4

Damage Magnitude = 87

DAMAGE HAS BEEN PLACED

[[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 87 0 0 0 0 0 0 0 0 0]]

1

[[2 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

```
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 87 0 0 0 0 0 0 0 0]]
```

The superintendent decided to REPLACE the damage

The amount of delay already occurred is 91

The cost of the delay is: 178

Construction Worker will REPLACE the damage

The amount of delay caused is 0 but the decision is: Right

The cost of the delay is: 87

5

Damage Magnitude = 16

DAMAGE HAS BEEN PLACED

[[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 16 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]]

1

[[2 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 16 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]]

The Superintendent decided to Repair the damage

The amount of delay already occurred is 44

The cost of the delay is: 60

Construction Worker will Repair the damage

The amount of delay already occurred is 0 but the decision is: Right

The cost of the delay is: 16

6

Damage Magnitude = 38

DAMAGE HAS BEEN PLACED

[[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 38 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]]

1

[[2 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 38 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]]

The Superintendent decided to Repair the damage

The amount of delay already occurred is 15

The cost of the delay is: 53

Construction Worker will Repair the damage

The amount of delay already occurred is 0 but the decision is: Wrong

The cost of the delay is: 38

7

Damage Magnitude = 23

DAMAGE HAS BEEN PLACED

[[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 23 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]]

1

[[2 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 23 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]]

The Superintendent decided to Repair the damage

The amount of delay already occurred is 35

The cost of the delay is: 58

Construction Worker will Repair the damage

The amount of delay already occurred is 0 but the decision is: Right

The cost of the delay is: 23

8

Damage Magnitude = 65

DAMAGE HAS BEEN PLACED

[[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

```
[ 0 0 0 0 0 0 0 0 0 0]
[65 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]]
```

1

```
[[ 2 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[65 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]
[ 0 0 0 0 0 0 0 0 0 0]]
```

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]]

The superintendent decided to REPLACE the damage

The amount of delay already occurred is 30

The cost of the delay is: 95

Construction Worker will REPLACE the damage

The amount of delay caused is 0 but the decision is: Right

The cost of the delay is: 65

9

Damage Magnitude = 91

DAMAGE HAS BEEN PLACED

[[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 91 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]]

1

[[2 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 91 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0]]

The superintendent decided to REPLACE the damage

The amount of delay already occurred is 43

The cost of the delay is: 134

Construction Worker will REPLACE the damage

The amount of delay caused is 0 but the decision is: Wrong

The cost of the delay is: 91

10

Damage Magnitude = 43

DAMAGE HAS BEEN PLACED

[[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]

[43 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0]]

```

[[ 2 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]
 [43 0 0 0 0 0 0 0 0 0 0]
 [ 0 0 0 0 0 0 0 0 0 0 0]]

```

The Superintendent decided to Repair the damage

The amount of delay already occurred is 80

The cost of the delay is: 123

Construction Worker will REPLACE the damage

The amount of delay caused is 0 but the decision is: Wrong

The cost of the delay is: 43

REFERENCES

REFERENCES

- Abdelhamid T.S., Schafer Don, Mrozowski Tim, Jayaram V., Howell G., Mohamed El-Gafy (2009) “Working Through Unforeseen Uncertainties through OODA Loop” Proceedings of the 17th Annual conference for the International Group of Lean Construction.
- Betts, Martin, and George Ofori. "Strategic planning for competitive advantage in construction." Construction Management & Economics 10, no. 6 (November 1992): 511. Business Source Complete, EBSCOhost (accessed October 17, 2011).
- Charles Perrow (1999) “Organizing to Reduce the Vulnerabilities of Complexity” Journal of Contingencies and Crisis Management. Volume 7, Issue 3 pages 150-155. September 1999
- Collyer Simon, Warren Clive M.J., “Project management approaches for dynamic environments”, International Journal of Project Management, Volume 27, Issue 4, May 2009, Pages 355-364,
- Cynthia C. Y. Tsao, Iris D. Tommelein, Eric S. Swanlund and Gregory A. Howell, “Work structuring to Achieve Integrated Product-Process Design.” Journal of Construction Engineering and Management November/December 2004 DOI: 10.1061/(ASCE)0733-9364(2004)130:6(780)
- Engwall Mats and Svensson Charlotta ‘Cheetah Teams.’ Harvard Business Review May 2009.
- Equifax Business Failure Report 2011 (http://www.equifax.co.uk/About-us/Press_releases/2011/EQUIFAX_2011_BUSINESS_FAILURES_REPORT.html) accessed on 15th October 16, 2011
- FMI/CMAA Sixth Annual Survey of Owners (http://cmaanet.org/user_images/owners_survey_6.pdf)
- Geraldi Joanna G. “Reconciling Order and Chaos in Multi-project Firms.”, Internation Journal of Managing Projects in Business. Vol. 2 No. 1 2009, pp. 149-158
- Grey Chris and Garsten Christina, “Trust, Control and Post Bureaucracy”, Organization Studies, Vol. 22, No. 2 March 2001.
- Herman Glenn Ballard, “The Last Planner System of Production Control.” Doctoral Thesis submitted to the Faculty of Engineering, The University of Birmingham.
- Howell G. (1999) “White Paper for Berkley/Stanford CE & M Research Workshop”

- Hwang, Peter, and J. David Lichtenthal. "Anatomy of Organizational Crises." Journal of Contingencies & Crisis Management 8, no. 3 (September 2000): 129. Business Source Complete, EBSCOhost (accessed October 20, 2011).
- Joana G. Geraldi, Liz Lee-Kelley, Elmar Kutsch "The Titanic sunk, so what? Project manager response to unexpected events", International Journal of Project Management, Volume 28, Issue 6, August 2010, Pages 547-558
- Keesoo Kim, Boyd C. Paulson 2003 "Agent-Based Compensatory Negotiation Methodology to Facilitate Distributed Coordination of Project Schedule Changes", Journal of Computing in Civil Engineering. Vol.17, No. 10, (2003).
- Kloppenborg, Timothy J., and Warren A. Opfer. "The Current State of Project Management Research: Trends, Interpretations, and Predictions." Project Management Journal 33, no. 2 (June 2002): 5. Business Source Complete, EBSCOhost (accessed October 17, 2011)
- Koskela Lauri. "We need a theory for construction." (1992)
- Laufer Alexander, Denker Gordon R., Shenhar Aaron J., "Simultaneous Management: The key to excellence in capital projects." International Journal of Project Management Vol. 14, No. 4, pp. 189-199, 1996
- Liker J.K. "The Toyota Way" McGraw-Hill; 1 edition (December 17, 2003)
- Markus Hällgren, Eva Maaninen-Olsson, (2009) "Deviations and the breakdown of project management principles", International Journal of Managing Projects in Business, Vol. 2 Iss: 1, pp.53 – 69
- Markus Hällgren, Timothy L. Wilson, (2007) "Mini-muddling: learning from project plan deviations", Journal of Workplace Learning, Vol. 19 Iss: 2, pp.92 – 107
- Markus Hällgren, Timothy L. Wilson, "The nature and management of crises in construction projects: Projects-as-practice observations", International Journal of Project Management, Volume 26, Issue 8, November 2008, Pages 830-838
- Mcmanus, H.; Hastings, D.; , "A framework for understanding uncertainty and its mitigation and exploitation in complex systems" Engineering Management Review, IEEE , vol.34, no.3, pp.81, Third Quarter 2006
doi: 10.1109/EMR.2006.261384
- Palaniappan, A. Sawhney, M.A. Janssen, K.D. Walsh 2007 "Modeling Construction Safety as an Agent Based Emergent Phenomenon", 24th International Symposium on Automation and Robotics in Construction (ISARC 2007). Construction automation group I.I.T., Madras.

- Pich Micheal, Loch Christoph and De Meyer Arnoud “On Uncertainty, Ambiguity and Complexity in Project Management”, Management Science, Vol. 48, No. 8, August 2008. Pages 1008-1023
- Polanyi M. “The tacit dimension.” Library of Congress Catalog Card number Ó6-21015
©Micheal Polanyi
- Raelin Joseph A. “The End of Managerial Control?” Group & Organization Management April 2011 36: 135-160, first published on December 31, 2010
- Reid Janine L. “Crisis Management: Planning and media relations for the Design and Construction Industry”, Wiley; 1 edition (March 1, 2000)
- Richard J. Curts and Douglas E. Campbell (2001)“Avoiding Information Overload through the Understanding of OODA loops, A Cognitive Hierarchy and Object-Oriented Analysis and Design” ©Curts and Campbell 2001
- Sawhney, A. Bashford, H. Walsh, K. Mulky, A. R. “Agent Based Modeling and Simulations in Construction” Winter Simulation Conference 2003. Volume 2 pages 1541-1547
- Simons Robert (1995) “Control in the Age of Empowerment” Harvard Business Review (1995)
- Snell Scott A. “Control Theory in Strategic Human Resource Management: The Mediating Effect of Administrative Information.” The Academy of Management Journal Vol. 35, No. 2 (Jun., 1992), pp. 292-327
- Susan M. Sanchez and Thomas W. Lucas. 2002. “Exploring the world of agent-based simulations: simple models, complex analyses.” In Proceedings of the 34th conference on Winter simulation: exploring new frontiers (WSC '02). Winter Simulation Conference 116-126.
- Turcotte John W., Director of Florida Department of Transport “Review of the Florida Department of Transport’s Performance in Controlling Construction Cost Overruns and Establishing Accountability for These Problems.” November 27, 1996.
- Wood, N. (2004). “Unknown unknowns: knowledge elicitation for multimedia in craft learning.” In: Challenging Craft: International Conference, Gray's School of Art, Aberdeen, Scotland, 8-10 September 2004