EXPLORING CREW BEHAVIOUR DURING UNCERTAIN JOBSITE CONDITIONS

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ABSTRACT

The dynamism and the inherent interactive nature of construction projects make them highly uncertain in nature and thus prone to unexpected events. Project level planning methods in construction assume a degree of certainty that is absent on projects. Unexpected events (such as equipment breakdown, coordination miscues, discrepancy between specs and drawings, etc.) are typically addressed by having the crew wait for a foreman or superintendent to find ways to handle the issue. This is a command and control structure that depends on a centrally controlling body. The research explores the question of whether the crew should wait for instructions or address the issue on their own. The research tests the hypothesis that a self-managed and autonomous construction crew will help combat the unexpected event more effectively than waiting for a resolution by a centrally controlling body. The two approaches are contrasted and compared for their effectiveness in dealing with unexpected events. An Agent based model shows; 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 takes into account the 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.

KEY WORDS

Production Management, Uncertainty, Autonomous Crews, Self-managed Crews

INTRODUCTION

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

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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 behaviour 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. Construction is characterized by "localized production" 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 behaviour of construction workers under unexpected events. The behaviour of construction crews with the ability to learn by making decisions (proactive) is contrasted with a construction crew that waits for the superintendent (reactive) to address the situation.

PROBLEM AREA AND MOTIVATION FOR RESEARCH

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 will cause delays in the project schedule because by definition they are 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 frequently late and over budget. 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.

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 (Turcotte 1996) 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.

LITERATURE REVIEW

"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 knowable. Some are hopeless to even contemplate (Hastings and McManus 2004). However, as the former United States secretary of state put it, we know they are out there, so we need to apply some thought on how to mitigate it.

There is a fair amount 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 the 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 very easily cause a case of an unexpected event. Hallgren and Wilson (2008) 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 and 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...”

Abdelhamid et al. (2009) studied the management of unforeseen uncertainties with the help of decision making cycles. The authors mention the OODA loop of Col. John Boyd as a suitable decision making cycle for tackling the uncertainties. The OODA loop is a continuous decision making cycle with four stages: Observe, Orient, Decide and Act. The OODA loop places great emphasis on the rapidness in decision making. Business strategies based on the OODA loop consider quick decision making as an important method to get ahead of the competition. Designed for air force purposes, the OODA loop has found use in major business strategies. The conclusion of the authors is that the OODA loop in conjunction with the Last Planner® System is a viable option to tackle unforeseen uncertainties. Geraldi et al. 2009 studied unexpected results and their responses in project management with a standpoint of finding what makes a response successful during unexpected events. The authors concluded that the successful responses were mainly based on three important pillars as shown in Figure 1.

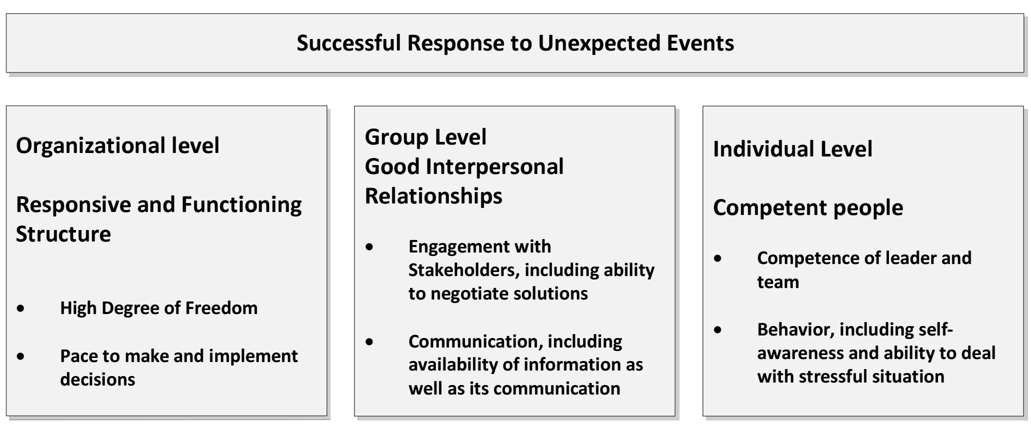

Figure 1: The three pillars to successful response (Geraldi et al. 2009)

The authors note that the ideas that emerge and the three pillars (Figure 1) 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 on flexibility and responsiveness rather than rule following. There is thus the need for a responsiveness and flexible structure in dealing with the unexpected events. The traditional centrally controlled structure prevalent on construction sites today is not very effective in dealing with these events.

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 unexpected events 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.

METHODS SUGGESTED IN LITERATURE TO MITIGATE UNCERTAINTY

Even though there is a lack of literature on mitigation of uncertainty and unexpected events in Construction, literature from Project Management, Crisis Management and Lean Construction provide tangible tools and principles for the same.

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.

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 in 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 them 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. Based on the input controls, 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.

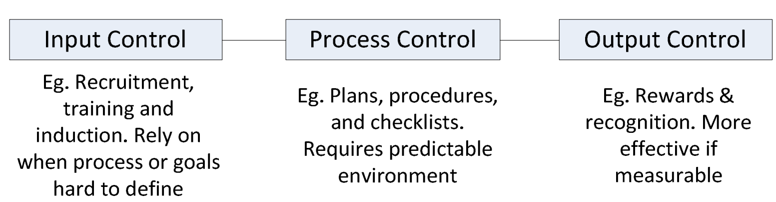

Figure 2: Control Methods (Collyer and Warren 2007)

It is important however to provide tangible boundaries within which the autonomous crews can acts. 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.

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. These decision making cycles afford a structure to the team that helps them make decisions under unexpected situations.

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.

Lean Construction also provides principles that can be used in the planning phases and the production phases of the construction project. Planning construction projects using Lean Workstructuring, Simultaneous Management (Laufer et al. 1996) and the Last Planner® System will help minimize the occurrences of these unexpected events. In the production phase, lean tools will help expose issues early through the use of the weekly work plans, 5S and daily huddles. Identification and swift solving of unexpected events will result in more effective mitigation.

RESEARCH METHOD

The conclusion from the literature review is that uncertainties in construction should be embraced and accepted as a challenge rather than artificially ruling them out (Abdelhamid et al. 2009). The study is aimed at unknown events not covered by this project contingency budget.

The probability of the occurrence of many uncertainties is low and is generally managed by a project contingency incorporated in the budget. 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 (2008) 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 explored the behavior of construction workers and compared the performance of a 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 her/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 foremen) who perform the work take a decision based on their knowledge and foresight. For more details, the reader is referred to Desai (2012).

MODEL DEVELOPMENT

The model is developed using python version 2.7. The model has the following classes (agents)

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

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.

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 damage occurred and makes a decision to solve the problem. The decision made by the superintendent in all cases is assumed to be the right one, i.e., the superintendent possesses 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, depicting the magnitude of the damage. The damage is created when the site is initialized.

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 is placed 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.

MODEL EXECUTION

The agent decides whether to repair the equipment or completely replace it. A randomly generated damage coefficient is checked whether it is less than 40. It would be impractical to replace the equipment if the damage was less than 40%. In this case, the agent decides to repair the equipment, otherwise the equipment is replaced. If the repair method is selected based on conditions, the model calculates the number of days the project is likely to be delayed during repair. The delay amount depends on the damage severity and the number of workers needed for the repair. The replace decision has a set delay time (3 days in this model). The entire process is repeated 100 times. The model outputs results in an excel spreadsheet.

Assumptions

The following assumptions were made during model development to maintain a parsimonious model.

- 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.
- The cost, in monetary terms, of repairing or replacing is not considered in the model.
- The Superintendent's decision is absolutely correct

Model Parameters

The model has the following parameters:

- The size of the grid
- The decision parameter
- Error rate of workers
- Learning factor for workers

RESULTS AND CONCLUSION

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 3 shows the delay to the project as respectively caused by the crew making the decision versus the superintendent making it. As shown, the delay is more when the crew decides to wait for the superintended, albeit her/his decision will be correct. There is also 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.

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 the 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.

This research 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.

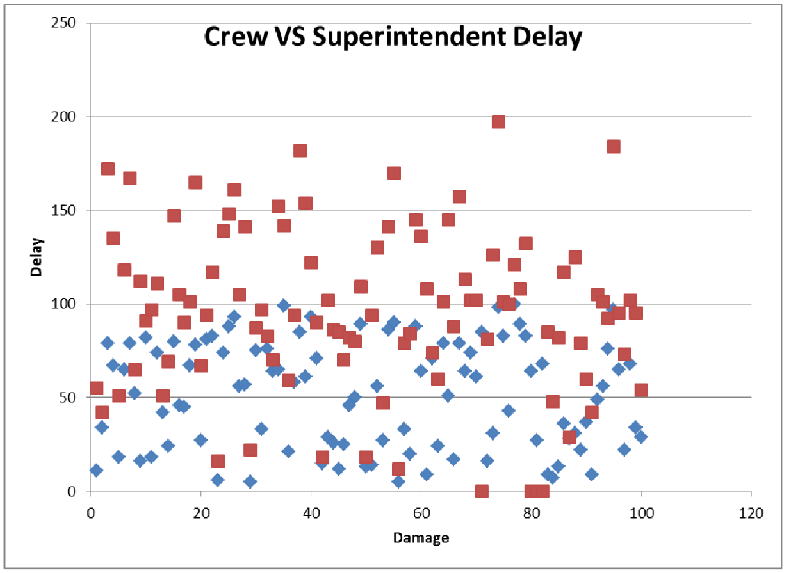

Figure 3: Delay caused by crew's decision (diamonds) vs. superintendent's decision (squares)

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 main findings can be summarized as follows:

- The occurrences of unexpected events are inevitable and we must prepare to combat them.
- A decentralized system appears to help the project to recover from unexpected events more effectively
- A responsible and flexible organization is helpful in recovery from unexpected events
- The main management figure (superintendent in this case) was under much less pressure in a system where the crews were autonomous and self-managed.

Based on these findings, further research is suggested in the following areas:

- An empirical study to test the effects of decentralized decision making on construction sites
- Expand the ABM to include multiple crews and test the effect of decision making cycles such as the OODA loop and the PDCA

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