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Towards Operational Hedging for Logistics Uncertainty Management in Prefabrication Construction

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Abstract: Current years, prefabrication construction has been widely used in the building industry, from which large number of uncertainties exist and may greatly influence the quality and efficiency. This paper proposes a vision of operational hedging to address these uncertainties. Main focus is placed upon prefab factory, prefab logistics, and on-site assembly which are three key phases in a prefabrication project. Several hedging strategies such as lead-time hedging, space hedging, and L+S hedging are introduced. A demonstrative case from Hong Kong Housing Authority is presented for explaining how these strategies are used for different decision makers to cooperate so as to improve the quality and efficiency of operational executions. This paper opens an area in where hedging methodologies, models, solution algorithms, as well as practical cases could be further studied in other area.

Keywords: prefabrication construction, supply chain, operational hedging strategy, logistics uncertainty.

1. INTRODUCATION

In recent decades, there is a growing tendency to use prefabs in the building industry. Especially in the dense urban area such as Hong Kong, the number of prefabrication house increased dramatically since 2001 (Jaillon et al., 2009).Prefabs are parts of the finial installations which are made of different kinds of materials and can be assembled directly on-site (Jaillon, Poon, & Chiang, 2009). Many researchers had unveiled the strengths toward applying prefabrication technology (Ho, 2001; Tam, Tam, Zeng, & Ng, 2007). Five major benefits can be summarized towards using prefabs other than traditional building methods. Firstly, the overall material cost can be reduced. Secondly, the duration of construction process can be shortened since prefabs can be assembled directly instead of going through the time consuming concrete pouring process. Thirdly, the quality of building materials can get better supervised and examined at the first stage. Fourthly, no value added activities such as deposit by-products which is generated from cast in-situ and other material wastage derived from plastering, rebar fixing, tilling and so forth can be reduced by and large. Fifthly, construction waste can be largely reduced up to 84.7%.

However, even lots of benefits can be brought from using prefab, the delivery of prefab is far from satisfactory. According to previous surveys, logistics uncertainties which derives from shortage of materials, equipment, delays in subcontractor's work, transportation delay and etc. are the major cause which leads to time and cost overrun of the construction projects (Assaf & Al-Hejji, 2006; Chan & Kumaraswamy, 1997). In addition, different from the traditional building process， the prefabrication components are casted off-site and will be delivered from the factory to the construction site. Taking Hong Kong for example, the prefabs are transported from PRD region to the Hong Kong construction site and cost for cross-border logistics takes up to 15-20% of the total prefabrication production cost. If prefabs are delivered later than the actual due date, the on-site assembly process will stop and wait and thus the penalty for working hour loss will occur. Additionally, cost for rescheduling will also incur. On this account, it is justifiable to pay considerable attention to the reliability of the prefab logistics process, since there is good potential for saving time and money.

There are three main phases in the prefab supply chain: the prefab factory, logistics and the finial construction site and uncertainties derive from the involved processes. The uncertainties include machine breakdown, lack of materials in the producing process traffic jam and low efficiency of custom clearance in the shipping process, and prefab damage in the assembling process. All of these unfavourable factors are the root of time and cost overrun in the construction project. Thus, the main thrust of this paper is to propose some methods to mitigate uncertainties among the prefab supply chain, so as to take advantages of using prefabs. In this paper, supply chain uncertainty and logistics uncertainty are quoted interchangeable to describe aforementioned uncertainties.

Since the time and money savings from adopting prefabrication technology will be easily wither away due to unreliable logistics process, a growing number of researcher have focused on ways to mitigate logistics uncertainties that cause delivery failure (Pheng & Chuan, 2001). Previous researchers have summarized several approaches to mitigate supply chain uncertainties, i.e. improvement of supply chain visibility, dual sourcing, transshipping, holding safety stock and etc. (Jüttner, Peck, & Christopher, 2003; Miller, 1992; Van Mieghem, 2003). However, due to the featured characteristics in prefab supply chain, some uncertainty mitigating methods are inadequate for solving all the issues For example, prefabs are not common products and thus

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cannot be produced in advance, transhipped, dual sourced and etc. In contrast, the prefab supply chain is relatively fixed and unchangeable once scheduled. According to Van Mieghem (2003), operational hedging, also called natural hedging, which involves a set of counterbalance actions i.e. routing, holding safety stocks, having warranty guarantees, etc. to enhance the reliability of supply chain. Since prefabs are special components that cannot be replaced by other products, enhancing the reliability of supply chain is more efficient way to hedge against logistics uncertainties. In this paper, we provides a vision of using operation hedging to mitigate logistics uncertainties so as to improve the entire efficiency and collaborative work within supply chain management in prefabrication construction.

The rest of this paper is organized as follows. Section 2 discusses the uncertainty of prefabrication logistics in three major phases: prefab factory, logistics, and construction site. Section 3 proposes a vision of operational hedging-based logistics uncertainty management under the research background. Section 4 gives a demonstrative case from Hong Kong to present the feasibility and practicality of the proposed strategies to improve the quality and efficiency of the construction project. Section 4 concludes this paper by providing our contributions and future research directions.

2. UNCERTAINTY IN PREFABRICATION LOGISTICS

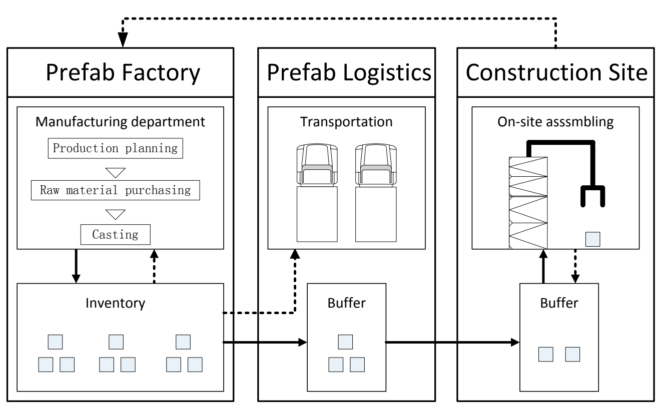

Fig. 1. The Prefab Supply Chain

Figure 1 shows the prefab supply chain. In this figure, we can see that there are three departments get involved, the prefab factory, logistics provider and the finial construction site. The prefab factory shoulders the responsibility to produce prefabs according to the on-site schedule and delivers the finished prefab to the construction site. In practice, in order to focus on its core competencies (Cheong, 2004), the prefab factory always outsources its logistics function to a third-party logistics (3PL). A 3PL company provides shipping and warehousing services. And the finial construction site assembles prefabs by crane tower. The dashed line in figure 1 shows material flow, while the dotted line represents the information flow.

With the optimal goals, the prefabs should be delivered in a just-in-time (JIT) manner that is right material arrive at right quantity, at right time and at right place. Unfortunately, there are lots of uncertainties exist in the prefab supply chain that hamper the JIT delivery. Consequently, the on-site assembly processes have to stop and wait. Supply chain uncertainties are derived from material flow, financial flow and information flow. Especially, logistics related uncertainties derives from operational risk and disruption risk (Tang, 2006). The operational risk are caused by inherent uncertainties such as demand uncertainty, supply uncertainty, price uncertainty and so forth, while the disruption uncertainties are relative more serious which are caused by natural or man-made disasters, such as flood, earthquakes, terrorist attacks and etc. It is challenging for the manager to figure out potential uncertainties and find corresponding efficient methods to cope with them. In this paper, the focus will be placed upon operation risks. According to above mentioned department in the prefab supply chain, uncertainties can be categorized as follow.

Prefab factory: uncertainties from the production process derive from (1) materials uncertainty: shortage of raw materials, material damage and etc. (2) production process uncertainty: machine breakdown, preventive maintenance, bad weather condition, festival season, disruption and etc. (3) crew uncertainty: lack of crew, worker strike, unskilful workers and etc.

Logistics: uncertainties from the logistics process derive from (1) transportation facility uncertainty: lack of specially trailers, trailer breakdown and etc. (2) transportation process: traffic jam, bad weather condition, low efficiency of custom clearance, accident, re-routing, disruption and etc. (3) crew uncertainty: lack of driver, unskilful driver and etc.

Construction site: uncertainties from the on-site assembly process derive from (1) material uncertainty: tardiness delivery of prefabs, lack of other building material and etc. (2) assembly process uncertainty: damage, accident, wrong operation, crane tower breakdown and etc. (3) crew uncertainty: lack of worker, unskilful worker and etc.

Any disturbance at any point will impact the performance of the entire supply chain. This problem is extremely serious in the prefabrication construction because prefabs are large, thus the bulky items should be hoisted by expensive crane. Penalty for working hour loss will occur and rescheduling cost which comes from express delivery and rearrangement will also incur. On this account, it is justifiable to pay more attention to the proper uncertainty management in prefab supply chain, for there are great potential to save money and time.

3. VISION OF OPERATIONAL HEDGING-BASED LOGISTICS UNCERTAINTY MANAGEMENT

Recently, a growing number of researchers pay closer attentions to the methods that mitigate uncertainty, for these unfavourable factors that directly impact company's continuity (Jüttner, Peck, & Christopher, 2003). There are two major concepts to mitigate uncertainties, i.e. financial hedging and operational hedging (Miller, 1992). Financial hedging is purchasing insurance in advance to avoid price fluctuation. This hedging instrument is widely used in a global market to hedge against foreign exchange risk. Operational hedging uses strategic or tactic approaches to mitigate uncertainties that a cooperation might incur. There are several ways to categorize operational hedging approaches. Miller (1992) classified different operational hedging approaches into five groups which are avoidance, control, cooperation, imitation and flexibility. Tang (2006) proposed four basic approaches for supply chain risk management (SCRM), i.e. supply management, demand management, production management and information management. These classifications provide general ideas for researchers and managers to design their own strategies. Since different industry has its own characteristics, which strategies is more suitable varies from one to another.

Several characteristics can be summarized in the prefab supply chain. (1) Inflexibility: prefabs are not identical products which can be stocked in advance. The form of prefab should be designed in the first stage and then produced in a production yard, so work-in-process inventory or safety stock of finial products are not suitable for prefabrication technology, since the form cannot be predicted. In this way, multi-sourcing, transhipment cannot be used to mitigate uncertainties in the prefab supply chain. Prefab supplier cannot be easily changed once chosen and none supplementary product can be used for replacement. (2) Expensive: prefabs are expensive compared with the traditional building materials. In addition, prefabs are bulky items that should be hoisted by expensive crane which are rented by days. If late delivery take place, the on-site assembly process will be stopped. Thus, expensive working hour loss will occur. On the contrary, if prefabs are delivered too early, extra space should be rented for storage. The holding cost in construction sites is even high. On this account, passively acceptance of the prefab logistics uncertainty is not wisdom.

According to the aforementioned characteristics, in this paper, we put forward a vision of hedging-based logistics uncertainty management methods to enhance the reliability of prefab supply chain. The principle of hedging it to take counterbalance actions to hedging against uncertainties in the supply chain (Van Mieghem, 2003). The concept of operational hedging in this paper is to make extra investment to enhance the reliability of a logistics process so as to positively mitigate uncertainties. Several kinds of hedging strategies are put forward, i.e. lead-time hedging, space hedging, and the L+S hedging.

Lead-time hedging: The lead-time hedging strategy can be adopted at any department with process uncertainty. In the prefab logistics, the process uncertainties exist in the producing, shipping and assembling echelon. Each process has an expected due date. However, since uncertainties always hamper the JIT delivery of prefabs. The buyer prefers to inform the supplier an earlier due date to buffer against unforeseen events. There are two ways for lead-time hedging. The first one is reducing lead-time length, while another is reducing lead-time variability. Both are referred as 'lead-time hedging strategy' and are reliable in the prefab logistics, since previous studies have pointed out that lead-time can be shortened by a crashing cost (Chang, Ouyang, Wu, & Ho, 2006; Ouyang, Chen, & Chang, 2002). In the production sector, the producing process can be shortened by enhancing order priority, overwork and etc. with an additional crashing money. Also, in the shipping process, the lead-time length and variability can be better controlled though using more reliable transportation service. Therefore, lead-time hedging strategy is feasible and efficient in the prefab logistics.

Space hedging: Another approach proposed in our paper is 'space hedging', since too early and later delivery are both unfavourable. A certain amount of space hedging against upstream uncertainties among the supply chain is important to avoid double handling for either early or later delivery. In the prefab logistics, keeping certain buffer space near the finial construction site is a good choice for the logistics provider, for it is responsible for the late delivery of prefabrication components. Since some previous research have pointed out that buffer acts as a decoupling point which separates the demand side from the supply side and thus provides a more reliable supply chain (Ben Naylor, Naim, & Berry, 1999). Additionally, buffer among the prefab supply chain would help average out the stableness of the supply chain though balancing the good times with uncertain disturbances (Inman, 1993). On this account, reserve proper buffer space is a feasible way to hedge against upstream uncertainties so as to avoid tardiness penalty caused by late delivery, extra holding cost caused by early delivery, and re-handle cost caused by either early or late delivery.

Both aforementioned strategies can be adopted separately or jointly. One thing to be mentioned here is that, even 'hedging' strategies mitigate uncertainties and are favourable for the execution department. However, it impacts the benefit of another department. For example, production lead-time hedging strategy is favourable for the buyer but add more pressure to the prefab factory, for it has to overwork within a shortened time period. In addition, space hedging is preferred for the prefab factory who is regarded to shoulder shipping service by itself but actually outsources to a 3PL, however, it impacts the benefits of a 3PL. Even a traditional 3PL is supposed to provide temporary storage service, holding more in its warehouse leads to low efficiency of warehouse management and congestion. Also, the empty space could be leased out for others with a higher market price. In this way, the conflicts always exist between two departments in the hedging strategy.

One thing to be mentioned here is that, supply chain members are independent entities. So, they will focus on their own profitability (Heydari, 2014). If their interests are conflicting, the optimal decision of individual group will lead to a suboptimal supply chain. On this account, proper coordination mechanisms i.e. revenue sharing, internal charge and etc. are needed to eliminate incentives for participant deriving from the global optimal situation.

4. A DEMONSTRATIVE CASE UNDER PREFABRICATION CONSTRUCTION

This section demonstrates a case from prefabrication construction which has been widely adopted by the Hong

Kong Housing Authority (HKHA) for its public projects. As a major construction client in housing development, HKHA plays a very active and important role in public housing development, especially on quality control, programme monitoring and safety management from the project inception stage up until the substantial completion of the project. In the prefabrication construction, logistics is very critical since the prefab components are produced in Pearl River Delta (PRD) in Guangdong and then moved by trucks to the assembly sites in Hong Kong. Thus, the focus of the demonstrative case will be placed upon three phases: prefabrication production, cross-border logistics, and on-site assembly.

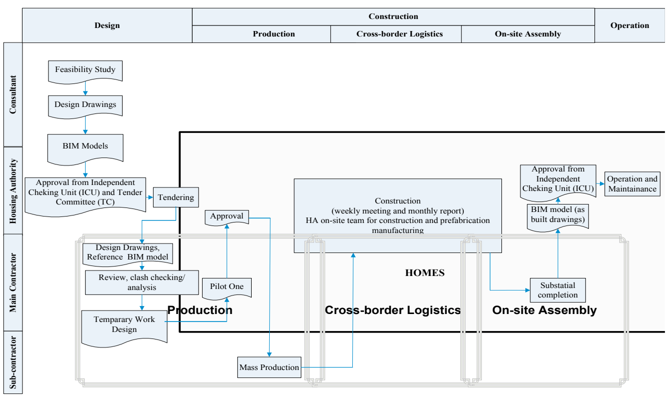

Fig. 2. Typical operations in prefabrication construction.

Fig 2 gives a brief description of typical operations in prefabrication construction in the above three phases:

For precreation production, a contractor should communicate with the prefabrication manufacturer to discuss issues such as clash identification, temporary working and workmanship before put the design into production. Before mass production, a sample called Pilot One for prefabrication component must be produced to ensure quality and that the specifications are met. All construction drawings and updated BIM (Building Information Modelling) models should be approved by the Contract Manager (typically a senior Architect) prior to construction.

For cross-border logistics, the logistics company would deliver the prefabricated components from the yard in Mainland China to the construction site in Hong Kong. This cross-border logistics requires the visibility of logistics status and real time information in order to achieve JIT delivery.

For on-site assembly, an on-site foreman or an assigned operator would check for defects/quality before erection. The results and relevant product information will be recorded and stored. According to the incurred project cost confirmed by Quantity Surveyors (QS), the Contract Manager will issue the monthly payment to the contractor. After substantial completion of the construction project, the construction drawings and as-built BIM models shall be approved by the Contract Manager and the ICU. A Certificate of Practical Completion will then be issued for the project. The detailed process flow and descriptions of the above three phases are provided in the following sections.

Within the phases, there are large numbers of uncertainties which confine the efficiency and effectiveness of prefabrication construction. First of all, disturbances such as machine breakdown, defective materials, mould frame problems, shortage of raw-materials, lack of labors, bad weather like black rain, and unforeseen accidents may greatly influence the prefabrication production. Delay of such production will cause serious tardiness of the construction project. Secondly, in cross-border logistics, uncertainties such as traffic jam, vehicle issues, weather conditions, low efficiency of custom clearance, and space shortage may also seriously affect the project progresses. In one side, the late arrivals of prefab components make a long waiting in assembly sites. In the other side, the earliness of their arrivals is not acceptable since there is no enough space for a long vehicle under limited areas. Thirdly, in on-site assembly, some uncertainties like unforeseen accidents, damage of prefab components, unavailable buffer space, and facility break down will bring negative impacts on construction projects. Therefore, it is necessary to hedge such uncertainties by using different strategies to ensure the reliability and quality of the construction projects.

For the speciality of prefabrication construction in Hong Kong, operational hedging may be suitable for handling these uncertainties. This section proposes a set of hedging strategies for dealing with the uncertainties:

Lead-time hedging is adopted for dealing with the uncertainties in prefabrication manufacturing. When receiving customer orders from assembly sites, production managers in prefabrication manufacturing companies set a lead-time for production orders. The lead-time is arranged for determining the due date of the finished products with several days earlier than that required by the customers. Using this strategy, customer requirements could be ensured when some uncertainties occur. If there are some uncertainties, for example machine break down, there is enough time for the production manager to work out a decision to adjust the prefabrication manufacturing. Thus, the possibility of delay will be avoided, improving the reliability of production and customer satisfaction.

Space hedging is used for handling the uncertainties in prefabrication logistics. When the finished products are ready for shipping, managers from a 3rd-party logistics company will make a transportation plan to determine how much space at which location could be reserved to ensure the prefabrication components could be delivered to the assembly sites in a JIT fashion. Using the space hedging strategy, the prefabrication components could be guaranteed to be moved to the assembly sites, ensuring the progresses of the construction project. For instances, if there is an accident which causes the damage of a prefabrication component, another similar or same item could be used from the space at a closed location which may hold the same or similar items. In this case, the damaged component has enough time for repairing, reworking, or disposal. The space hedging strategy has two perspectives. First is the decision of location. That means where is the space should be located. Second is, once the location is determined, how much space should be reserved for a project. These two perspectives contain several research points such as location optimization, routing problem, space pricing, etc which are interesting with significant merits for prefabrication construction.

L+S (lead-time and space) hedging is integrated for addressing the uncertainties in on-site assembly. This strategy is mainly used in logistics phase which focuses two dimensions. Firstly, the lead-time is used by the logistics managers for hedging the transportation uncertainties. When a logistics manager get a delivery task, he/she will set the date when to move the finished prefabrication components to a reserved location or assembly sites and which kind of transportation service level should be chosen. The date may be slightly earlier than the required from the assembly site, thus, the uncertainties could be hedged in logistics phase. In addition, using reliable transportation service is an effective way to manage lead-time variability which is a major cost of rearrangement. The reason is the required prefabrication components are moved to some places near the assembly sites. When the assembly sites need a certain type of component, it is possible to deliver to specific site in a JIT fashion. Secondly, space hedging is considered by the logistics manager for determining where the location will be arranged and how much space may be reserved for the construction project. The integration of lead-time and space hedging ensure the arrival of prefabrication components in construction sites where final assembly operations will be carried out. L strategy guarantees the delivery of finished prefabrication components could be moved at what time. While the S strategy ensures the prefabrication components could be moved to where so as to meet the assembly requirements from the construction sites.

With the above three strategies, decision makers in prefabrication construction are able to deal with the uncertainties from the operational hedging. There are several significance by using these strategies. In the first place, the logistics uncertainties management in prefabrication construction could be achieved by a reasonable and suitable manner which mainly uses the time and space hedging for reduce the risks and enhance the reliability. Secondly, for different stakeholders in a construction project, they are able to use the strategies to deal with different uncertainties under different situations. Thus, the project progresses and quality could be ensured. Ultimately, the strategies not only streamline the decision-making within the prefabrication manufacturing, logistics, and on-site assembly, not also improve the efficiency and effectiveness of the operations. Therefore, such mode could be extended into other sectors such as manufacturing and E-commerce.

5. CONCLUSIONS

This paper introduces an operational hedging vision for logistics uncertainty management in prefabrication construction, aiming to improve the efficiency and effectiveness of decisions throughout the key stages such as prefabrication manufacturing, prefabrication logistics, and on-site assembly. Several key uncertainties are discussed detailed and a demonstrative case from Hong Kong Housing Authority (HKHA) is presented so that practical industrial is able to use the strategies proposed in this paper, for example, time hedging, space hedging, and L+S hedging to ensure the efficiency of integration of decisions (strategic level) and their executions (operational level).

Several contributions are made. Firstly, uncertainties from different phases are analysed in prefabrication construction. The analysis could be used for guiding different decision-makers to fully understand current conditions which may propose some research questions for academia so as to improve the construction industry profoundly. Secondly, the vision of using operational hedging for logistics uncertainty management in prefabrication construction could provide some opportunities to upgrade and transform the industry by using the time and space hedging strategies, ensuing the quality and smoothness of a construction project. Thirdly, the hedging strategies are very meaningful in prefabrication construction. This paper opens an area in where hedging methodologies, models, solution algorithms, as well as practical cases could be further studied in other area since the limited resources often confine the operational executions. Thus, the social impacts could be extended.

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