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Lean Construction Supply Chain

A Literature Review

Author:
Jiamei Ren

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Supervisor:
Tina Karrbom Gustavsson

Master of Science thesis

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Author:	Jiamei Ren
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Abstract

The aim of this thesis is to enhance the management of supply systems in construction industry using lean principles. This study is an attempt to identify what kind of activities causes' construction process delay and how to perform lean concept into supply chain in practice. The objective is to assure on-time delivery of information and materials to construction sites at lowest cost and maximum value for the customer. These study problems have been analysed from a lean construction supply chain perspective, concentrating on decreasing and eliminating non-value adding activities in order to maximum the value for the customer. Supply complexity in construction in order to better understand which sections are easy to generate non-value adding activities.

In the thesis, literature review is the main research method to support analysing and finding, including Ohno Taiichi identified seven wastes from Toyota Production System; five lean principles described by Womack and Jonas; Theory of constraint illustrated from Goldratt Eliyahu M.

1. Introduction

In this chapter will introduce a brief background, illustrate the characteristics regarding the construction supply chain, show the purpose and objectives, submit the research questions and list the contents of each chapter.

1.1 Background & Problems

Construction industry is a tremendous investment in long period, dynamic production phase with diverse uncertainties. In construction system contains different sub-systems, which interrelated and influenced each other. Those relationships constitute the whole. The task of a project manager is to organize every phase in scientific order and well scheduled. However, the construction system is a dynamic process and influenced by internal and external factors, such as weather, budget, government, technique issues and resources. Each of the factors will affect the project. Hence, project works over schedule and over budget will occurred.

In the production process, this is no perfect plan regarding the logistics of a project. The schedule always planned well before the project performing. However, the planning could be performed poorly due to certain unforeseen issues. Considering that there is a strategy to improve the efficiency and make a good use of buffer time in construction process.

Research has shown that in traditional construction projects only approximately one-half of the tasks assigned for a given week are likely to be completed in that week. (Forbes & Ahmed, 2011). Flow variability greatly influences original schedule, as a delay in work completion by one trade directly affects the downstream activities of the next session. (Forbes & Ahmed, 2011)

1.2 The characteristics of construction process

From rational construction arrangement, construction process includes necessary activities match to effectively control final output of project production, and the input of the process is decided by owners' demands to the construction project. Through a series of cooperated or interactional activities, the final output of construction project process management is the construction project product which can meet the owners' needs. The lifespan of construction process contains several main sections: project idea, feasibility studies, project development, pre-design, design, tender, production and handing over. The key section in construction process is: Initiation, design, construction and operation.

1.3 The characteristics of construction supply chain

From lifecycle of construction project perspective to define construction supply chain: Construction supply chain is a series functional activities, taking owners' perspective and requirements as objectives, begin with project requirements, then defining the project, financing the project, designing the project, constructing the project, handing over the project, maintaining the project until reconstruction or demolish session.

From Construction Company's perspective, supply chain is meet owner's requirements, setting contractors as core actors through information flow, logistics and cash flow to forming a constructing network with suppliers, sub-contractors, architects and owners.

In terms of structure and function, for Vrijhoef and Koskela, the construction supply chain is characterized by the following elements (Vrijhoef & Koskela, 2000):

“• It is a converging supply chain directing all materials to the construction site where the object is assembled from incoming materials. The «construction factory »is set up around the single product, in contrast to manufacturing systems where multiple products pass through the factory, and are distributed to many customers.

- It is, apart from rare exceptions, a temporary supply chain producing one-off construction projects through repeated reconfiguration of project organizations. As a result, the construction supply chain is typified by instability, fragmentation, and especially by the separation between the design and the construction of the built object.

- It is a typical make-to-order supply chain, with every project creating a new product or prototype. There is little repetition, again with minor exceptions. The process can be very similar, however, for projects of a particular kind.”

1.4 Lean construction supply chain

Construction supply is an important section during the construction process. It influences the production duration and the budget of construction in many ways. Good arrangement and scientific implementation can be time-saving and money-saving.

The highlight and final task is using lean principles into construction supply chain as a guideline to implement in practice. From theory perspective, it is a combination between lean and supply chain.

Construction supply chain is like a network, it contains different actors (suppliers, manufacturers, assemblers, retailers, customers) and different related sections (choose right suppliers, manufacturing, and delivery) to the key consideration. In Lean construction supply chains including reducing the storage costs within the contractor of concern and onsite storage

Using lean strategy into supply chain already become a success factors to better meet clients' needs and improve the supply efficiency. However, how efficiency is depending on how is actually performed. A company like Toyota introduced "lean" principles to improve efficiency, that strategy makes supply chain more productive and cooperative for achieving maximum business goal.

1.5 Objective and Aim of the study

The aim of this thesis is to enhance the management of supply systems in construction industry using lean principles. Initially, to identify what kind of activities causes' construction process delay and how to perform lean concept into supply chain in practice. The objective is to assure on-time delivery of information and materials to construction sites at lowest cost and maximum value for the customer, optimizing the construction supply chain to reach effective delivery system and quick respond to the customer. That's reason why I choose the research questions, and questions can be well explained by those theories introduced in Chapter 3.

The research questions of my interest are:

- What are the reasons for safety buffers being wasted?**
- How to improve performance of lean construction supply chain?**

Chapter 1 is an introduction part, mainly describe the purpose of the report, submit the research questions and introduce the theories which used in the report.

Chapter 2 illustrate the research method. Introducing the research plan and what is research method used in the report.

Chapter 3 is theoretical framework. Lean, Theory of Constraint, Last planner System and Partnering are introducing and analysing in this chapter.

Chapter 4 is an analysing part. Discussions regarding the theoretical framework and some limitations in lean construction supply chain are developed from theoretical framework part.

Chapter 5 is a conclusion part. The research questions are answered according to above analysing part. Recommendation to the project managers is outlined. And give an expectation and direction for the future development in lean construction supply chain.

2. Research methods

2.1 General research plan

This thesis starts with a phenomenon in construction industry, which is common and difficulties in construction system. Identifying possibilities to develop and improve, which can be settled in lean construction area. Theoretical study is the main research method used in the report, including several theories illustrates in order to build the foundation for the report. To reach the final finding, a combination with several key theories is made.

Since Lean and Lean principle as a concept can be use in any area, it does not have pertinence in construction industry. Construction supply chain is a fact in construction needs principles to direct and optimize. Hence, a good combination between theories and fact is made.

2.2 Literature review

The aim of a literature review in the report is to verify the relevant theories as a knowledge base and help the reader to understand the relevant concepts and theories, in terms of Theory of Constraint, Last Planner System, Partnering and Lean Principles. Those theories I picked have an influential contribute in the field of Lean and widely used in diverse industries, not only in construction. The sources used are based from printed books, journals and articles.

3. Theoretical framework

3.1 Lean

Lean can be used as a concept, principles, a type of ideology or a method to apply to activities or an organization management's guideline. Lean can also be used in any parts of construction process, such as design phase, construction phase or procurement phase, in order to acquire a long-term development.

Lean is also a set of principles, approaches, and methodologies that can be applied individually or organization. When lean principles are used a method to management they are continuously performed and can become a long-term philosophy for directing organizations to be easy, clear and well-managed. (Schniederjans, 2009)

3.1.1 Definition of lean

“Lean” operating principle began in manufacturing environments and is known by a variety of synonyms; Lean Manufacturing, Lean Production, Toyota Production

System, etc. It is commonly believed that Lean started in Japan (Toyota, specifically), but Henry Ford had been also using similar concept about Lean as early as the 1920's, as evidenced by the following quote:

The most important reason about keeping the price of Ford products low is gradual minimizing the production process. In manufacture process, developing long production cycle must be increased the production budget. (Henry Ford (1926) in Kilpatrick (2003))

“A systematic approach is to identify and eliminate waste through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection.”(Kilpatrick, 2003)

3.1.2 Learn from Toyota Production system

“The Toyota Production System (TPS) is an integrated socio-technical system, developed by Toyota that comprises its management philosophy and practices. The TPS organizes manufacturing and logistics for the automobile manufacturer, including interaction with suppliers and customers. The system is a major precursor of the more generic ‘lean manufacturing’ Taiichi Ohno, Shigeo Shingo and Eiji Toyoda developed the system between 1948 and 1975. ” (Toyota Motor Manufacturing Kentucky, 2006-2012)

To some extent, lean can be seen as the elimination of waste. Taiichi Ohno (co-developer of the Toyota Production System) identified seven wastes to be concentrated by Toyota system. Taiichi Ohno suggests that these account for up to 95% of all costs in non-Lean manufacturing environments. These wastes are:

- **Overproduction** – Producing more than the customer demands. The amount of production is depending on a pull system, which means the manufacture will produce the market real needs. The number of market products will be ordered from the market, the manufacture will produce according to the market requirements. In this way, the production will avoid waste and help the customer save budget.
- **Waiting** –Lean principle requires all resources delivering just at the right time, including material, information, equipments, machine, etc. If the resources delivered earlier than the plan that need extra space lay out the equipment. On the other hands, if the resource delivered late than the schedule that will cost extra time to wait the process inducing the process behind of the schedule.

“Just in time is a ‘pull’ system of production, so actual orders provide a signal for when a product should be manufactured. Demand-pull enables a firm to produce only what is required, in the correct quantity and at the correct time.” (Ohno, 1995)

- **Transportation** –Material should be transported directly to the place of use. In traditional way, the raw materials transport from the vendor to a warehouse, then transport to the construction site put into use. Lean system requires that the material bought from vendor then transport to the construction site directly avoiding the process of transporting the products from warehouse to the construction site. The materials can assembly on site then put into use directly. That's can be greatly decrease the transporting fee and storing fee, and made the transporting system tightly.

- **Non-Value-Added-Processing** –Reworking is a big obstacle in value-added-process. Reworking including correcting the design, product and maintain mistakes. It costs time and money to fix those mistakes. A technique called Value Stream Mapping is used to analyse and design the material and information flows, which can help identify non-valued-added activities.

- **Excess Inventory** –Compared to Overproduction, inventory over the demand will cause the negative effect of cash flow and increase the budget of renting fee. Using Lean Principle to control inventory can adjust cash flow and optimize arrangement of budget.

- **Defects** –Any defects in construction process will bring a series of negative effects. Materials are wasted when construction errors occurred, according to this; labour force must be in needed to make a correction, extra labour force will cause extra budget. Obviously, defects will cause a series of drawbacks.

- **Excess Motion** – According to the Transportation, Excess Motion is a close distance movements of inventory. Although close distance movements transportation fee did not cost too much, it can bring other problems. Extra motion will influence the order of workflow, need extra person to guard and make an arrangement. (Ohno in Kilpatrick, 2003)

The NIST Manufacturing Extension Partnership recently surveyed forty of their clients who had implemented Lean Manufacturing. Typical improvements were reported as follows (Kilpatrick, 2003):

- Cycle time reduced by 90%
- Productivity increased by 50%
- Work-In-Process Inventory reduced by 80%
- Quality improved by 80%
- Space Utilization reduced by 75%

3.1.3 Lean principles

Five lean principles described by Womack and Jonas (1996) apply to any organization. The principles are:

-Identify Value: To make a clear vision and mission from customers and through negotiate with customers to build a common goal and pursue the jointly value.

-Map Value stream: Through Map Value Stream to clear the task details and identifies the unnecessary steps. To build a common goal with stakeholders can avoid divergence in the later process.

-Create Flow: To create steps by logical order according to the value stream that helps the task finish smoothly by logical flowing. And it is easier to see the defects from the flow.

-Establish Pull: The rational business relation from customer and manufacture is formed through Pull system which is the amount of manufacture produce is according to the customers need.

-Seek Perfection: Pursuing the perfect relation between actors involved and perfect construction result although it is not easy to reach.
(Womack and Jonas (1996) in Forbes and Ahmed, 2011)

Womack defines lean as “doing more with less” by using “the least amount of effort, energy, equipment, time, facility space, materials and capital – while giving the customers exactly what they want”. In modern construction industry, it is popular using lean thinking into practical way.

Compared to conventional manufacturing principles, products manufactured using lean principles have required significantly less resources to produce and have resulted in the following (Technology Century 10/2001)

- Productivity gains of 300-400%
- Labour productivity increased an average of 25% a year.
- Defect rates reduced from more than 2000 to less than 50 parts per million (PPM) and in many to less than 10 PPM.
- Cost of quality cut by over 60%
- Work-in- process inventory slashed by more than 80%
- Revenue per 1000 square feet of factory space was raised 350%
(Iris, 2009)

3.1.4 Lean construction principles

The Construction Industry Institute CII identified five lean principles in their study PT 191:

- Concentrated on clients
- Culture and people
- Workplace organization and standardization
- Elimination of waste
- Continuous improvement and built-in quality

3.2 Theory of Constraint

The Theory of Constraints (TOC) is an overall philosophy developed by Dr. Eliyahu M. Goldratt, usually applied to running and improving an organization. TOC is applied to logically and systematically answer these three questions essential to any process of ongoing improvement: (Mabin, Balderstone, 1999)

- “What to change?”
- “To what to change?”
- “How to cause the change?”

“TOC is more than a set of tools or techniques, though it certainly contains these. It is more fundamentally a paradigm shift which demands that we think about our problems and solutions, our goals and objectives, policies, procedures and measures, in a different way.”(Goldratt, 1998)

W.Dettmer provides an excellent comparison and contrast of TOC and Lean approaches, concluding “TOC provides a useful system- level framework for directing lean thinking efforts where they will do the most good (the system constraint) and avoiding the pitfalls of applying them where they will do harm.”(Leach, 2000)

3.2.1 Constraint analysis

Constraint is a process to resist and hinder to reach the goal, and constraints could happen in every process. That’s kind of obstacle need different areas actors to guild and figure out the solution, including project managers, engineers, schedulers and foremen. Foremen as last planners who are most related to the construction site will know more information from construction site than any other actors. According to this, it is necessary to have a communication between foremen, project managers, engineers and schedulers.

For construction processes to be learn:

- Weekly schedule must be accurate and detailed.
- Completed work must be updated on time.
- Constraints must be identified clear and exact.

(Forbes & Ahmed, 2011)

3.2.2 Critical Chain

1997, Dr. Eliyahu Goldratt introduce theory of constraints into practice in project management called critical chain. Critical chain focus on constraints of a project in order reaches the final goals smoothly.

“As a new methodology for systemic project management considering uncertainties and constraints in the project, critical chain deploys all resources to remove causes and undesirable effect of constraints. The goal of critical chain is to complete the project on time considering a pre-defined budget and scope while optimizing the resources consumption. It must be mentioned that, critical chain is an approach which deems the interaction of algorithmic methods and human influences for successful project management.”(Rabbani, Ghomi, Jolai, Lahijia,2005)

Anything lost in the critical chain could influence a lot since the critical chain is the constraint of a project. The project will behind of the schedule induce the stakeholders cannot acquire the benefit as expected. However, any chance improved from critical chain could help the project finish earlier dramatically. Therefore, using lean principles concentrate on the critical chain is the main task.

3.2.3 Critical Chain Project Management

Critical chain project management (CCPM) is a method of planning and arranging projects that puts the main emphasis on the resources required to execute project tasks. It was developed by Eliyahu M. Goldratt. This is in contrast to the more traditional critical path, which emphasize on the process order and rigid scheduling. A Critical Chain project network will prefer to keep the resources levelly loaded, but will require them to be flexible in their start times and flexible to switch between tasks and task chains to keep the whole project on schedule. (Goldratt, 1997)

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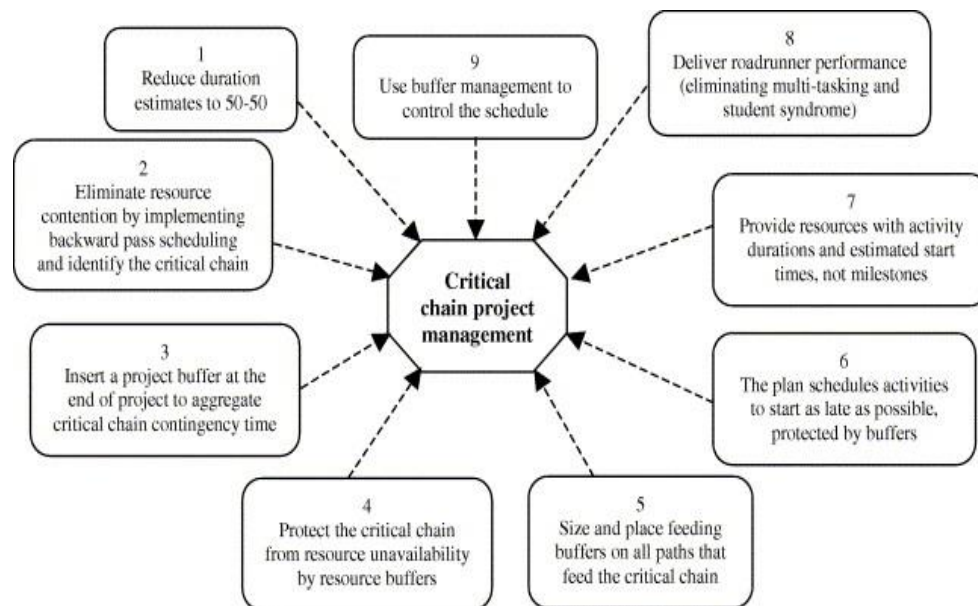


Fig.1. changes in traditional project management system caused by implementing the critical chain approach (Leach, 2000)

3.2.4 Possibilities of practical problems

- When you responsible for one task, first thing is consider how long it will take to finish the task. After consideration you think it will take one week to finish it. Then you think it is much safer if add several days as security consider, in case there are unexpected factors influence the schedule. In order to make sure the task can be finished on time without interruption you decided the task will take two weeks. Actually one more week is act as a safety backup during two weeks schedule. Building a safety factor for one task schedule is necessary and also a common way to organize the time schedule. However, let's take a close look at things into reality. When we got a safety factor for one task, people will mentally relax and think it is not urgent task. Mentally relax will ease down the physical behaviour. To some extent, safety factor will be waste from people procrastination. This phenomenon is called Student syndrome. It refers to the phenomenon that many people will start to fully apply themselves to a task just at the last possible moment before a deadline. This leads to wasting any buffers built into individual task duration estimates. It was noted by Eliyahu M. Goldratt in his novel titled Critical Chain.(Goldratt,1997)
- In most cases, project should work in a multi-project environment. From customer's perspective, they have a tendency that want their project put into the first level and finish as soon as possible. Sometimes it has to stop the current project instead to begin another one in order to let it not delay too much. Actually, to make several projects overlapped performing will decrease concentration, loss of efficiency, disorder the original project schedule.

-
- There is one phenomenon for project performing. The project manager is not willing to finish project earlier than original plan although it can be finished earlier. One reason for that is the resources are not ready to allocate, the labor force cannot arrange on time to match the earlier finishing. On the contrary, it will bring trouble for next session. Obviously, only improving one session's speed is not enough to enhance the whole project process.

3.2.5 Critical Chain Method & Buffer Management

Critical Chain Method, developed by Dr. Eliyahu M. Goldratt (1997), is a schedule network analysis technique which includes task dependencies, limited resource availability & buffers. "A buffer is a block of time which protects a deliverable from being affected by delays upstream."(Goldratt, 1997)

In CCM, as calculation is based on set of activities in the critical chain, hence estimated finish dates for each activity is not of much use. Also, time gain or delay in an activity is fully passed throughout the chain activities. The internal buffers added to tasks are made explicit and summed up. The summed up value is called project buffer. As per CCPM, project buffer is part of project, hence project schedule keep unchanged even after stripping off all the activity safety margins. And keeping them improves protection against uncertainties. (Vargas, 2009)

Also, 50% probability time estimates are used in calculating the activity durations in CCM instead of traditional 95% probability. Difference between original schedule estimates and new schedule estimates gives the project buffer. In general project scenario, there is 100% chance that activity-wise safety margin get exhausted by poor buffer management. In CCM, pooled project buffer is used as safeguard the entire project & even it is utilized up to 50% allows project completion well within the schedule. (Vargas, 2009)

Kailash Awati and Arati Apte use following figures to describe how to add different type of buffers into the critical chain according to the Goldratt formulated the critical chain method.

- **The Resource Buffer**

"If there is no completion date for a task, how does a successor task performer know when he or she needs to be ready to start work? This problem is handled via a notification process that works as follows: the predecessor task performer notifies successor task performers about expected completion dates on a regular basis. These notifications occur at regular, predetermined intervals. Further, a final confirmation should be given a day or two before task completion so all successor task performers are ready to start work exactly when needed. Goldratt calls this notification process the resource buffer." (Awati, Apte, 2007). It is a

rational way to ensure the timing of task begins and finish is suitable for the project's schedule. There is no wasted time for waiting the gap of activities.

- **The Project Buffer**

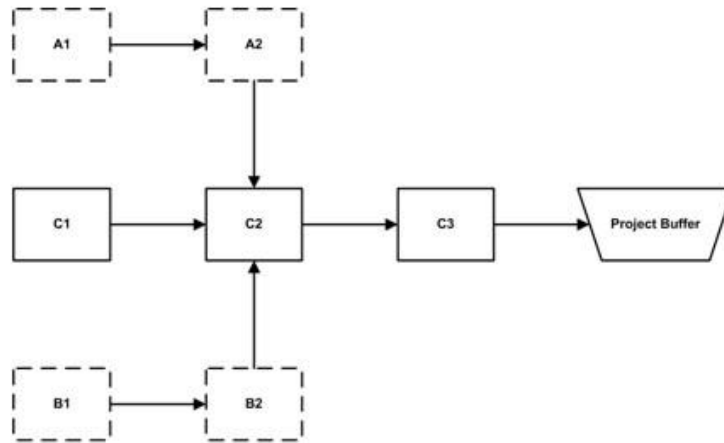


Figure 1: Critical path with project buffer (Source based on Awati,Apte, 2007)

It is reduced activity estimates, removed completion dates for individual tasks and make sure that resources choose tasks when they are in need. Since tasks now only have a 50% chance of completion within the estimated time, it needs to put safety buffer in somewhere and it depends on identifying the constraint in a project is the critical path. Any delay in the critical path necessarily inducing a delay in the project. Obviously, the safety should add somewhere on the critical path. Goldratt's insight was the following: safety should be added to the end of the critical path as a non-activity buffer. He calls this the project buffer. If any particular activity is delayed, the project manager "borrows" time from the project buffer and adds it on to the needed activity. On the other hand, if an activity finishes early, the extra time acquired is added to the project buffer. Figure 1. Depicts a project network diagram with the project buffer added on to the critical path. (C1-C2-C3 in the figure).

- **The Feeding Buffer**

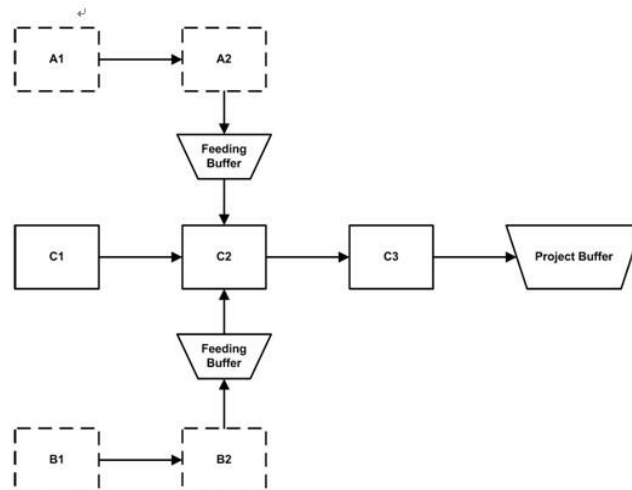


Figure 2: Critical path with project and feeding buffers (Source based on Awati, Apte, 2007)

As shown in Figure 1. The project buffer protects the critical path. However, delays can occur in non-critical paths as well (A1-A2 and B1-B2 in the figure). If non-critical path is contains a lot activities, these delays can affect subsequent critical path. To prevent this from happening, Goldratt suggests adding buffers at points where non-critical paths join the critical path. He calls these feeding buffers. Figure 2 illustrate the same project network diagram as before with feeding buffers added in. Feeding buffers are sized the same way as project buffers are - i.e. based on a fraction of the safety removed from the activities on the relevant (non-critical) path.(Awati & Apte,2007)

The critical chain – general case

In general, the arrangement of steps order is according to the resources. The resource arrangement is depending on the project manager's current projects. If project managers work on multiple tasks simultaneously, the resource arrangement will influence by this factor. It is better to avoided multitasking; however it is common circumstance in the reality construction. The first step is to make resource level the schedule. To make sure the tasks are performed by the same resource by logical order avoiding simultaneously. The use of resource conflict will avoid from making a logical arrangement of resource leveled. This resource leveled critical path is the critical chain.

The above can be illustrated by modifying the example network shown in Figure 3. Assume tasks C1, B2 and A2 (marked X) are performed by the same resources. The resource leveled critical path thus transition from Figure1 and 2 to Figure 3. The critical chain route is in red line starts from C1 and ends up with project buffer.

Notice that the feeding buffers change location, as (by definition) these changed points where non-critical paths connected with the critical path. The location of the project buffer remains unchanged. (Awati,Apte, 2007)

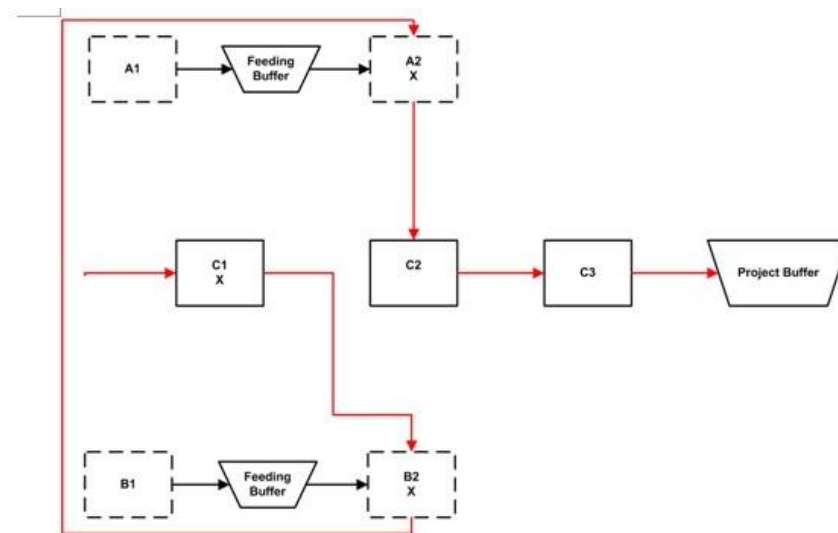


Figure 3: Critical chain (Source based on Awati &Apte 2007)

3.2.6 Developing the Critical Chain Plan

Chesapeake Consulting Inc. summarizes the technical aspects of applying the *Theory of Constraints* (TOC) to project management according to the book *Critical Chain* by Eli Goldratt.

- Identify the project's constraint.

In general, the critical path is the longest chain of the project; it contains time and construction steps. Obviously, time and construction steps are the two primary factors to forming a critical chain.

- Exploit the project's constraint.

It is important to decrease any lost time in the critical chain, and optimizing any gains during the critical chain. Generally a project manager and team identify the tasks to be finished and the expected time to complete each task. Then they add the times on each path, identify the critical path, and add the critical path time to the expected start date to determine the expected complete date.

- Subordinate other elements to project are constraint.

The next step in this process is to subordinate all other activities (decisions, policies, objective circumstances and etc.) to the maintaining and/or improving of the critical chain schedule.

- Elevate the project's constraint

The next step in the process is to elevate the constraint, i.e. reduce the length of the critical chain. Based on this definition, it summarized as followed:

- Reduce the number of dependent tasks
- Reduce the time to perform tasks
- Reduce number of dependencies caused by common resources

-
- Do not allow Student syndrome to become the system's constraint. If in the previous steps the constraint is broken, go back to Step 1.

Be sure a critical chain is not prolonging with some factors, such as invalid policies, rules or unsure certainties.

3.3 Last Planner System (LPS)

The main tool of Lean construction planning is the Last Planner System (LPS). The intention of the LPS is to establish a better coordinated and earlier process design similar to manufacturing, where process design is usually finalized before the manufacturing process starts. The LPS is a tool used to transmit planning responsibility towards foremen and field personal. Last planner is a method trying to systematically reduce waste in construction, by preparing all the designs, permits and other resources before execution. Several manufacturing techniques have been tried out to speed up on site construction work up like: 5S, Kanban, Kaizen events, quick setup/changeover, Poka Yoke, Visual Control and Five Whys, and TQM.(Ballard,2000)

Flow variability greatly influences lean practices, as a delay in work completion by one trade directly affects the following activities of the next session. The lean planner system uses lean methods to provide improved project control. In fact, the last planner is in the most important process to match labour and material resources in order to fulfil assignments in response to downstream demand. The last planner system technique as refined by Ballard (2000) decentralizes decisions and empowers to foremen that are in direct contract with the work to plan and schedule detailed tasks instead of following the superior instructions for each of the tiny procedures ; in effect, they become the last planner. Foreman is empowered; they have a power to reject assignments that fail to meet agreed criteria (Howell, 1999).

“The last planner technique for scheduling is effective because it focuses on a short-time horizon so it becomes a technique for continuous production.”(Forbes & Ahmed, 2011)

Principles:

- Assumption: construction project schedule is really forecasts; on the other hand forecasts cannot be accurate.
- Planning is more detailed and appoints closer one gets to do the work.
- Constraints should be identified and coped with by a team effort.
- Construction team members should be high related and trustworthy.

- Plan failures/breakdowns should be treated as an opportunity for learning, not for negative actions. To create an environment shares the mistakes and experiences. (Forbes & Ahmed.2011)

3.4 Problems of the construction supply chains

Much research work and real test cases analyses have assessed that construction is ineffective and many problems can be observed. Analysis of these problems has shown that a major part of them are supply chain problems, originating at the interfaces of different parties or functions, as represented in Figure 4, among which:

- **Client/design interface**

It is not easy to reach the client's preference and wishes. It is common that design part changed several time because of the client's requirements.

- **Design/engineering& technique interface:**

Incorrect documents, design changes, calculate mistakes, challenge of new techniques and etc.

- **Engineering/purchasing & installation interface**

Inaccurate data, engineering drawings not fitting the use, material does not fit the criteria and etc.

- **Purchasing & preparation/suppliers interface and purchase & preparation/subcontractors interface:**

Inaccurate data, information needs not met, adversarial bargaining and subcontractors change.

- **Suppliers/subcontractors interface and suppliers/site interface**

Delivery is not followed by planning, wrong and defective deliveries; long storage period, awkward packing, and large shipments; back and forth transport.

- **Subcontractors/site interface:**

Subcontracted work does not meet the original plan; construction site condition cannot meet the design condition.

- **Site/completion of building interface:**

Divergence occurred in handing over part because of different criteria. (Vrijhoef, 2001)

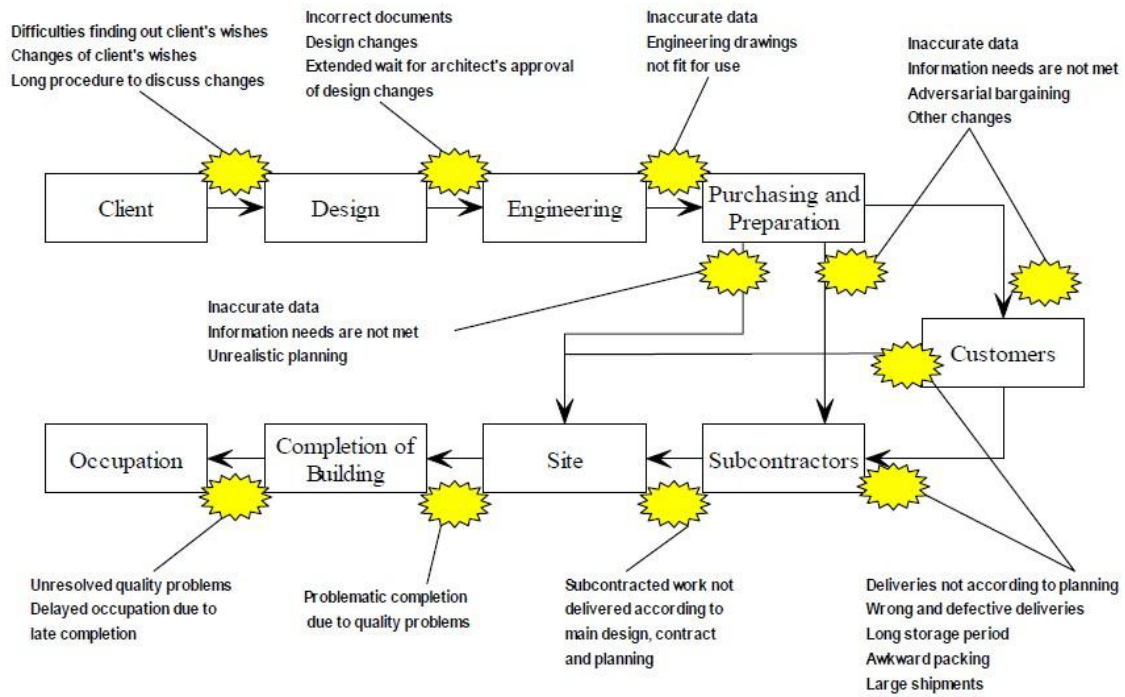


Figure 4, Generic problems in the construction process (Vrijhoef, 2001)

3.5 Supply chain management

Handfield and Nichols defined generic supply chain and supply chain management; they think the supply chain encompasses all organisations and activities related with the flow and transformation of goods from the raw materials stage to the final customer, as well as the associated information flows. These materials and information flow cycle formed the supply chain. While, supply chain management is the integration and management of supply chain organisations and through building integrated organisational relationships, effective business processes, and high levels of information sharing to create high-performing value systems that provide actors in organisations a sustainable competitive advantage. (Handfield and Nichols ,2002)

3.5.1 Definition of Supply chain

The term “supply chain” contains several interdependent steps of activities, including order of process and overlapping process as well as flows between them, supported by infrastructure (people, equipment, building, software, etc.) These flows illustrate a real or forecast customer need going in one way, and supply going in the other way in order to fulfil that demand. (Tommelein, Ballard, and Kaminsky, 2009)

Lambert and Cooper (2000) suggest that a supply chain is not a chain of business with one-to-one, business-to-business relationships, but a network controlling diverse businesses and relationships. Similarly, the supply chain of construction projects usually consists of a network of multiple business and multiple relationships. The management of diverse relationships is important for the quality, budget, and transport of products and services (Olander and Landin. 2005). Furthermore,

customers and suppliers must be integrated in the supply chain to make sure the continuity of the process.

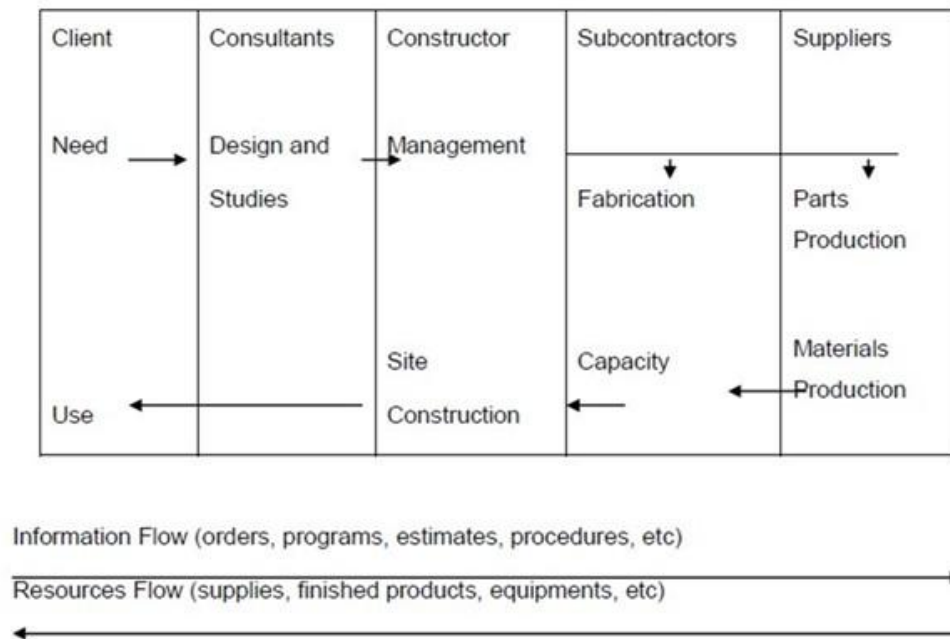


Figure 5, Model of supply chain in construction (Source based on Koskela, 1999, Model of Supply Chain in Construction)

From the above figure, it is showed that there must be several supply chains existing in construction projects, because different clients have different requirements and expectations and different projects also have their own characteristics. The purpose of incorporating the principles of supply chain management in construction is to obtain competitive and comparative advantages through value creation, cost reduction and the integration of all the parties in the construction process, with the goal of meeting the clients need for both internal and external way. (Koskela, 1992.)

3.5.2 Supply chain management

This section illustrates how supply complexity impacts production systems in construction generating waste and potentially influences the date of project completion. Uncertainties are existing construction industry in vary factors accordingly with the complexity of each project. “Supply chain management is the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole.”(Christopher, 1992 cited by Hong-Minh 2002).

Tommelein (2003) performed an extensive study about supply chain practices in the U.S. construction industry. This study defines Supply Chain Management (SCM) as “the practice of a group of companies and individuals working collaboratively in a

network of interrelated processes structured to best satisfy end customer needs while rewarding all members of the chain”. The definition explained Supply Chain (SC) as an organization to working collaborated within a network of interrelated processes. (Arbulu and Ballard, 2004)

Supply chain management is about managing the flows by rational and logical order to arrange cash flow, information flow and physical production flow that meet the client’s need as a final goal.

Sterzi also argue that supply chain management can be achieved as the development of techniques and methods that enable a company acquire a competitive advantage. In fact, it performs integration and managerial improvement of the whole supply chain through a close collaboration between the focal companies with suppliers. (Sterzi, Isatto, and Formoso, 2007)

Figure6. Illustrates the general directions of these flows. Demand and supply flow in opposite directions but may follow different routes. Information flows both ways. Products and services also may flow both ways.

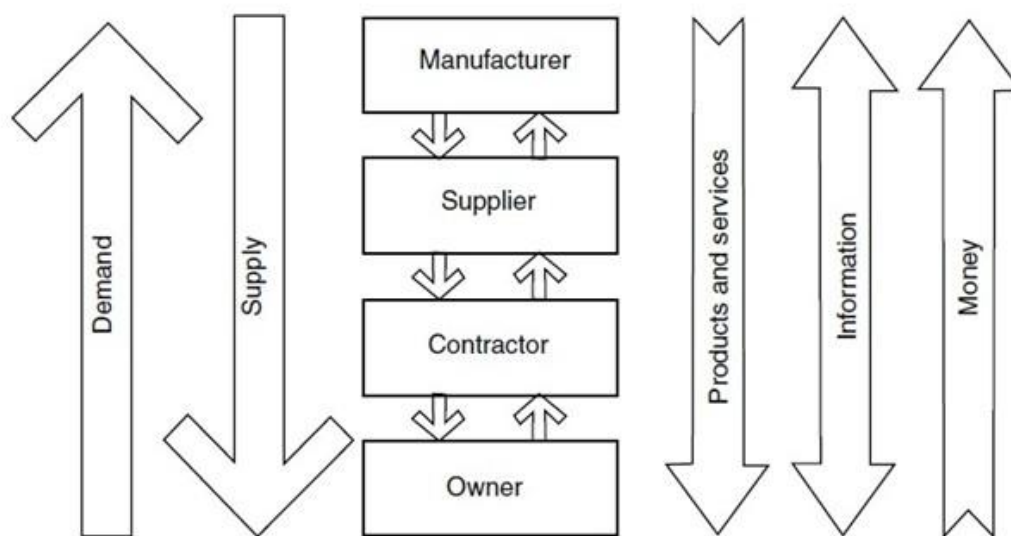


Figure 6, Example of supply and demand with flow of products/services, information, and money in a supply chain. (Source based on Forbes & Ahmed, 2011)

3.6 Relationships in supply chain

During the supply chain circle, many actors get involved and influence the chain, such as designer, contractor, sub-contractor, supplier, and sub-supplier. Their related each other with their own profits. Building good relationship can help the supply chain developed positively.

Negative relationships between subcontractors result in poor project performance. Site arrangement, schedule predictability, cost estimate, material transportation are key performance indicators that show if project performance is good or bad. The correlation of these key factors illustrate that they are substantially related within the relationship during construction supply chain.

3.6.1 Relationship in main-contractor and sub-contractor

Subcontractors and suppliers are playing an increasingly important role in project construction. The result of this increased involvement is that main contractors are increasingly concentrating their efforts on managing subcontractors rather than performing their main responsible.

Manufacturing commentators have recognised the positive impact closer working relationships with suppliers can have on product quality (Womack & Jones, 1996) whilst construction industry commentators prone to the use of partnering to improve relationships (Latham, 1994; Egan, 1998; CII, 1991). However, most work undertaken in construction partnering has been largely main contractor (MC)-client based, compared with little or no mention of adopting partnering with subcontractors.

The main contractor that initiated this study believed that in order to perform effective productivity it had to work more closely with its sub-contractors and develop closer working relationships. The main contractor developed a research strategy in order to create an environment on site where it can be seen obviously that sub-contractors perform more effectively in meeting customer needs, than they can when working on sites of other main contractors. (Matthews, Pellew, Phua and Rowlinson, 2000)

According to Nobbs (1993) the contribution of Sub-contractors to the total construction process can account for as much as 90 per cent of the total value of a construction project. He suggested that the increased involvement of SCs in the transition from the traditional craft-base has induced a greater relay on increasingly sophisticated technological based products, which has led to main contractors concentrating their efforts on managing site operations rather than employing direct labor to undertake construction work. (Humphreys, Matthews, Kumaraswamy, 2003)

As main contractors have realized that the greatest potential for cost savings lies with sub-contractors, the prevalence of unfair contract conditions, subcontract auctioning and other onerous practices has increased (Matthews, 1996). Many sub-contractors do not have the necessary aptitude to undertake work satisfactorily and, as a consequence, are unable to give their clients the service they expected and many of the undesirable traits common to the MC-SC relationship are also common to the SC-sub SC relationship. (Matthews, Pellew, Phua and Rowlinson, 2000)

3.6.2 Relationship in suppliers

In construction project commonly exists the adversarial standpoint between main contractors and their suppliers. Temporary contract negative influence the long-term relationships between main contractors and suppliers are an ordinary thing. (Beil, 2009)

One of the key tasks for procurement is to choose proper suppliers. A selection criterion is to make sure the suppliers quality, including the suppliers capabilities, reputation and culture, not only focus on the lowest price. Choosing the lowest cost for each supplier cannot guarantee the lowest cost for the whole value stream. On the contrary, more suppliers get involved in the supplier chain will higher the budget and risks instead. For this point of view, to acquire positive supply chain cycle requires mutual trust and respect between owners, project manager, contractor, and sub-contractor and material suppliers. Obviously, strategic relationship is the pre-requisites for supply chain system. (Beil, 2009)

Key to timing production scheduling is the delivery of materials needed to produce a finished manufactured product or to deliver a service. This requires a close relationship with suppliers, involved in part by allocating most of a firm's business to one or just a few suppliers that can be trusted to perform deliveries without failure. There are two purposes that choose only one or a few suppliers get involved:

- (1) The amount of business with the supplier will make the lean firm a dominant customer, which in turn can demand greater respect and service.
- (2) It saves time to do the paper work and unnecessary waste of time dealing with large numbers of suppliers. (Schniederjans, 2009)

Supplier relation principles

-Seek single- source suppliers

Choosing a single-source supplier can save time and effort to manage multiple suppliers and can add great pressure to force suppliers reducing the cost of goods.

-Seek long-term relationships with suppliers

Keeping a long-term good relationship with a supplier to know they can depend on the business of the manufacturer, which in turn allows them to better customize service to the manufacturer. It also helps the supplier to reduce the cost of budget, since bank financing it easier for them when they have a major, long-term client. (Schniederjans, 2009)

3.6.3 Comparison between traditional construction supply system and innovative construction supply chain

Derek Walker is Professor of Project Management at RMIT University and Steve Rowlinson is Professor in the Department of Real Estate and Construction at the University of Hong Kong describe their view of procurement in Procurement System from the stakeholder perspective and make a comparison between traditional supply system and innovative construction procurement.

Traditionally, supply process in construction is pursuing to the lowest price for each product and other budget (e.g. transportation, operation fee). The most important part of traditional supply system is how to perform business transaction with suppliers through price comparison among suppliers competition, then choose the lowest price competitor as a co-operator. Although the quality of materials and date of delivery are important factors during procurement process, under traditional procurement model, they prefer putting price negotiation at first step instead of examine the material quality and date of delivery. Obviously; commercial thinking is the decisive reason to choose how supply systems are final consideration. Actually, it is not wise to pursue immediate interests. The final goal is acquiring continuous flow and cooperation to deliver the maximum value to the customer.

- **Traditional supply systems in construction**

Procurement can be the key section in supply systems. Better understanding of supply dynamics procedure and complexity which will make explicit that supply can and should be controlled.

The traditional form of procurement is where the designer does not have direct link with the specialist and all communication is through the main contractor who in many cases will not accept design liability. This results in a grey area of responsibility and liability as information is passed from one to the other. In general, the designer or the architect is the leader of the project and represents the client to implement the design process. The architect becomes having the certain power and takes on the responsibility to make sure the project is delivered on time and within the budget. The traditional method of procurement, the client appoints independent consultants, on a fee basis, who fully design the project and prepare tender documents upon which competitive bids, often on lump sum basis, are obtained from contractors. (Walke & Rowlinson, 2008)

- **Innovative Construction Procurement**

The difference of innovative construction approach is that gives client opportunity to get involved in the process to make a decision in the design part. The client requires having strong leadership to direct an effective team in order to achieve the final goal. Innovative procurement prefers long-term cooperate relationship and keep the organization diversity and complexity in order to fulfil the different client's needs. In this type of procurement, manufacturers get direct involvement, including design phase, budget and logistics. Obviously, the manufacturer and the main contractors

will build a tight relationship during transportation and installation process. (Walke & Rowlinson, 2008)

The decision making process in the innovative construction procurement differs from the traditional in a way. Firstly, key decisions need to be made in the early procurement process in order to avoid expensive alteration to the design. Decisions also need to be made according to the environmental implication and on site related benefits in order to decrease its impact on neighboring properties and site traffic. The effects of transportation logistics on budget and sizes and on the inter-relationships of modules also need to be taken into account in the decision making process. It is important to note that because this system of procurement mainly according to the prefabrication process, therefore the initial space planning, subsequent detailed design, installation are inter-related. The design needs to be completed finished prior to the commencement of manufacturing.

The characteristics of innovative construction procurement keep diverse and flexible in order to fulfil the different client's need. For example, developers are more preferring turnkey contract in design phase, manufacture phase and erection services. Some clients prefer to appoint an architect to responsible in whole design process. Then the appointed architect make a preliminary work with a design team and modular manufacturers, which is used as an foundation for tendering, either by a main contractor or modular specialist directly. (Walke & Rowlinson, 2008)

3.7 Partnering in the construction supply chain

“Partnering is the formation of a project team to deliver a construction project; the team commits to open communication in a spirit of trust, and works to accomplish mutual project goals. While the team members work supportively to meet mutual goals, they also focus on their individual goals. Yet, they recognize that their individual success is linked to the overall success of a project.” (Forbes & Ahmed, 2011)

Partnering has become an increasingly popular form to management organization. Essentially the relationship is based on trust, dedication to common goals, and an understanding of each other's individual expectations and values. (Matthews, Pellew, Phua and Rowlinson, 2000). Compared with traditional construction supply system, using partnering concept into supply chain increase the collaboration within the project, different parties sharing the same value and goals to strength the relationship.

Traditionally, the architect is the first supplier to be involved in the construction process. However, other suppliers are increasingly becoming involved earlier (Kamara & Anumba, 2000). This upstream participation in the construction process

has led to changes in the management of the buyer-supplier relationship, with a tendency towards the establishment of partnerships. (Twigg 1998; Emmitt, 2007)

The basic principle of supply chain management and partnering model is collaboration, share resources and information and mutual trust as a foundation to pursue common goals and achieve win-win solution.

Strategic alliances help the project manager to control workflows and activities on site. In addition, the ease of communication between the project manager and the suppliers enhances the ease of negotiation that provides flexibility in terms of delivery on demand and change of orders. (Pheng, Fang, 2005)

4. Discussion

Comparing with the past years construction industry, modern construction industry increasingly focus on the scientific production procedure. In terms of scientific order, those theories mentioned before can be seen as a guideline to help project manager to find a right direct.

Firstly, Lean as a concept that can help project managers to make an elimination of waste. Such as items' overproduction, extra movement of equipment, extra inventory and non-value-added-process, those sections are always caused extra budget and unexpected time-consuming accidents. With that in mind, as a project manager should have an ability to identify the waste section and try to avoid and eliminate.

Secondly, according to Goldratt's Theory of Constraints develop the Critical Chain Plan. In general case, the critical path is the longest chain of the project that including all the important construction sections. Then project managers add the critical path time to the expected start date to determine the expected complete date. A general time plan will form from critical path.

Last but not least, after having a critical path, three different type of buffers (Project buffer, resource buffer and feeding buffer) need to be added into the critical path in order to make sure the schedule not delay by unexpected activities. Those three buffers have specific positions to add according to their different functions. Project buffer protects the critical path, so always add at the end of critical path. Resource buffer is more flexible, depending on the part of resource need. The feeding buffer always adds between non-critical path join the critical path.

Last planner system as a tool cooperated with those three steps. It transmits the responsibility from project managers to foremen and field person. That can be created a quick respond to an unexpected accident.

Supply chain management is about managing the flows by rational and logical order to arrange cash flow, information flow and physical production flow that meet the client's need as a final goal. It seems like a macro-strategy management ideology, and is responsible for the whole chain management, including all the parties involved in the construction process. On the contrary, partnering is a micro-cooperate model in project management. The target group of partnering is main parties, such as owner, contractor, sub-contractor, consultant organization, and Design Company and material suppliers. The mainly task of partnering is reaching the common goal in order to get profits for all parties at the same time.

4.1 Limitations

It is clear to know what lean construction supply chain is through theoretical research. In supply chain process, "lean" act as a requirement to narrow down the research objective. Theory of Constraints, Lean Principles, Supply Chain Management, Partnering and Last Planner System are the theoretical foundation to illustrate and analyze the construction supply chain. When use "lean" implementation part, it exists several limitations influence the results:

- Subcontractors involved in the early stage will reduce the effectiveness of the general contractor. Putting the main actors in the early stage it strengthens the relation build and the chain collaboration. However, it is difficult to make a final decision if too much information absorbed. How to manage the actors performed at the right time can be a challenge.
- It is difficult to choose qualified subcontractors with experiences in lean construction supply chain. To a large extent, effective lean implementation is depends on the attitude of subcontractors performing and project participants' persistence and trustworthy. A good "lean" performer can bring enormous beneficial to a project.
- Lean construction supply chain can be beneficial to large and complicated project. The strength of lean construction supply chain cannot obvious represent in small and simple projects.
- Lean supply chain as a solution needs extra training to implement.

Through making a combination of those theories, there are some suggestions to lean construction supply chain:

- Selected fewer and competitive suppliers and subcontractors work collaborate with main contractors. Minimizing the number involved in supply chain and makes long-term contracts with those competitive project participants.

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- To make sure the main project actors get early involvement that mutual goals and value can be build in the early phase.
 - Reducing non value-adding activities, compress the supply cycle time.
 - Building continuous improvements into supply chain process. Any kinds of effort makes improvement should be assessed and encouraged. On the contrary, any mistakes are made should be documented and punished to ensure the same mistake will not repeat.
 - Encourage the supply chain members to share their experience, suggestions, and past failure examples which can potentially improve the members relationships and enhance the collaboration within the chain. Building strong in-house relationships can improve collaborative environment more than only pursuing value.
 - Optimize the project, not the pieces. Sutter Health says “project work is messy. Projects get messier and spin out of control when contracts and project practices push every activity manager to press for speed and lowest cost. Pushing for high productivity at the task level may maximize local performance but it reduces the predictable release of work downstream, increase project durations, complicates coordination, and reduces trust.” Controlling the supply chain from a holistic view, not only focus on one session’s procedure.
 - Decentralized decision making for certain actors in order to minimize the process steps and give a quick response, increasing information flow and workflow at the same time.
 - Transparency of budget. The elimination of waste in supply chain processes require a clear cash flow to make sure decisions on customer value can be taken. Supply chain budget and cash flows must be addressed, which helps project manager to find the unreliable problems and give a quick respond.

5. Conclusion

The aim of the thesis is to improve the management of supply systems in construction industry by using a combination with lean into construction supply chain. Partnering can be effectively incorporated into the construction process which has lean supply chain as its objective. Successful implementation of lean construction supply chain will require a holistic view that included not only shorten one session of the supply chain but also integrating every parts and actors as a whole. To reach this strategy, Partnering system needs to be built in order to reach a positive relationship based on mutual understanding and trust.

5.1 Research questions

Q1: What are the reasons for safety buffers being wasted?

Buffer is a block of time which protects a deliverable from being affected by delays upstream. (Abel, 2008). The reason of inducing the buffers being wasted can be diverse. Here are top three reasons I concentrate on:

- The student syndrome

Waiting till the last minute to start because the resource knows he/she has plenty of time due to all the safety he/she included, that lead to wasting buffer.

- Multitasking

A resource has several tasks for various projects to complete and try to work on them simultaneously, thereby increasing the schedule of critical path for a specific task. Several project overlapped performing will decrease concentration and loss efficiency.

- Avoiding finish earlier

The project manager is not willing to finish project earlier than original plan although it can be finished earlier. Certain objective factors did not prepare well, such as the resources, labor force. So, the project managers are avoiding finish earlier than scheduled.

Q2: How to improve lean construction supply chain?

-A reduced proportion of non-value-adding activities, compressing the supply cycle time.

-Fewer and better quality suppliers and subcontractors

-Main participants get early involvement that mutual goals and value can be built in the early stage.

-Optimizing the whole process not only concentrate individually.

-Encourage participants to share their experiences, suggestions and past failure examples.

5.2 Recommendations

The implementation of lean construction supply chain is challenging for project manager. Based on the findings of the thesis, the following recommendations for project managers are submitted to support lean construction supply chain improvement.

- Lean supply chain need to be supported and developed for subcontractors. The lean concept and principle may be not easy for accepting for subcontractors.

Training subcontractor in practice way instead of concept learning seems more wisdom.

- Construction supply chain system will occur problems when subcontractors' lack of involvement or insufficient planning. To avoid this, continuously improvement of supply chain management to make sure consistency of every section is followed by right track. The effort to build continuous improvement into the construction process is to reduce waste during the critical path and carry out value-adding activities continuously.
- Building long-term relationship with suppliers or sub-contractor. Good relationship with suppliers and sub-contractor is a foundation of cooperation which can help supply chain goes smoothly and makes continuous improvement.
- Hiring lean experts in the early stage as a director can help actors who involved in the project establish strong awareness to implement.
- Decentralized decision making minimizes the steps of information flow and work flow. Putting foremen in the right positions and give their certain rights to make decisions. Waiting time for decisions to pass through the layers of organization structure impedes the workflow. Subsequently, it would delay the other trades that follow the activities (Pheng, Fang, 2005).

5.3 Proposal for further research

How effective about construction supply chain's performance is depending on how much extent of "Lean" used into "Chain" in practical way. Problems, theories, solutions were highlighted in the report. However, research needs to be continued about chain development, in order to make continuous and long-term improvements to meet the client's satisfactions from investments and stakeholder's continuous profits. Furthermore, lean construction supply chain has its limitations. It cannot perform well in certain small-sized and simple projects. How to implement this strategy widely use in construction process still need to develop and practical experience to direct.

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