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SUPPLY CHAIN AND LOGISTICS: A KEY TO EXECUTING INDUSTRIALISED BUILDING SYSTEM (IBS) IN MALAYSIA

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ABSTRACT

Industrialised building system (IBS) has become a priority in modern construction methods, enhancing building components' quality, speeding up completion time, and reducing construction costs. The building components are manufactured off-site and later assembled on the project site. Therefore, the efficiency of logistics is a crucial element in the supply chain process to ensure the efficient movement of components and information to fulfil demands. This paper discusses how several companies from Japan, the United Kingdom, and Italy successfully improved their process of construction prefabrication components through the adaptation of an efficient and effective supply chain and logistics management concept. Results showed that the lean construction principle was opted for their supply chain and logistics. The element of lean principlse such as just-in-time, kanban, continual improvement (kaizen and last planner), and coordination among both upstream suppliers and downstream customers have initiated successful improvements in their productivity. These successful concepts can be considered in maximising the full potential of an IBS supply chain and logistics management in the future.

Keywords: supply chain management; logistic; lean construction; industrialised housing construction; industrialised building system (IBS)

INTRODUCTION

As a developing country, the rapid growth of the construction industry has become the catalyst of Gross Domestic Product (GDP) by increasing economic activities, government income, investment, and employment (Adnan et al., 2019; Azman et al., 2019; Nawi et al., 2011; Zairul, 2021). This rapid construction is influenced by Malaysia's demand to construct affordable housing to cater to the increasing population growth. The traditional construction method has shifted to Industrialised Building System (IBS) to generate mass production, ready-to-assemble, and standardise product development.

The processes to produce the IBS components are almost identical to those in the manufacturing industry. The supply chain of these modular components involves planning, component design and development, sourcing, manufacturing (fabrication), finishing and touch-up, storage, transportation, assembly, and installation. However, a construction project is unique in its temporary production system, which must be compatible with the proposed physical structure and aligned with the client's project goals.

Inefficient production flow, supply chain and logistics can affect the project completion time, cost overrun, and poor quality of the components. In the survey conducted by Kamar et al. (2012), IBS contractors highlighted site planning and logistics as important factors limiting the use of IBS. Insufficient and late delivery of IBS information, equipment and components on site have been the barriers to the success of IBS implementation. Further research by Azman et al. (2019) and Adnan et al. (2019) supports this claim, adding that cooperation between contractors and the skill of the technical team also contributed to the barrier to a successful implementation of IBS.

Multiple organisations in industrialised housing construction have proven their optimisation efforts and successful techniques in producing either precast concrete components or modular housing which will be discussed throughout the paper. This knowledge is crucial to understand since IBS projects undergo similar processes.

INDUSTRIALISED BUILDING SYSTEM (IBS)

Industrialised Building System (IBS) is defined as the innovation of modular coordination (MC) in the planning to utilisation of construction projects by using standard manufacturing designs. The standard planning and utilisation of such projects include the components designs, sourcing, manufacturing, assembly, and installation of the overall project. Sharing several similarities with precast construction, such as the manufacturing of components off-site before the installation on-site into a complete structure, IBS can be distinguished by the standard dimensioning that follows MC in its components, differing from precast constructions which have diverse specifications for each of their components. This claim is supported by research indicating that all of the IBS components are produced in controlled dimensions (Din et al., 2012; Prabowo, 2019).

In Malaysia, the construction industry introduced IBS in the 1960s following visits to European countries by the Ministry of Housing and Local Government (MHLG) and Public Work Department (PWD) to assess the housing development program (Azman et al., 2019; Thanoon et al., 2003). Aside from the typical structural system prefabrication of beams, columns, walls, and stairs, several other components of industrialised housing, such as the envelopes, movable and permanent internal partitions, and movable and permanent utilities, are also manufactured according to a standard to support the IBS innovation.

Azman et al. (2012) stated that the Department of Housing and Urban Development (HUD) in the USA sets standards for the prefabrication of heating components, plumbing works, air conditioning, thermal, and electric systems of industrialised housing. In addition, a study conducted on prefabricated housing in Hong Kong validates the application of prefabrication of the fabrics and internal partition walls for the public housing projects on the island (Jaillon & Poon, 2009; Prabowo, 2019). With these standardised components composing most of the total value of the house, only a mere fraction of the installation process is needed.

This undoubtedly raises the value of utilising IBS in the construction sector to the end user, who are the building occupiers.

METHODOLOGY

This paper reviews the existing knowledge of supply chain management and logistics concepts, which historically began in the manufacturing industry, and examines how these concepts are currently being reformed in industrialised housing construction. Understanding the appropriate concepts to practice in industrialised construction is crucial. In the manufacturing industry, multiple products go through the factory and are then delivered to the buyers. The building or structure components are assembled based on demand and design from various incoming raw materials and later distributed to the site project.

A narrative review method was used to explain the existing knowledge in selected studies, and results were analysed based on a qualitative level (Kazi et al., 2021; Mayer, 2009). Three different studies conducted in Japan, the United Kingdom, and Italy were selected due to their successful practice of supply chain and logistics concepts in producing construction prefabrication components and modular housing, respectively.

The success factors were analysed using fishbone diagram to emphasise the effective and efficient concepts adopted as the 'causes' and the achievement as the 'effects', as shown in Figure 1. Fishbone analysis is significant in revealing factors that contribute to great impacts that help in future program planning (Kartikawati, 2023; Lenawati et al., 2023; Li & Lee, 2011). Thus, the effective and efficient concepts obtained from these studies can be applied in managing the supply chain and logistics in Malaysia's IBS scenario.

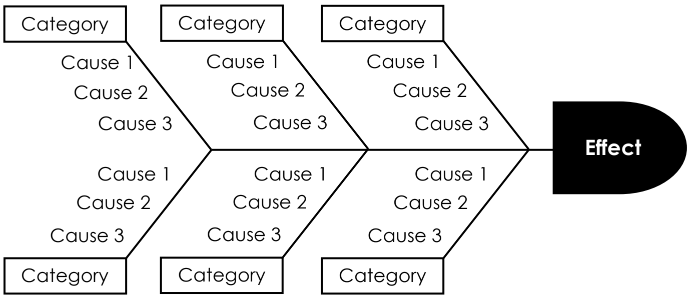

FIGURE 1 Fishbone Diagram (Cause and Effect Diagram)

OVERVIEW OF SUPPLY CHAIN MANAGEMENT AND LOGISTICS COLLABORATION IN CONSTRUCTION

The term 'supply chain management' (SCM) is widely known in the manufacturing sector. It describes the chain of product supply from the raw material to the end user. SCM includes activities such as planning, product design and development, sourcing, manufacturing, fabrication, assembly, transportation, warehousing, distribution and post-delivery customer support.

SCM in construction is a set of practices aimed at managing the entire chain of construction from the raw material production to the delivery of a finished structure to a customer. The construction sector has been quite delayed compared to other sectors in terms of adapting SCM (Al-Smadi et al., 2022; Cherns & Bryant, 1984; Riazi et al., 2019). According to them the most important aspects of the industry are customer specificity of the final product and the participation of several other value-adding parties.

Leading European and North American architects, builders and manufacturers have come out with the idea of producing houses in factories since Henry Ford developed the standard production line for car manufacturing (Gann, 1996; Ndahi, 2006). The evolution of ‘system building’ in the 1960s was influenced by the idea of a simple, standardised, slender frame, slab doors, flexible floor layouts, lightweight movable internal walls and external non-load bearing cladding houses by Le Corbusier (Russell, 1981). Contractors realised that standardisation of parts could cheapen components, reduce on-site labour requirements, speed up the construction process and potentially provide a high-quality product because the factory tolerance was higher than those achieved on site.

Three principles of the development of industrialised housing construction are standardisation, prefabrication and systems building. Standardisation was the pre-requisite for factory production of components. Bricks were the first, the most basic and standardized components to be produced. Prefabrication is the production of components under factory conditions aimed at reducing cost, increasing speed of construction and quality. Two types of prefabrication are those with prior design and those that are produced for a specific reason. The former was produced for a general market while the latter was produced to order (Kendall and Teicher, 2010). This statement was later supported by current research stating that the prefabricated building design increases the speed and cost savings of construction with its flexibility and ease of manufacturing process (Adnan et al., 2019; Prabowo, 2019). Systems building adopted in the 1960s coordinated the use of prefabricated components with the design of the building. The mass housing programs in 1960 facilitated the adoption of bulk purchases of components which gave local authorities, consortiums and building contractors great control of the parts.

Engineered-to-order (ETO) products are produced externally tailor-made to customers’ designs with known building blocks. (Al-Smadi et al., 2022; Ballard & Arbulu, 2004; Levandowski et al., 2015). Prefabrication of components and systems, and construction of building panels and modules in manufacturing plants to be delivered to the site for quick assembly has been a breakthrough in industrialised construction. The elimination of non-value-adding activities such as waiting times, transports control increases the value-adding activities during production. Corwley (1998) states that standardisation, prefabrication, and system buildings are the main principles of industrialisation. Kamar et al. (2012) reported industrialised construction needs synchronisation of construction, manufacturing, and design processes. Emphasise of the planning, partnering, rationalisation, standardisation, and more effective management.

Recent years have seen more implementation of lean construction in the industrialisation of construction. The utmost core principle of lean construction is waste management (Abd Shukor et al., 2021; Ahmed et al., 2020; Ballard & Howell, 2003; Fearne & Fowler, 2006; Green, 1999; Hasmori et al., 2020; Zairul, 2021). Another important aspect of lean construction is the just-in-time (JIT) method to efficiently handle logistics and stock of material (Fearne & Fowler, 2006; Hasmori et al., 2020; Jørgensen & Emmitt, 2008). In addition, Green and May (2005) and Shukor et al. (2021) added that manufacturing components off-site can add value to waste reduction. Managing the production flow process is an integral key to successfully implementing lean construction.

However, evidently, the project of the 1960s did not raise overall productivity and was rarely cheaper or quicker than traditional techniques. This is due to the components being inappropriate for interconnection with components from other manufacturers. The Henry Ford manufacturing method was difficult to apply because of the ever-changing work area. Other than that, the market for mass-produced houses is not stable and could not be organized easily due to methods of financing, the nature of land ownership and consumption of housing. Moreover, the design does not meet the client's desires (Gann, 1996). This scenario also happened in Malaysia, according to Hasmori et al. (2020).

According to Kornelius and Wamelink (1998) and Al-Smadi et al. (2022), customers control a great deal of the final product's dimension, physical attributes, application of material, logistics parameters such as delivery date and project duration, thus, ultimately complicating an efficient supplier-contractor relationships leaving it vulnerable to disruption. In addition to that, extensive preparation for procedure approval, conflict of interest between parties and matters regarding the public works hampers the application of a successful SCM in the construction industry. This claim is supported by a study done by several researchers in which the standardisation of design and material with transparent information transfer is crucial to improving SCM manufacturing (Gurgun et al., 2024; Hasmori et al., 2020; Riazi et al., 2019).

Unlike the unsuccessful attempt at industrialised housing in the US, the Japanese come a long way from the traditional woodworking craft of house building to an attempt at industrialised housing in the 1950s. Pressure to industrialised housing came from numerous factors such as the shortages of skilled carpenters, depletion of timber supplies, low-quality housing, rapid economic growth and urbanization, oil-shock price rises and also the need for a better quality of housing with perseverance to earthquake and fire risk which is quite common in Japan at the time (Gann, 1996). In addition, the demand for construction work to repair war-damaged housing and improve the general quality of the building stock increased, prompting a need to produce an improved way of construction and to research the safety of new technologies.

Industrialised system of housing started as a combination of different levels of factory and site-based activities. Major prefabricated structural systems include timber frames in pre-cut sizes of 2x4 inches, steel frame factory-made light gauge welded panels or frames, modular steel frame systems and reinforced concrete systems, mainly used for flats. In line with the Japanese government's goal to promote the growth of housing production since the 1950s, emerge 5 big companies that have research and development (R&D) facilities each employs several hundred scientists, technologists, ergonomists, architects, and engineers to dominate the Japanese market such as shown in Table 1 (Gann, 1996). These companies are Sekisui House, Misawa Homes, Daiwa House, Sekisui Heim, National House, and Toyota Homes.

All these companies did not in the beginning started in the housing industry except Misawa. Misawa Homes was established in 1967 as a company specializing in prefabricated housing. Sekisui Heim and Sekisui House both established by Sekisui Chemicals the former hoped to exploit the housing market for its plastic products and the latter competed for modular houses in Japan. Daiwa House was established in 1958 by Daiwa, a tubular steel fabricator. National House was established by Matsushita Group as a housing division for the conglomerate. In 1976, a car producer company by the name of Toyota diversified its business into housing production as Toyota Homes. This has been the tradition in the Toyota family where new business inventions must be established by each generation in the family (Gann, 1996).

TABLE 1: Japan's big 5 house manufacturers (Gann, 1996)

Firm	Approx. number of houses in 1993
Sekisui House	70 000
Misawa Homes	50 000
Daiwa House	40 000
Sekisui Heim	34 000
National House	32 000
Toyota Homes	4 000

Although some studies are directed toward supply chain management, little is known about the SCM of the construction industry (Al-Smadi et al., 2022; Atkin, 1995; O'Brien, 1999; Riazi et al., 2019; Zairul, 2021). The current available situations of SCM in construction are the strategic coordination of information flow, task, and process of the various networks of organizations involving delivery of construction of a standard caliber, through the firms and later onto the customer, systematized.

Activities and tasks of the main contractor site's preparation including the construction design team and clients are designated as the upstream in terms of the foregoing. While downstream is defined as the activities of the supplier, subcontractor, and special contractors. To boost the full potential of SCM for the industry, the downstream is considered to be the weaker half and needs to be developed and improved (Al-Smadi et al., 2022; Riazi et al., 2019; Saad et al., 2002).

Jorgensen (2008) reported that the last planner system is the chosen key to provide efficient control of production planning. The last planner system is a weekly work plan to manage the workflow. If any problems arise, the root cause is determined, and countermeasures are formulated so the repetition of the problem will not occur anymore. Jorgensen adds that lean construction would require a certain level of cooperation by its participants (Jørgensen and Emmitt, 2008). Though each player has strengths of their own, their competence and efforts need to be integrated successfully even when sometimes it causes high coordination costs to be applied. Construction SCM can successfully solve major problems in the construction industry if quality partnering and quality control management are adopted (Adnan et al., 2019; Azman et al., 2019; Kanji & Wong, 1998). Construction parties need to view SCM as a vital part of construction emphasizing the visualization of a clearer and wider view of the total quality management of the construction. Recommendations include a strong enabler and an efficient communication system as a part of the project management.

A review of supply chain management and logistics in selected studies has led to a better understanding of the matter. The next section discusses how several organizations from three countries have improved their process of construction prefabrication components by adopting an efficient and effective supply chain and logistics management concept.

SUCCESS OF JAPAN’S TOP HOUSE MANUFACTURERS IN THE 1990S

House buyers in the Japan metropolitan are progressively changing from acquiring simple homes to differentiating the difference between customization and functional quality, obtained through mass production and aesthetic qualities. Customers are presented with an organization of design and sales activities staff, to make modifications of the house design on CAD system to provide 2D and 3D design (Gann, 1996). This is the start of the supply chain management of construction in Japanese housing companies at the time. Figure 2 shows the fishbone diagram of successful Japan’s House Manufacturers in the 1990s.

Being the largest in the industrialised housing industry at the time, Sekisui House provides a high degree of customisation to its customers. While controlling the whole design process from start to finish, the processes were assisted with computer-controlled machines such as frame-building robots and transferring systems dedicated to the logistics of parts and subassemblies. Every part was tagged precisely according to its designated groups in the design.

For each industrialised house, it is estimated that nearly 30,000 items were incorporated into a house from which customers can customise from 2 million different kinds of parts.

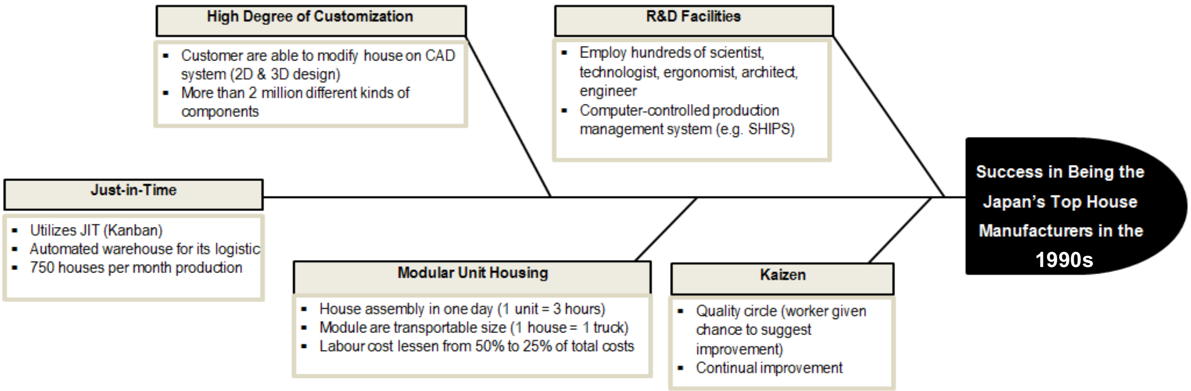

FIGURE 2: Fishbone Diagram of Successful Japan’s House Manufacturers in 1990s

Between 20 to 25% of the finished product was assembled in the factory and then later delivered to the site to be installed. Another 30% of the product was outsourced to a vendor supplier, interpreted as the service, fixture and furnishings of the house, while 20% more of the total value was for site works and the rest was the marketing and management. The biggest of the Sekisui Factory factories in Japan was in Kanto which employs 500 people and can produce up to 750 houses per month. Automated warehouses occupy about 70% of its area to keep components.

While Sekisui Heim employs a slightly different method of entering the industrialised housing industry by using the modular system, designs based on modules of transportable size as shown in Figure 3 (Linner and Bock, 2012). A recent study also mentions the use of modular steel building systems in Hong Kong (Prabowo, 2019). A productive single truck is all it takes to carry one unit of house to the designated sites. Assembly lines in the factories produce these modules up to 30% of the complete product including structural, panels, wiring, plumbing and other finishing such as wiring for TVs, video, and telephone output. The site works only consist of up to 15% of the total work which can be completed in a day thus reducing labour costs from 50% to 25% of the overall cost (Gann, 1996). An artificial intelligence logistics production management by the name of SHIPS (Sekisui Heim Information and Production System) controls millions of permutations of components in producing industrialised houses for the factory.

Customers can customise their homes with each house containing about 10,000 parts from the 270,000 components stored in the factory inventories. Work on the modular begins by cutting steel members for framing, and then complete installations of necessary panels, windows, doors, staircases, services, bathrooms, kitchens, and finishes are properly installed.

FIGURE 3: Sekisui Heim's Model M1 Reached Production of 3000 Building/Year for Several Years (Linner, 2012)

Constructions of the modular units are constructed 3 days prior to the day of installation and the just-in-time (JIT) delivery systems are used to delegate the components of the house. Similarly, in the automotive industry, Sekisui Heim employs quality circles and the Kanban cards system of JIT to organise works. The quality practice in prefabrication projects has yielded 26% reduction in construction cost compared to traditional construction practices which are frequently related to problems such as material waste, hack and rework defect components, accidents on site and delays (Ahmed et al., 2020; Faghirinejadfard et al., 2016;

Hasmori et al., 2020; Zairul, 2021). Thus, proper supply chain management and logistics management have brought success in Sekisui Heim's competitiveness in the industry and allowed the company to manage 1000 people in its factories – efficiently producing 600 houses per month (Gann, 1996).

LEADING UNITED KINGDOM'S ENGINEERING TO ORDER (ETO) COMPANY TO PRODUCTION OPTIMIZATION IN 2002

Malling Precast Products Ltd. located in Essex, United Kingdom worked with Strategic Project Solutions, a management consultant to improve their production performances (Ballard and Howell, 2003). Precast concrete is considered an engineered-to-order (ETO) product and is often insinuated with long lead times that would limit the time and pace of production. Thus, a project to reduce disruption was undergone by Malling Precast Products Ltd. by utilising lean construction to improve manufacturing by employing manufacturing techniques such as decoupling buffer, make ready process, one piece flow and pull and last planner.

Decoupling Buffer

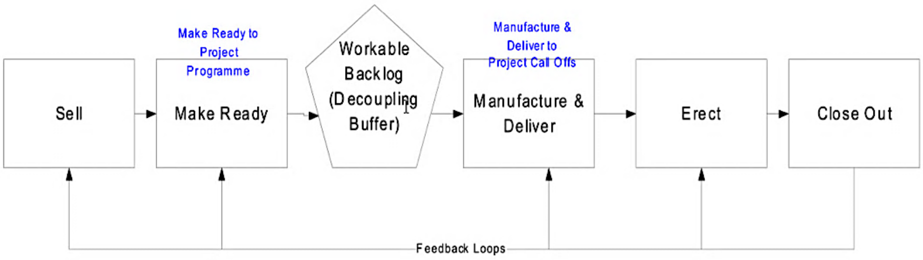

FIGURE 4: Decoupling Buffer Solution (Ballard, 2003)

Ballard and Howell (2003) described the issue at hand for fabricators of the construction industry are the uncertainty of demand. Malling Precast Products Ltd.'s traditional solution; utilises a backlog of orders as a means of information transfer however it is inconsistent and does not provide an optimum solution for all players. A buffer to absorb variability called the decoupling buffer that exists between the prefabricated stage and fabrication stage such as shown in Figure 4 was suggested. This decoupling buffer consists of a buffer of information by the manufacturer instead of a pile of precast walls, beams, or columns. It was also meant as a way for customers to examine the manufacturer's skill set without any payment. Orders are made ready for product scheduling but can be called off one week before the day of the delivery. In addition, lean construction portrays a decoupling buffer perfectly since it does not increase the customer's lead time, minimising waste and generating value for both the customers and manufacturers. By applying decoupling buffers, a second element of improvement of better forecasting for Malling Precast Products Ltd was also observed. Better load matching and capacity would be achieved by synching the buffered project schedules with the load forecast (Ballard and Howell, 2003).

Feedback Loops

Make Ready Process

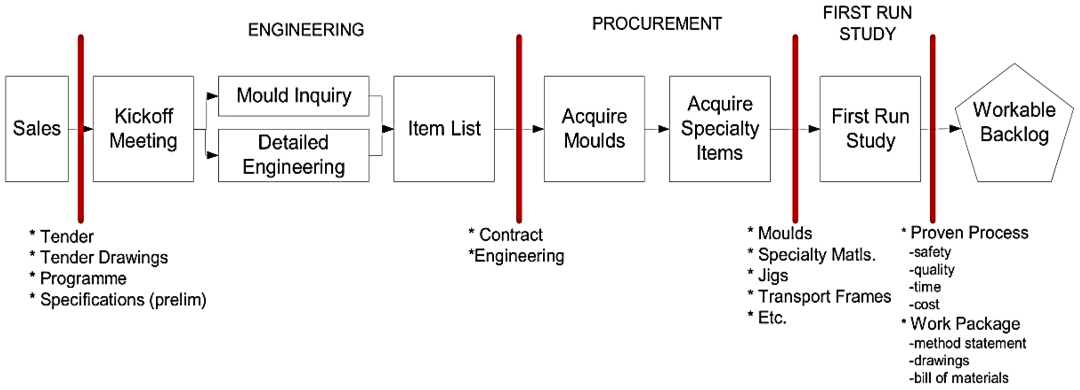

FIGURE 5: Make Ready Process (Ballard, 2003)

The ‘make ready’ process was structured as a series of gates, from which exists a specified benchmark of passing for each gate. Figure 5 shows an example of a make-ready process that was undergone by Malling Precast Products Ltd as a lean production effort. From the sales department to the engineering part, a gate of specifications is created in terms of the tender, tender drawings, programme, and initial specifications (Ballard and Howell, 2003).

After crossing over through the first gate, a kick-off meeting would commence with the participants being from each department of engineering, shop, manufacturing, and site. As a solution to improve the coordination between all players of the manufacturing, from upstream to down streaming the kick-off meeting was a proper improvement in adding value to the whole lean transformation induced by Malling Precast Products Ltd. Meetings discuss rough programmes, issues, decisions, and preliminary actions.

Once the meeting dissolves, engineering detailing and mould design will proceed in tandem. Precast elements were drawn up for the requirement of gate two includes design, details, sources, weights, bills of material etc. After a third gate of mould and logistics appointments, tests run a study of the previous elements were done to recheck safety, quality, time, and cost. Test runs can be scheduled two weeks before delivery time. Subsequently, designated adjustments are made; the productions created a workable backlog to be queued up in the weekly schedule of Malling Precast Products Ltd but are still eligible for a week of call-off period from the site.

Manufacturing Transformation

After the workable backlog was successfully transformed to the production team the advancements of lean construction were continued. Ballard (2003) reported that the assignment of the production team was transformed using the last planner intervention. Problems relating to the rate of production would be investigated and acted upon. The importance of Last Planners (front-line supervisors) is observed as crucial for the workflow to be controlled locally, by working in a cell that ‘sees’ the whole system’s performance (Ballard and Howell, 2003).

Individual production cells are upgraded with a one-piece flow and pull concept to transform Malling Precast Products Ltd’s previous work module of the push system that builds up inventories. The pull mechanism works by eliminating builds of Work in Process (WIP) inventories, lowering cycle times and in addition adding value to cell robustness and flexibility. It is proven in the Malling Precast Products Ltd study; that the lead time of the manufacturing cycle time can be reduced by 1 to 1/3 days duration with the implementation of lean construction. Other than that, productivity in production has been calculated to increase about 100% to 181% for the site's products. This, in turn, increases the total revenue of Malling Precast Products Ltd by a significant amount before lean construction transformation.

Substantial improvements of Malling Precast Products Ltd are achieved with no major technology applied or specific operations altered. No new machinery was even brought into the system. Changes are rather focused on the management philosophy in the work structure focusing on optimisation of work and minimising waste. Production was tailored to suit customer demand effectively.

All these approaches succeeded the said United Kingdom's ETO company to production optimisation in 2002 as shown in the fishbone diagram Figure 6.

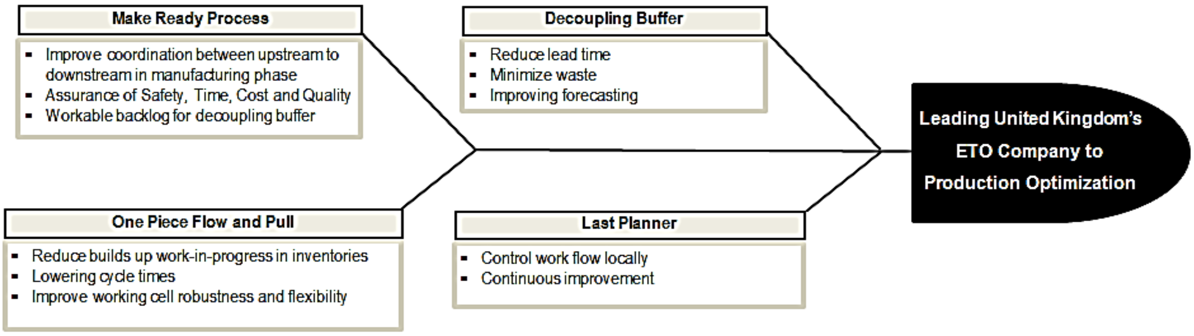

FIGURE 6: Fishbone Diagram of Successful United Kingdom's ETO Company to Production Optimisation in 2002

EFFICIENT WORK-IN-PROCESS (WIP) LEVELS IN ITALY'S CONSTRUCTION PROJECT IN 2014

Another interesting finding focuses more on the recent supply chain system based in Italy. Matt, Dallasega and Rauch (2014) discovered that in the construction industry, production lines of multiple parts cannot implement the Kanban cards system optimally. Not enough rooms are present for a standard container, even if it was true, the Work in Process (WIP) would be higher than anticipated. To solve this, a system called CONWIP (CONstant Work in Process) is cited to be the system that can adhere to the problem. This system shares the benefit of a pull system and can be used in a large variety of manufacturing processes. CONWIP production sets the WIP levels and measures output. The card that passed through the whole production line is the same card that is attached at the beginning of the line. Once it has reached the end, the card is sent back to the beginning in line with a card queue (backlog) to continue onto another container of the whole process. The only difference is that the cards are given different rates of priority each cycle (Matt, Dallasega and Rauch, 2014).

The construction industry is one of the sectors where it's considered to lag in effectively fusing supply chain management into its core. This is due to the ever so changing of demands the customer (Matt, Dallasega and Rauch, 2014). Fearne and Fowler (2006) agreed by stating current construction supply chain is far from optimal due to the control of the production rate does not consider the construction speed of the site. Therefore, a supposed bottleneck from the production to the site is generated. A CONWIP system re-adjusts accordingly the rate of both sides of the construction and production by keeping a steady stream of cards to keep the bottleneck busy. If the construction rate is higher than the production, the readjustment of the supply is undergone to cater to such demands. If unpredictable events such as natural disasters occur, the backlog of production commences to balance the two sides.

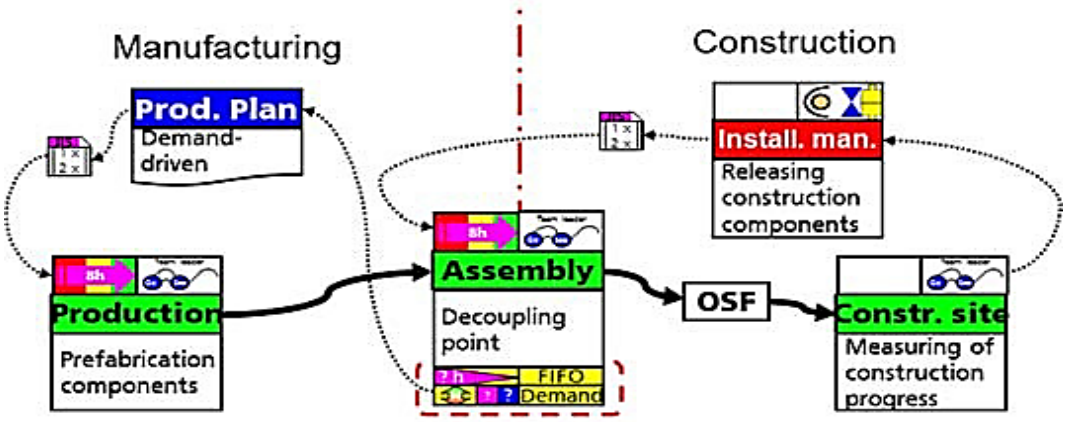

Figure 7: Double Control Circuit for Delivery Request from Site (Matt, 2014)

Normally, readjusting the rates of production would be a hassle because of factors such as the scale effects of large batches and economical transportation by the manufacturer. In addition, problems such as storing materials from scaled production are problematic, especially in urban areas. Since ETO component installations are planned daily, at the end of the week a record of effective work was recorded to plan for the coming weeks. In this concept, to reduce wastage of producing ETO components; prefabricated components from stored ETO's (supermarket) are supplied in short-term releases of products from production to construction. This is in line with the concept of reducing lead time and wastage within the production and construction.

Matt, Dallasega and Rauch (2014) studied an enlargement hospital project in Bolzano Italy has found that most of the non-value-adding activities were caused by the lack of material on site. The CONWIP was implemented with the planner, project manager, production manager and site manager through weekly meetings at the company. In the study, Matt detailed an engineering process of aluminium frame installation being implemented with CONWIP. The average lead time to produce the aluminium frames was recorded and the pace of the production with the pace of the installation on site was synchronised (Matt, Dallasega and Rauch, 2014).

Reduced-value-adding activities are observed after CONWIP implementation. This would, in turn, reduce wasteful construction downtime and maintain the current budget of the project within its limitations. In addition, by reducing the lot area, the chances of early detection of quality problems should be exceeded.

Moreover, a higher degree of capacity utilisation can be achieved in the project. To sum it all up, by minimising WIP, the non-value-adding operations can be controlled reaching optimal capacity for construction. Figure 8 presents the fishbone diagram of successful efficient Work-in-Process (WIP) levels in Italy's company construction project in 2014.

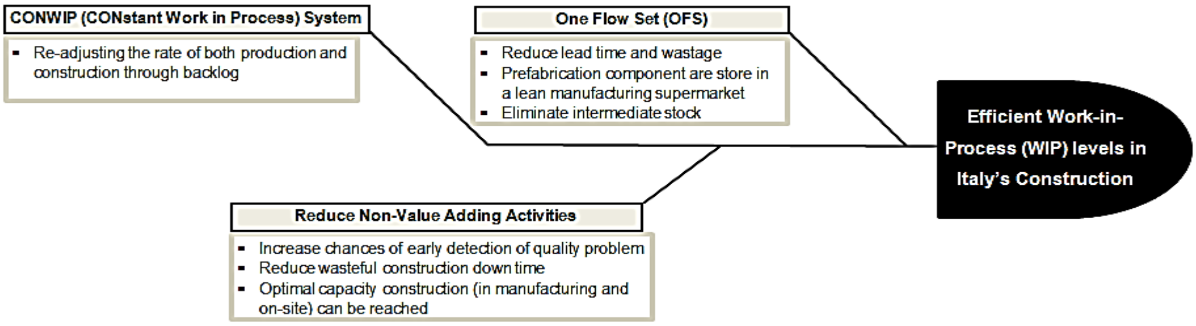

FIGURE 8: Fishbone Diagram of Successful Efficient Work-in-Process (WIP) Levels in Italy's Construction Project in 2014

SUMMARY OF SUCCESSFUL COMPANIES IN JAPAN, UNITED KINGDOM, AND ITALY

In summary, the selected companies from three distinct countries have revealed the lean principle was opted for in their supply chain and logistics practices in industrialised housing production. The element of lean principles such as just-in-time, Kanban cards, continual improvement (kaizen and last planner), and coordination with both upstream supplier and downstream customers are seen to produce successful improvement in their productivity through reduction of the total cost, elimination of wastage and towards supply chain and logistics optimisation.

Reducing total costs is achieved through several strategies. Firstly, by eliminating inventories, companies can save on storage and holding costs. Secondly, employing fewer laborers helps cut down on wage expenses. Lastly, minimising on-site work reduces associated expenses such as equipment rental and transportation costs.

Efforts to eliminate wastage focus on various fronts. This includes reducing intermediate stock, adopting pull systems to prevent the build-up of work-in-process inventories, and identifying and removing non-value-adding activities. Additionally, maintaining quality control during fabrication ensures that resources are not wasted on defective components.

Optimising supply chain and logistics involve implementing strategies like decoupling buffers, backlogs, and CONWIP (Constant Work in Progress) systems. These mechanisms streamline the flow of information and materials throughout the supply chain, leading to more efficient logistics operations. By enhancing coordination and reducing delays, companies can minimise costs and improve overall productivity.

The improvements of the implementation of the supply chain management need to be monitored continuously for productivity advancement purposes.

CONCLUSION

Based on the narrative reviewed, the approach adopted in industrialised construction has synchronisation with the manufacturing industry. Japan's lean concept has contributed a significant impact on automobile production (Toyota) and this concept yet has been widely practiced in Japan's industrialised housing construction and in other countries of the United Kingdom and Italy as mentioned earlier. The principles of industrialised housing construction such as standardisation, prefabrication, and system building components are produced under factory conditions where these require a similar supply chain process under the manufacturing scenario. However, the difference is housing industry needs to tackle the higher degrees of flexibility in client design as well as the condition of the site for components delivery and installation.

Engineering-to-order (ETO) manufacturing organisations from the United Kingdom and Italy as reviewed in this paper have learnt the just-in-time knowledge under the lean concept which is currently applied in lean construction that emphasises waste reduction, efficient transportation and stock holding construction components. The organisations also revealed that the pull system is adopted rather than the push system for the component production process as they do not stock the components in their warehouse or inventories as the pull system is practiced in producing the components when there are demands. A queue card method called Kanban cards used in the pull system benefits the organisations to precede production on a priority basis. To improve the supply chain process, several mechanisms, such as decoupling buffers, backlogs, or CONWIP, are applied as a transition of information between the manufacturing and construction processes. All these processes are observed and controlled through the last planner or in other words continual improvement (Kaizen term in Japan) to ensure the supervision line keeps feeding any discrepancies or problems raised during the process.

These are how lean construction philosophy is applied in the construction supply chain execution. This is important due to the understand of the development of industrialised building systems (IBS) in Malaysia construction industry nowadays. Newly started-up organisations without a strong knowledge of supply chain and logistics are very risky to lose owing to the 'industrial nature' of multiple components production. Therefore, this research also more or less supports the profound knowledge that is significant in developing business models to start up an IBS establishment (capital fundraising). This will benefit small enterprises by establishing IBS manufacturing facilities, especially in non-developed and developing countries.

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