Journal of Engineering and Applied Sciences 5 (2): 71-77, 2010
ISSN: 1816-949X

Application of Lean Production System in the Construction Industry: An Empirical Study

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Abstract: As competition intensifies, many enterprises take drastic measures to sustain their competitive advantages. One of these measures is lean production system that was first introduced in the 1990. The purpose of this study is to apply lean production principles to precast fabrication. This study first describes the origin and concepts, specifically the 14 management principles and 4P models of lean production system to pinpoint how this system can be applied. Then two of these principles are applied on precast plant management by using fuzzy logic. A real case is examined using the proposed method. The result from this study demonstrates that applying lean production system in precast fabrication can reduce waste and increase values for customers.

Key words: Lean production, precast manufacture, fuzzy logic, precast, fabrication, Japan, Toyota

INTRODUCTION

With the recent reform of world economic, factors such as cheap labors, easy access to professional workers and available land space have become key resources for conglomerates. To survive, enterprises start searching for new revenue sources and implementing new cost cutting initiatives. In other words, they want to be able to supply high quality and customized products of appropriate quantities at the appropriate market timing.

Internally, enterprises want a stable, flexible and adaptive production system that can manufacture products meeting market demands. To achieve this goal, enterprises start implementing lean production system to eliminate wastes and improve company bottom line. Womack and Jones (2003) even made a bold prediction that lean production system will become the standard production system in the 21st century.

Handicrafting production: In the early 20th century, handicraft production was the dominate production method in Europe. The range of industries that employed this method at that time stretched from automobile, decorative arts, furniture and all the way to high end sports cars.

In fact, the single function tooling industry was mature and prevalent that the processing plants were able to produce sophisticated handcrafts for customers. Mentoring was the only means that craftsmanship knowledge and techniques were passed on to new employees. However, handicrafts were generally more expensive. As mass production became more accessible and feasible to suppliers in major European markets, handcrafting then became less popular and employed only by suppliers serving niche markets.

Mass production: In 1908, Ford Motor Company began utilizing interchangeable parts or the concept of standardization and employing the division of labor approach in their production process. The moving assembly line was formally introduced and implemented in production plants in August 1913 and the cycle time for each assembly line worker was reduced from 513-2.3 min by then. After the World War I, the automobile industry entered the mass production era. At early 1920s, Alfred P. Sloan Jr. was hired by General Motors to restructure the entire corporation.

By 1925, he institutionalized the decentralization approach (similar to profit center) and required all departments to regularly provide detailed reports on sales, market shares, inventories and losses. This decentralized and organizational approach effectively boosted performance for all company departments, especially the manufacturing plants, engineering department and marketing and sales department. This production and management philosophy made the US the top automobile manufacturing country in the world in the 1960s. Peter Drucker, the management guru even remarked that the US automobile industry is the industry of all industries in the world. Since 1910, mass production became the top production method in the automobile industry and stayed that way the following 60 years. However, as consumers demanded product variety and customization in the 1970s, the lean production approach introduced by Toyota Corporation was then adopted by major automobile manufacturers and became the benchmark standard that large enterprises look up to improve efficiency for their organizational activities.

Lean production: In the early 1990s, enterprise managers in the west started to feel competitive pressures from Japanese counterparts. These operational management methods employed in Japan consume significantly less resource and can produce products of a higher quality standard. Hence, Western managers started to follow suit and implement these Japanese methods (White and Prybutok, 2001). Among all other industries in Japan, the automobile industry was the most competitive one in the world. The quantity of automobiles they alone manufactured almost outnumbered the quantity of these produced by all manufacturers combined in the western world. This situation forced Japan to face challenges of upcoming economic bubbles. However, even in the bubble, the profit per unit of sales for each Toyota slid by only 5% . This result made Toyota a contemporary case for business schools.

In 1987, scholars such as Womack started to take notice of the Toyota phenomenon and realized that the lean production method or the one employed by Toyota was very different from mass production. They were troubled by how they should accurately name this production method. Then John Krafcik, a young assistant from MIT described this method as one that requires less effort, working space and throughput time (Krafcik, 1988). Less capital and input were consumed by each part of the production system.

This production system only needs proportionally less input to economically manufacture products that confirm to designs and are short of defects. Hence, the word Lean was formally utilized to name the system. Since then, this production method revolutionized operations for not only the automobile industry but also other industries such as chemical processing, pharmaceutical, textile, footwear, architecture and medical supply industries. Its application further covered such service industries as banking, insurance, hospital and postal services.

In recent years, the construction industry in Taiwan has shown sign of aggressive developments. This can be discerned from national projects undertaken in various parts of Taiwan, scientific parks in Nangang, Neihu, Taichung and southern Taiwan, National Highway No. 6 Elevation-Road project that is aimed to accelerate tourism developments for the Nantou region or even, the controversial Suhua Highway Project. As the construction techniques and technologies continue to advance, civil architectures become more secure and can last longer. The construction duration is also shortened. However, no sound production management system is currently available for the construction industry which results in excessive wastes and high project costs. Therefore, this research applies the Lean Production Method on precast plants to reduce inventories to eliminate wastes and to lower demand variability.

Toyota production system: TPS (Toyota Production System) is the core of the lean production method. Toyota Automatic Loom Works, Ltd. founded by Sakichi Toyota was the predecessor of Toyota Motor. After his industrial tours in the US, Sakichi Toyota identified that automobiles were the future product trend in the market. Upon his return to Japan, Sakichi Toyota established Toyota Motor and started recruiting talents. Sakichi ever invented the Type G automatic loom which not only can produce textiles efficiently but also can reduce the number of defectives by stopping looming operations altogether when it detects any broken horizontal or vertical yarns. This was known as human-oriented automation. Additionally, Kiichiro Toyota, the son of Sakichi Toyota, further introduced the JIT concept or just-in-time concept which was aimed to deliver right materials or components of the right quantity to the right assembly lines at the right time.

Seven wastes of lean production system: To lower in-process inventory and associated carrying costs, Taiichi Ohno, the father of the TPS system developed a pull-based production method. Inspired by the demand driven production concept commonly found in the US retailing industry, Taiichi aimed to eliminate all kinds of wastes in a production plant and investigate the root cause for these unreasonable wastes. This is the purpose of lean production which focuses on supplying components or parts of the correct quantity to each of the processes at the right time to raise productivity and quality. Wastes here refer to activities that do not add values to production processes. Ohno specifically defined seven types of wastes.

Waste of overproduction: In traditional manufacturing processes, workers typically work overtime to keep up with their schedule. This appears to raise productivity but in the mean time, it also produces extra in-process inventories which judging from the standard of lean production is a waste.

Waste of transportation: The transportation of materials within the production processes does not add values to products themselves. Hence, one of the goals for lean production is to avoid unnecessary transportation whenever possible.

Waste of waiting: This includes idle time that workers spend on waiting for machines to complete operations and that managers spend on waiting for information to make decisions.

Waste of inventory: In traditional assembling operations, complete elimination for in-progress inventories are still impossible but in terms of lean production, these extra inventories are deemed one of the root causes for manufacturing problems.

Waste of making defective products: Defectives will always exist in the manufacturing processes. Defectives do not create values for products and consume extra resources for the following clean up tasks. Thus, lean production emphasizes that workers should perform their tasks right from the beginning.

Waste of motion: Workers should acquire necessary components at the shortest duration and with minimal labor resources. Therefore, required components should be delivered at the appropriate timeframe or wastes will be produced as the result.

Waste of process itself: Unnecessary processes should be eliminated even from the product design phase. Additionally, process improvement procedures should exist in the production processes to reduce wastes.

4P model and 14 management principles of the TPS: Fujio Cho, Chief Executive Officer (CEO) of Toyota Motor and Jeffery Liker both promoted the phrase Toyota Way in 2003. In his book titled The Toyota way: 14 management principles from the world's greatest manufacturer, Jeffery described 14 management principles of TPS. A 4P model as shown in Fig. 1 was used to discuss the TPS. The explanation of the TPS 4D-model is shown in Table 1.

Philosophy: In the most primitive level, all Toyota managers view their company as a means to create values for customers, the society, communities and employees. The motive that Sakichi Toyota invented the Type G automatic loom was to make life easier for women living in rural areas. Then he required Kiichiro Toyota, his son to found a car-making company to contribute it to the world. Even today, all Toyota managers strictly follow this philosophy which then became the foundation for all principles.

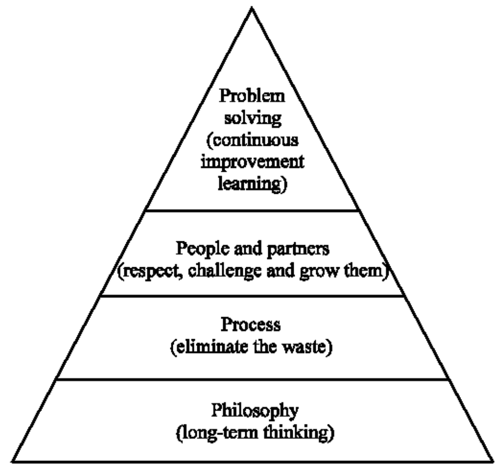

Fig. 1: TPS 4P model (Liker, 2003)

Table 1: TPS 4P model summary

Level	Explanation
Problem solving (continuous improvement and learning)	Continual organizational learning through Kaizen Go see for yourself to thoroughly understand the situation Make decisions slowly by consensus, thoroughly considering all options; implement rapidly
People and partners (respect, challenge and Grow them)	Grow leaders who live the philosophy Respect, develop and challenge your people and teams Respect, challenge and help your suppliers
Process (eliminate waste)	Create process flow to surface problems Level out the workload Stop when there is a quality problem Use pull systems to avoid overproduction Standardize tasks for continuous improvement Use visual control so no problems are hidden Use only reliable, thoroughly tested technology
Philosophy (long-term thinking)	Base management decisions on a long-term philosophy, even at the expense of short-term financial goals

Process: All Toyota managers learn from their consultants and working experiences that when their follow correct procedures, they will get correct results. For instance, if they take actions to reduce inventories or eliminate wastes then they can lower production cost and improve product quality in the long run. The most difficult part is to measure return on long term investments and short term efforts as some causal relationships between them are easy to measure while others are not.

Then you just have to believe that your decisions are truly beneficial in the long run. For instance delivering components to the assembly line once each hour seems like a terrible waste but these actions are the necessary initiatives for the continuous process flow.

They may appear to be wasting time and energy but problems may occur if these actions are not taken seriously.

People and partners: Challenge your employees and partners to grow them and create values for your organization. In TPS, many tools were designed to uncover hidden problems and challenge employees. So they are forced to think and grow with the organization.

Problem-solving: Continuously solving root problems encourages the organization to become a learning organization. The same problem will re-occur if the root problem is not identified and solved at the first time they appear. Also, teams and individual employees will learn from the problem solving process.

14 principles

Principle 1: Make decisions base on a long-term philosophy, even at the expense of short-term financial goals.

Principle 2: Create a continuous process flow to bring problems to the surface.

Principle 3: Use pull systems to avoid overproduction.

Principle 4: Level out the workload (heijunka). Work like the tortoise not the hare.

Principle 5: Build a culture of stopping to fix problems to get quality right at the first time.

Principle 6: Standardized tasks and processes are the foundation for continuous improvement and employee empowerment.

Principle 7: Use visual control so no problems are hidden.

Principle 8: Use only reliable, thoroughly tested technology to serves your people and processes.

Principle 9: Grow leaders who thoroughly understand the work, live with the philosophy and teach it to others.

Principle 10: Develop exceptional people and teams who embrace company's philosophy.

Principle 11: Respect your extended network of partners and suppliers by challenging them and helping them to improve.

Principle 12: Go and see for yourself to thoroughly understand the situation (Genchi Genbutsu).

Principle 13: Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly (nemawashi).

Principle 14: Become a learning organization through relentless reflection (hansei) and continuous improvement (kaizen).

MATERIALS AND METHODS

Lean production application: Precast fabricators face challenges when they manage production operations. Customers demand on on-time delivery and delay in product delivery postpones corresponding project progress. In addition to financial penalty and contract denegation, delay in product delivery also jeopardizes business reputation for the precast plants. Therefore, fabricators typically start the production process once architecture design is completed. However, since the construction site does not usually have sufficient space for cast storage and customers frequently change their delivery requirements and work-in-process products are set inside precast plants waiting for delivery. To protect fabricators from the impact of demand variability, this study developed an evaluation method. A pull system, as mentioned in Principle 3 was adopted to approximate the production date and reduce wastes of overproduction, transportation, waiting and inventory.

Studied case: This study applied the evaluation method on a real case to illustrate the application process for implementing the lean production system. This case is a furniture shopping center. The structure of the shopping center uses precast materials and both the 4th floor and B1 floor belong to the same owner. The project budget was about USD$ 57,000. The total number of precast materials used for each floor is shown in Table 2. There are 195 crossbeams and 290 beams used in B1F.

Evaluation method: In the production system, customers typically exhibit various degrees of satisfaction in relation to the delivery date. To clearly describe this problem, Wang *et al*. (1999) developed an algorithm that can be applied to the JIT system and calculate an unsure delivery

Table 2: Precast materials required for each floor

Floor	Column	Crossbeam	Beam
B1F	0	195	290
1F	51	31	7
M1F	35	120	165
2F	72	113	143
3F	72	118	158
4F	72	122	179
RF	15	13	17

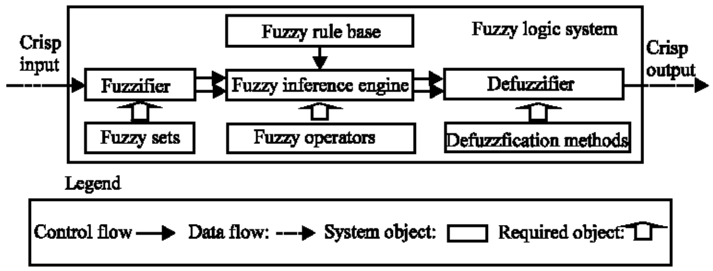

Fig. 2: Schema of fuzzy logic system

date. Considering situational characteristics and information uncertainty, Adenso-Diaz *et al*. (2004) also developed a fuzzy logic model to evaluate relevant information. To alleviate the negative influence that demand variability generates for precast plants, this study postpones the production starting date to reduce the risk precast plants are exposed. This strategy also reduces production risk and risks associated with design changes. However, the decision for the production starting date relies on fuzzy logic to process uncertain and imprecise messages and hence to evaluate appropriate buffers. Fuzzy logic has been proven effective in processing uncertain information and dealing with complicated systems. This study therefore used Membership Function to represent uncertain product quantity.

Fuzzy logic: This study employed fuzzy logic to develop BEM. Fuzzy logic was first proposed by Zadeh (1965) to deal with imprecise information. In general, fuzzy logic is fuzzy sets. In other words, the level of this theory is not clear cut. In a narrow sense, fuzzy logic is a logic system for performing fuzzy reasoning (Zadeh, 1965).

Fuzzy logic is frequently used to simulate human decision making process. Its purpose is to make a well-informed decision in a rather imprecise situation. It provides an approximate but effective description for complicated, unclear or hard-to-analyze mathematical systems. Most fuzzy logic systems comprise four major components: fuzzification, fuzzy rules, fuzzy inference engine and defuzzification (Fig. 2).

Fuzzification: Fuzzification is a linguistic variable that converts an input value into a degree. Membership function is then used to define the relationship between the input value and linguistic variable. Demand variability stems from customers and it increases risks of loss and inventory increments for precast plants (Ballard and Arbulu, 2004). Reasons causing demand variability are complicated. However, some project characters are proven

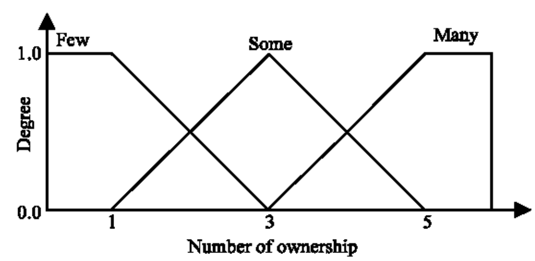

Fig. 3: Ownership membership function

to be more likely causing demand variability: functions (features) of a building; ownership and the use of precast materials. The ownership Membership Function is shown in Fig. 3. In the Fig. 3, three variables, some, few and many are used to describe input values for the ownership value.

Fuzzy rule: A fuzzy rule describes the fuzzy relationship between the input value and the output value. This kind of rules provides measurable descriptions for professional knowledge and linguistic forms. The fuzzy rules for the shopping center are listed as:

- If owners are many and the ordered precast materials are structural items then the demand variability is high
- If owners are many and the ordered precast materials are wall items then the demand variability is high
- If owners are many and the ordered precast materials are curtain wall items then the demand variability is low
- If there are only some owners and the ordered precast materials are structural items then the demand variability is low
- If there are only some owners and the ordered precast materials are wall items then the demand variability is medium
- If there are only some owners and the ordered precast materials are curtain wall items then the demand variability is low

- If there are only a few owners and the ordered precast materials are structural items then the demand variability is low
- If there are only a few owners and the ordered precast materials are wall items then the demand variability is low
- If there are only a few owners and the ordered precast materials are curtain wall items then the demand variability is low

The 1st rule applies when most precast materials are beams or columns. In this rule, the size property for the structural element is not likely to vary and hence, the chances that demand varies are low.

Fuzzy inference: Fuzzy inference simulates human decision making process. It analyzes possible outcomes by applying the fuzzy rules and composition operator. Given a set of fuzzy rules then the fuzzy inference is able to identify the relationship between fuzzy input and fuzzy outputs. This study used the min-max operator. The comprising process is shows in Fig. 4.

Defuzzification: Defuzzification is a fuzziness transforming process to obtain a specific input using fuzzy inference. This study utilized the Center of Maximum (CoM method) to defuzzify the fuzzy result within the center zone. This method is shown in Fig. 4. The Fig. 4 shows the buffer zone needed for demand variability.

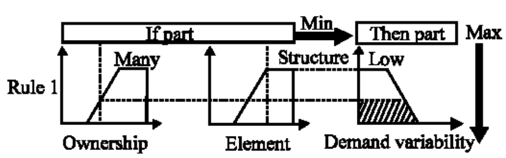

Fig. 4: Min-max composition operator

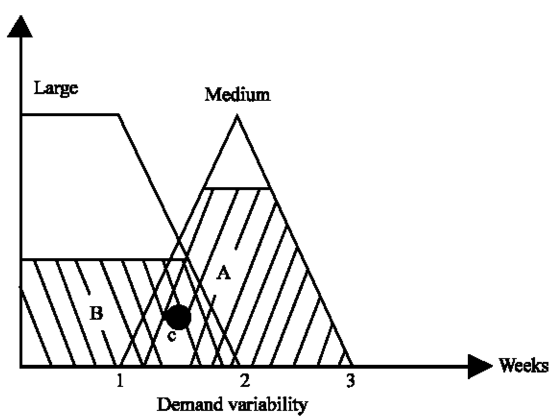

Fig. 5: Center of maximum fuzzification

Table 3: Input for the BEM model

Value	Function of construction	Ownership	Material type
Original input	Shopping center	1	Structure
Specific value	1	1	5
Fuzzy value	(1,1,0)	(1,0,0)	(0,0,1)

The higher demand variability is, the later is it for the precast plant to start the production process to reduce risks associated demand variability (i.e., design change). In Fig. 5, zone A shows medium demand variability and zone B large demand variability.

Zone C or the overlapped zone is calculated once. This center zone represents the reasoned result from all the fuzzy logic rules and the inventory cycle is about 1.5 weeks.

Case study: Three inputs for the evaluation method, (function of construction, ownership and types of precast materials) are show in Table 2. The original input shows the status for the input variable, ownership and the precast column and beams (structural items). To represent each fuzzy input, specific values are used to describe the original status. For example in Table 3, 1 is used to represent the ownership status on the x-axis.

In function of construction and Material Type columns in Table 3, 1 is used to represent the shopping center and 5 is used to represent structure. As shown in Fig. 3, 1 equals few ownership, 0 equals some ownership, and 0 equals many ownership.

Hence, (1,1,0) is used as the fuzzy value to represent the shopping center and some ownership and 2 between 1 and 3 can be used to represent the fuzzy set (0.5, 0.5, 0).

RESULTS AND DISCUSSION

Table 3 shows the application for the fuzzy value, which illustrates how buffer is calculated. The inference result is shown in Table 4. It is indicated in the Table 4 that the buffer for each floor is 14 days and by counting backward then the estimated erection dates, evaluated fabrication due dates and actual fabrication finished date are all plotted in Fig. 6.

Table 4: Inference results

Story	Time buffer (days)
B1F	14
1F	14
M1F	14
2F	14
3F	14
4F	14
RF	14

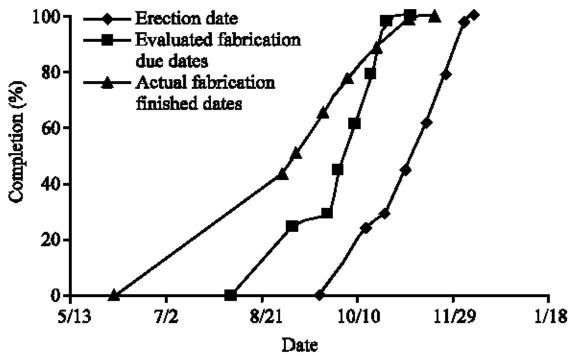

Fig. 6: Comparison between the atual fabrication finished dates and evaluated fabrication due dates

The Fig. 6 shows that the evaluated fabrication due date is closer to the erection date than the actual fabrication finished date and 16% inventory reduction rate is shown as the result.

CONCLUSION

This study describes Lean Production System which is originally used in the manufacturing industry. Toyota spent 25 years (1940-1960s) to perfect the system and reduced the cycle time from 3 h to 3 min. This study applied this system on precast plants and developed a evaluation method. This method can alleviate the impact that demand variability generates on precast plants and reduce the inventory level.

Most precast plants use the mass production approach to manufacture their products. The studied case illustrates that the pull-based production method can effectively lower the inventory level. Moreover, impacts caused by demand variability can be alleviated. The project status and production decision can thus be more clear and precise.

ACKNOWLEDGEMENTS

This research is funded by grant NSC 96-2221-E-212-020 and NSC 95-2221-E-212-051 from the National Science Council (Taiwan), whose support is gratefully acknowledged. Any opinions, findings, conclusions or recommendations expressed in the study are those of the researchers and do not reflect the views of the National Science Council. The researchers would also like to thank the investigated precast fabricator for supporting this study. Special thanks to Chin-Yuan Ko who help in collecting data.

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