4th Construction Specialty Conference
4e Conférence spécialisée sur la construction

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

Defining an Agile Construction Management System

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Abstract: Both competitive market forces and growing societal needs have triggered the demand for rapid delivery of infrastructure projects, or at a minimum, for projects completed on schedule. However, schedule delays are common and recurring in construction, inevitably resulting in rework, cost overruns and legal claims. Construction delays can cause problems to more than the schedule, such as cost, quality and safety issues. Handling delays requires solutions that are adaptive and flexible. When it comes to flexibility, the theory of agile software development and relevant methods shed light on handling changes that could result in delays. In manufacturing, service-oriented production principles require adaptive and flexible management systems to deal with rapid changes for increasing customization. A flexible and efficient production management system, namely agile construction management is defined here to achieve agility throughout the entire project life cycle. The first element of the agile construction management system is a framework. The framework consists of agility drivers, agility enablers, and agility metrics. Agility drivers are the types of delays and their causes. The enablers target various delay causes, and are grouped into five categories including strategy, generic practice, people, technology, and theoretical model. The influence of agility enablers on the construction project system, either positive or negative, can be measured through agility metrics. Since agility is a complex concept, there are several approaches for evaluation, including agility index methods, fuzzy agility index methods, and the analytical hierarchy process.

1 INTRODUCTION

Schedule delays are common on construction projects, which can negatively impact the overall project performance. This situation is partially due to the nature of design and construction processes, which contain dynamic interactions among diverse parameters, such as project attributes, participant experience, and time and cost constraints. In addition, time delays are usually accompanied by other problems such as cost, quality and safety issues. In an attempt to try to manage delays, researchers have studied the root causes of construction delays in certain geographical areas or for certain types of projects. By ranking the occurrence probability of these delay factors, these studies provided construction professionals with a guideline in preventing similar delays from happening in future work. Other research has focused on how to present delays in the context of the schedule impact, and determining the influence of delay events and related liability of project participants. In spite of these achievements in analyzing delays, there remains a problem of consistent and significant delays on construction projects. Solutions to delay problems are still the responsibility of the project manager, who mostly relies on past experience and standard planning and scheduling solutions. As project complexity continues to increase, this experiential approach will be insufficient.

The complexity of construction projects and delay causes requires an integrated approach to solve this problem. There are only so many potential delays that can be foreseen and planned for at the start of a project. For unforeseen delays, there is a need to introduce flexibility into the project to minimize the risk of schedule delays. What is more, this flexible mechanism should not only benefit scheduling but also facilitate the improvement of overall project performance. Based on extensive literature review, agility and agile development principles provide a solid basis for handling uncertainty in construction delays. These principles have been proven through successful application in other engineering disciplines. Accordingly, with the ultimate goal of reducing delays in construction, an agile management system is proposed in the form of an explanatory framework. Besides introducing agility as an innovative managerial idea in construction management, this study aims to provide a platform to guide future research on this topic, such as validating the proposed framework as well as measuring the effectiveness of being agile.

2 BACKGROUND LITERATURE REVIEW

2.1 Delay-related Research in Construction

Completing large construction projects on time is challenging since delays can occur for various reasons. Among these reasons, however, it is difficult to identify the uniform root causes, which could vary depending on the project environment. Assaf and Al-Hejji (2006) concluded that a critical delay cause recognized by construction project parties in Saudi Arabia is change orders. Other issues such as building permit approval, inspection, and changes to laws and regulations have been identified as major delay causes for construction projects in Florida (Ahmed et al. 2003).) A review of literature has identified many delay factors (Odeh and Battaineh 2001, Faridi and El-Sayegh 2006, Lo et al. 2006, Sambasivan and Soon 2007) which can be further grouped into eight categories as shown in Table 1.

Table 1: Construction delay factors and related examples

Delay Factor	Example
Project-related	Short contract duration, Legal disputes, Type of contract, Type of bidding
Owner(consultant)-related	Delays in payment, Change orders, Late in approving documents, Poor coordination
Contractor-related	Difficulty in financing project, Rework due to errors, Conflict with subs, Ineffective planning
Designer-related	Mistakes in design documents, Lack of constructability, Inadequate experience
Labor-related	Labor shortage, Unqualified workforce, Low productivity level of labors
Material-related	Material shortage, Delay in delivery, Damage of materials, Late procurement
Equipment-related	Equipment breakdowns, Shortage, Low productivity
External environment-related	Delay in obtaining permits, Weather issues, Safety accident, Traffic restriction, Change in Government rules, Unavailability of utilities

Construction delays can also be classified to reflect the responsibility for delay events. The term non-excusable delay is used to describe time overruns due to contractors' mistakes. Excusable delays consisting of compensable and non-compensable ones distinguish delays caused by the owner or owner's agents, and incidents beyond the control of both the owner and contractor. To facilitate resolving disputes in delay claims, another type of analysis was developed, called delay analysis techniques, such as the collapse but-for (CBF) technique, time impact technique, windows technique and isolated delay type (IDT) technique (Hegazy and Zhang 2005, Mohan and Al-Gahtani 2006, Yang and Kao 2009). One goal of these techniques is to identify delay duration by looking backward at schedule performance and comparing the as-planned, adjusted with as-built schedules. Another purpose lies in determining the impact of delay events and related liability for each project party.

When it comes to delay reduction in construction, the general practice is still simple, such as refined planning, monitor scheduling and enhanced communication. In academic research, relevant findings are also limited. Hastak et al. (2008) summarized delay-reduction methods from professional documents provided by the Construction Industry Institute (CII) and broad survey investigations. The result is categories of forty-six schedule reduction techniques, thirteen management techniques and eleven CII best practices that can be used selectively to reduce project cycle time as well as improve project performance. Moreover, other research was undertaken to reduce delays indirectly from associated aspects in construction. Based on concurrent engineering principles, Bogus et al. (2005) suggested reducing project delivery time through overlapping design and construction activities. In addition, given the increased uncertainties during overlapping processes, other studies addressed change management strategies to mitigate delays caused by unexpected changes (Lee et al. 2005, Motawa et al. 2007). In real practice, projects can be delivered through fast tracking independent project activities and procedures which allows projects to be completed in the least amount of time possible.

Construction is a project-based activity where every project has an unique project environment. A real challenge to reduce delays is to cope with time overruns caused by unexpected issues. In such a fluid environment, it is intuitive to keep a certain amount of flexibility as well as engage in continuous improvement, which not only minimizes the overall risk of uncertainty but more importantly, enhances relevant project performance. Accordingly, agility and agile thinking are consistent with this goal.

2.2 Overview of Agility and Relevant Application

Agility, as a concept that incorporates the ideas of flexibility, responsiveness, adaptation and coordination under one roof has become widely used across various research disciplines (Dyer and Ericksen 2009). It literally refers to the ability to deal with uncertainties effectively (Sharifi and Zhang 1999). In the software development industry, agile methodologies were developed including self-organization, collaboration, and process adaptability throughout the project life-cycle. Focusing on how to respond to changes, these methods encourage positive reaction toward changes by allowing incremental planning and increased customer involvement, and anticipating changes for subsequent learning experience (Abrahamsson et al. 2002). In more complex interdisciplinary industries, standalone agile methods are inadequate to ensure a coherent agile performance because of complicated organizations, longer development cycles and rigorous standard compliance. Thus, a series of agile system strategies is required, and the manufacturing industry sets such an example as agility had been substantially explored under the name of agile manufacturing.

In manufacturing, service-oriented production principles require adaptive and flexible management systems to deal with rapid changes for increasing customized products. Increasing use of agility-related methods in manufacturing bred the idea of agile manufacturing, which was defined as the capability of surviving and improving in a competitive environment of continuous and unpredictable changes by reacting quickly and effectively, driven by customer-oriented products and services (Jin-Hai et al. 2003). The agile enterprise, as an extension of agile manufacturing application, describes an organization that utilizes agile principles to achieve success. Compared to traditional management principles, agile principles can be distinguished based on different aspects as shown in Table 2 (Owen et al. 2006).

Table 2: Comparison of agile and traditional management

	Agile	**Traditional**
Attitude to change	Embrace change	Control/avoid change
Approach to risks	Proactive adaptation	Reactive
Management structure	Flat and team-based	Close and hierarchical
Attitude to customer involvement	Key to organization leaning	Irritating obstruction
Nature of planning	Delayed decision on planning	Sequential and comprehensive

In a rapidly changing market, large-scale design and production systems running under central-control and distributed-operation environments are more likely to suffer project overruns. Any external turbulence or internal uncertainty can easily put product delivery behind schedule due to the complex and rigid information exchange process between control and operation units. Relevant “ripple effects” above and beyond time delay such as scope and cost issues, generate a requirement for a systematic solution to solve delay problems. The agile principles mentioned above were further evolved into agility-related strategies, covering technologies, people, information systems, and business processes.

One attribute of the agile strategy is to increase the flexibility and responsiveness of shop floor operation by integrating process planning and production control. According to Lim and Zhang (2004), software-based artificial intelligence systems were developed to achieve agility in manufacturing. The system has cross-functional agents of different working stations which are designed to run their jobs autonomously for individual goals, and cooperate with each other to achieve global goals efficiently. Inspired from the adaptive biological evolution process, Tang et al. (2011) simulated the production system as a living organism where control and regulation stations run as “neuron” and “hormone” respectively.

2.3 Agility in Construction and Possible Research Potential

The manufacturing industry has seen dramatic improvements in productivity, while reducing lead times and costs. However, the construction industry has not seen such positive results though it has many similarities to manufacturing in managing complex operations, as well as a rapidly changing market and dynamic customer requirements. Research into improving construction operations has focused on various aspects. For example, lean construction, inspired from lean production ideas, appeared to improve the overall construction productivity through the continuous working process of eliminating waste. Agility, another underlying theory thriving in manufacturing is still emerging in construction. Some studies have assessed the possibility of engaging agility in construction management. Owen and Koskela (2006) reviewed the strength of agile manufacturing before arguing the construction industry might potentially benefit from agile project management because of proactive responses to unpredictable changes. Owen et al. (2006) addressed Agile Project Management (APM) as tentatively appropriate for the design phase of construction which contains more customer involvement, conflicting requirements, and constant trade-offs because the APM allows for the embracing of changes for continuous improvement, a creative solution particularly to complex requirements. Furthermore, the concept of Agile Construction was proposed recently by Daneshgari (2010) and characterized with responsiveness and adaptation to unexpected changes.

To deal with complex delay issues, existing literature results associated with delay cause identification and delay analysis techniques seem reactive instead of proactive. Complex delays require a systematic thinking in a “big picture” that enhances the entire project performance. Especially for those unpredictable delays, there is a research gap in providing an integrated method characterized with agility as a proactive alternative to mitigating delays. What is more, even though the theory of agile project management and agile construction have been mentioned in construction-related studies, the effort is still sporadic and addresses the topic only in the context of general discussion to optimize the overall project performance instead of a specific goal. As a result, agile ideas are rarely used in construction, even though agility has been successfully used in other industries. Therefore, there is a need to formalize this concept through a framework of an agile construction management system focusing on reducing schedule delays.

3 METHODOLOGY

In order to create a framework for agile construction management, a comprehensive review of existing literature was first conducted. The literature review covered the area of agile construction management as well as agility in software development and manufacturing. Since agility encompasses multiple meanings and principles, the first task is to provide a clear and specialized explanation for what agility means in construction and to propose an agile management framework so as to eliminate ambiguity. Given that the concept of agile management is still emerging in construction, a conceptual framework is considered appropriate as a type of intermediate theory that attempts to connect all aspects of research interest. Thus, reducing delays can be viewed more like a “problem solving process” which starts from “problem identification” (delay causes), “solution development” (theoretical/empirical data and practice) to “result evaluation” and “lessons learned” (validation of delay-reducing methods). Also, the proposed framework acts as a map that gives coherence to all “milestones” during the process of delay-reduction.

Accordingly, an agile construction management framework, as the primary means in this study is developed with components focusing on mitigating schedule delays in construction. Moreover, the proposed framework attempts to outline possible resources related to agility, and draw up logical procedures to be agile in project management. Each framework component is explained in detail, thus increasing awareness for pursing agility in construction management. Meanwhile, some framework components are expected to serve as a guideline for construction professionals to cope with uncertainty-related delays in practice.

One key component that can help with uncertainty is the agile enabler (further described in Section 4.2.4). Following development of the agile framework (Figure 1), a series of interviews were conducted with owners, architects, and construction contractors to further explore the potential of agile enablers in mitigating construction delays.

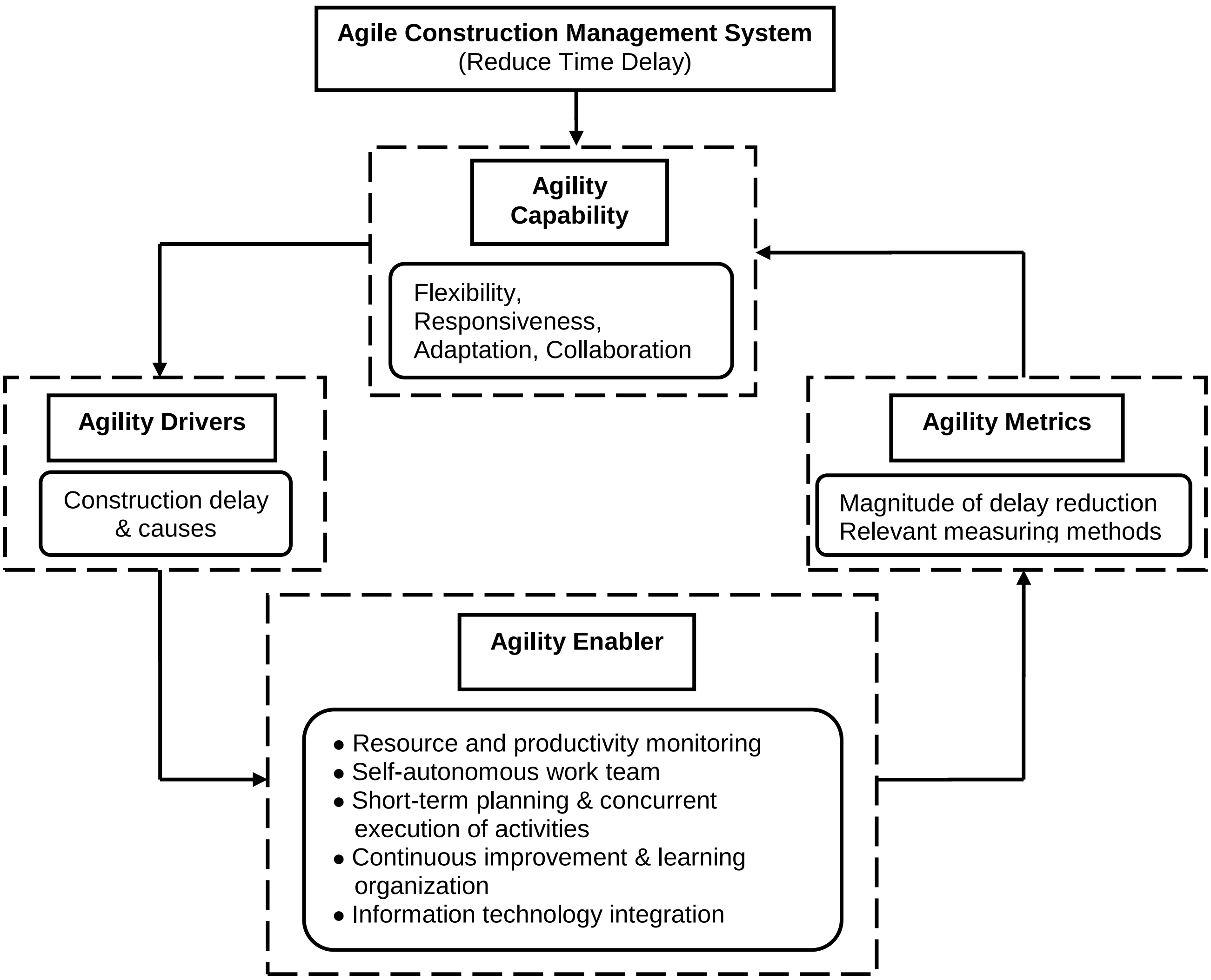

Figure 1: The framework of an agile construction management system

4 RESULTS

4.1 Framework Overview

In order to accomplish agility in dealing with construction delays, an agile construction management framework is proposed as shown in Figure 1. In general, the framework is designed for three functions. First, the framework presents a path to pursue agility in a cause-effect manner. Second, the framework suggests methods (also known as “agility enablers”) to allow a project to become agile. Third, the framework provides a path to validate the proposed agile ideas, including all framework components. When building components for the agile framework, this study particularly refers to existing results from agile manufacturing. Manufacturing has set an example for construction because of its dramatic improvements in productivity and in-depth customization. If each construction site is considered as a “temporary production line”, the highly “standard production” will turn out to be the future trend of construction. Therefore, ideas inspired from agile manufacturing are incorporated in developing agility in construction.

4.2 Component Analysis

4.2.1 Agile Construction Management System

Being agile cannot be attained overnight. Instead, it is a highly iterative and incremental process which is referred to as an agile construction management system in this study. Recurring delays in construction boost demand for developing systematic strategies. In this case, agility is recognized as a competitive advantage to better cope with increased project uncertainties. Variability associated with unexpected changes is viewed more positively as a “learning opportunity” for long-term self-improvement. At the project level, the agile construction management system should provide construction professionals with specific agile methods to manage unforeseen project delays. The best solutions would be those offering the “best value” after balancing the trade-offs between time and other relevant project goals. At the enterprise level, the agile construction management system implies criteria consisting of agile methods which should be implemented widely from the project planning, execution, and every step of the decision-making process until it finally becomes a core competence for the enterprise in an increasingly challenging market.

4.2.2 Agility Capability

Agility capability generalizes the ultimate attributes to be achieved for being agile. Unlike a simple interpretation, defining agility is more like a brainstorming process to develop a pool of associated ideas, as applicable. Several research studies have taken this approach, and the major results are summarized in Table 3.

Table 3: The attribute of agility and an agile organization

Article	*Flexibility*	*Responsiveness*	*Adaptation*	*Self-direct*	*Collaboration*
Yusuf, Y.Y. et al. (1999)	√				√
Ramasesh, et al. (2001)	√	√	√		√
Devadasan, et al. (2005)	√	√	√	√	
Vázquez-Bustelo and Avella (2006)	√			√	√
Lin, et al. (2006)	√	√			
Tsai, et al. (2008)	√	√	√		

According to the Table 3, flexibility is undoubtedly the basic value of agility. Responsiveness and adaptation are selected as the other two most typical characteristics. In running specific project activities, agility highlights a self-motivated and collaborative working atmosphere. Empowered working teams are formed to run jobs more positively while being less disrupted by over-control or micro-management. Meanwhile, they can be allocated flexibly to work together in case of urgent tasks, which can form long-term "partnerships" for the enterprise-level strategy.

One attribute of agility distinguished beyond regular "flexibility" lies in "embracing changes" which can be explained as anticipating changes and learning from changes. In other words, traditional adaptation to changes means an entity attempts to adjust itself passively when changes occur. Change is the driving force while an entity's action is only a result of that force. Instead, "embracing changes" expects the entity to take advantage of changes to place itself in a better position. Embracing implies a two-way process where the entity not only responds to changes but can also influence them.

Construction projects can also benefit from this characteristic. For example, if designers "welcome" inputs or changes from owners and contractors during the design phase, this can reduce change orders that arise later in construction. As a result, delay events associated with designer's changes could be reduced. If a construction project is labeled as an agile construction management system, other agile attributes such as self-direction, collaboration, and partnership should be applied in all phases of the project delivery process.

4.2.3 Agility Drivers

In computer software development and manufacturing industries, agility and relevant ideas were initially addressed to respond to changing requirements on customization. Dynamic "changes" become the original incentive of agile management principles. In construction, "changes" in all project phases also exist, and inevitably disturb the as-planned schedules when delays arise. The motivation to accomplish agility in this study focuses on reducing, or at least mitigating time delays. If delays consist of expected delays and unexpected delays, we need to work on them separately. Literature results including identification of delay causes and delay analysis techniques are more appropriate for dealing with expected delays based on the empirical data and practice. Agile ideas are proposed to work on both expected and unexpected delay scenarios.

4.2.4 Agility Enablers

Agility enablers literally refer to a series of methods which can bring agile performance during the project delivery process. Also, agile methods bear a function to alleviate time delays, in particular. Given that schedule performance is integral to project objectives, delay prevention requires a systematic effort throughout the project. In this case, the agile manufacturing industry provides a good example in applying agility to production management. Numerous agile enablers have been developed in terms of people (organization), technology and enterprise level strategies. Many of them are applicable for construction when each project is considered as a temporary production line.

Construction inherently possesses a certain degree of flexibility as owners' requirements or rules and regulations change. Most approaches to flexibility are reactive, such as change orders and as-built plans. Other practices, like short-term planning may work but are still inadequate to deal with increasing job complexity. In this study, agility enablers consist of agile methods inspired from both agile manufacturing and flexible construction practices. The following five agility enablers were identified through literature and deemed to be immediately applicable to construction. These five enablers were further evaluated through a series of exploratory interviews with owners, architects, and construction contractors. The results of these interviews are presented in a separate publication.

<u>Real time resource monitoring and productivity measurement:</u> If delays are generally caused by changes to original plans, agile construction management emphasizes the responsiveness to changes which is to figure out the time (i.e., time to detect and time to react to changes) taken to deal with changing scenarios.

The longer it takes to identify a problem, the less time is available to formulate an appropriate response. Agile construction management focuses on shortening the time to detect the unexpected changes by monitoring resource usage with field feedback. For adaptation to changes, agile construction management highlights knowing the productivity as well as a thorough understanding of resource usage. Only if project managers know exactly how much time and resources it will take for the work to be completed can they determine more accurate plans to make up the time lost by delays.

Self-autonomous work teams with multi-functional crews: In order to get quick response to unexpected changes, agile work teams should be organized as self-motivated and empowered cells. Project manager as a leader but not taskmaster should facilitate agile teams to continuously adapt to improve their methods as they incorporate lessons learned from the previous cycle into the next iteration. In addition, agile work teams should consist of multi-functional crews, which can largely save time for deploying people from other teams in case of unforeseen tasks.

Short-term planning along with concurrent execution of activities: Short-term planning is considered as one of best methods to maintain flexibility in a highly-fluid construction site. Frequent review of original plans can keep all project participants in communication with each other. Timely adjustment to plans can effectively diminish the risks of time delay due to unexpected events. In addition, delay is usually related to a productivity issue in terms of idle time and resource waste. Thus, overlapping independent construction activities can effectively reduce this waste of time for creating a flexible, efficient and streamlined work flow.

Continuous improvement based on learning organization: Agile management emphasizes learning from changes, which is an enterprise-level strategy. This learning is a collaborative process with all project stakeholders actively working together to capture constant feedback, and learning lessons from the previous iteration. An iterative process of planning, changing, evaluating, and learning can drive agile work teams to improve the entire performance. Consequently, it makes teams more responsive to changes and less sensitive to associated negative impacts.

Information technology integration: Fluent project execution is built on smooth communication between all project entities. Following this logic, the communication can be more agile as inputs from different parties are integrated to one interface. Accordingly, the emerging Building Information Modeling (BIM) technology is conceived of as a platform for managing change and coordinating all project information. BIM literally allows more flexible information sharing and performs efficiency calculations on “what-if” scenarios, which indirectly reduces delays due to misunderstanding and ineffective communication of tasks and objectives.

4.2.5 Agility Metrics

Agility, as a fairly new concept in construction could bring challenges in understanding how it handles changes and protects time schedules from being interrupted by uncertainties. It raises an important question on metrics to measure the effectiveness of being agile. Manufacturing has been leading in this aspect for its successful experience in agile manufacturing. In order to measure agility, it is difficult to find a uniform metric for agility itself. Instead, performance measurement, as a process of converting effectiveness and efficiency of different dimensions to reasonable measures to report, has been found appropriate for this task. Within the agile enterprise, intensity levels of agility became the major metric assessed by agility indexes, accumulative results of dimension measurement. In this study, the agility metric will be more specific, associated with delay-reduction, which means the magnitude of delay duration can be reduced for impacted project activities if agility enablers are used.

Based on pre-determined metrics, agility can be evaluated in two steps. The first step is qualitative where a survey will be conducted among relevant experts to collect professional opinions on target topics. The follow-up is a quantative analysis focusing on how to convert the linguistic data to numerical and comparable results. The major quantative approaches include Agility Index Method (Yusuf et al. 2001), importance ranking methods based on an AHP (Analytic Hierarchy Process) model (Ren et al. 2000), and FAI (Fuzzy Agility Index) Method (Lin, et al. 2006).

4.3 Possible Future Work

Attempting to create the agile framework solely based on the previous literature is limited by the narrow work of the researchers. The follow-up of this study will have the proposed framework validated and enhanced by engaging professionals in the construction area. An interview study or survey investigation is an appropriate method to collect data in terms of linguistic opinions. Considering the single qualitative description of being agile is vague and abstract, if agility is used as a critical criterion to evaluate delay management, the next step of this research will focus on quantifying the effectiveness of being agile to reduce delays. One possible direction of future work is testing the proposed agile ideas by analyzing the magnitude of delay reduction when the agile methods are implemented. Accordingly, a project schedule simulation can be conducted based on a real project case being delayed. Also, a questionnaire survey for experts in the construction industry and a method converting relevant linguistic opinions to numerical results are required. However, due to limited time and scope of work, this paper covers only the framework for agile construction management.

5 CONCLUSION

Construction is usually challenged to complete projects on schedule. In order to deal with increasingly complex delays, this study shifts the original idea of getting rid of delays to reducing or neutralizing delays by adding "agility" to the entire project management. Agility, a concept originating from agile manufacturing and other engineering areas, is found to be well-suited to construction management because of its potential to break barriers of "over control" and facilitate a flexible, responsive, collaborative and solutions-oriented construction delivery process.

Going beyond flexibility which deals with fragmented activity changes, being agile means a project is treated as an integrated system and its components are able to interact with each other against all kinds of uncertainties. Accordingly, agile construction management as a conceptual framework is defined. Some components in the proposed agile framework like agility drivers and agility enablers are expected to offer guidance for practitioners to prepare for unexpected delay events. Though no single set of enablers can reflect all aspects, the key is to understand the relationships between the enablers, to deploy and integrate them, and finally to transform them into competitive capabilities.

Last but not least, agile principles have been partially applied by some innovative construction companies (Daneshgari 2010) on certain construction stages such as the design phase and supply chain management. In order to convince more people that being agile is a valuable trait to enhance project performance, more research is needed.

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