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Improving Formwork Engineering Using the Toyota Way

Chien-Ho Ko[1], Wei-Chieh Wang[2], and Jiun-De Kuo[3]

[1]Associate Professor, Department of Civil Engineering, National Pingtung University of Science and Technology, 1, Shuefu Rd., Neipu, Pingtung 912, Taiwan. E-mail: ko@mail.npust.edu.tw

[2]Graduate Student, Department of Civil Engineering, National Pingtung University of Science and Technology, 1, Shuefu Rd., Neipu, Pingtung 912, Taiwan. E-mail: m9833011@mail.npust.edu.tw

[3]Graduate Student, Department of Civil Engineering, National Pingtung University of Science and Technology, 1, Shuefu Rd., Neipu, Pingtung 912, Taiwan. E-mail: m9833005@mail.npust.edu.tw (corresponding author).

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Abstract: Construction is a labor-intensive industry with formwork engineering requiring a disproportionate amount of labor and costs. Formwork accounts for approximately one-third of the cost of reinforced concrete construction, partly because traditional formwork processes frequently result in delivery delays and material waste. The purpose of this research is to adapt production concepts pioneered by Toyota (the "Toyota Way") to improve formwork engineering. The Toyota Way of production consists of four tiers of management philosophy, known as the "4Ps" model. This research adopts the 4Ps as steps for formwork improvement. The first step, "establishing long term vision," emphasizes long term considerations for formwork improvement. Step two, "establishing value streams," reviews formwork flows and eliminates wastage. The third step, "developing the crew," forms mold workers as a team. The final step is "developing a culture of continuous improvement" that provides a basis for constant review and provides a basis for continuous progress. The present research used the Toyota Way to improve formwork engineering. The improvements include reductions in resource waste and increases in operational value. In the long run, the proposed model could provide a learning and growth platform for individuals, the business unit, and the company's extended network of partners. It could also serve to spur innovative thinking in the improvement of formwork engineering.

Keywords: Formwork engineering, the Toyota Way, value stream mapping.

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1. Introduction

The construction industry has evolved from task specialization to dramatic reductions in human labor, causing the responsibilities of specialized technicians and management to gradually increase over the years. According to statistics from Taiwan's Construction and Planning Agency, average wages in the construction industry are higher than that of any other industry category (CPAMI, 2008). Taiwan's construction industry was boosted both in 1947 with the launch of ten large-scale infrastructure projects, and then again in 2004 with another ten large-scale infrastructure projects, causing the industry to experience double-digit growth within the industry (Tao, 2000; CEPEY, 2004). However, these two boom years were followed by a flat period and then negative growth (DGBAS, 2011).

Construction is a labor-intensive industry, with formwork accounting for a disproportionate amount of labor and costs. Reinforced concrete accounts for approximately 87% of total housing construction in Taiwan by floor area (Peng, 1991, 1992). In addition, formwork is one of the four most significant cost factors in reinforced concrete construction (the others being concrete engineering, steel bar engineering and electrical engineering). Formwork generally accounts for approximately 15% of the total construction cost, and approximately one third of the cost of building structures. Therefore, formwork engineering is not only critical for the successful completion of construction projects, but is also a critical factor in construction industry profitability.

The boom and bust experience of the construction industry contrasts sharply with that of the automobile industry which has experienced great advances in technological development, quality, and profitability. Toyota Motor Corporation (formerly Toyota Textiles) began implementing the Toyota Production System (TPS) and Total Quality Control (TQC) in 1950 and enjoyed steady growth and profitability (Li and Yang, 2009). In 2008, Toyota produced 8.79 million vehicles and overtook General Motors as the world's largest automobile maker (Dong, 2009). Critical to Toyota's success is "the Toyota Way" a set of principles for continuous improvement, including establishing a long-term vision, establishing value streams, developing the crew, and developing a culture of continuous improvement.

The purpose of this research is to utilize the production concepts of the Toyota Way to improve formwork engineering. In the Toyota Way, improvements are carried out in four steps: the first step is to "establish long term vision," which encourages management to make decisions in a long-term context. The present research first defined the core value of formwork engineering, and then improved formwork engineering through instilling long-term sustained management concepts. The second step is to "establish value streams," and its core value is to eliminate waste. This research uses this concept as the basis for drafting a value stream map for formwork engineering to eliminate wasteful practices through inspecting the value of every work step. The third step is to "develop the crew," in which the core value is to instill respect for people, nurture superior engineers, and then form a superior implementation team. This study adopts this concept by working with formwork suppliers to standardize work implementation processes, ultimately transforming these suppliers into key business partners. The fourth step is to develop a "culture of continuous improvement" which emphasizes ceaseless improvement and learning.

This research establishes frameworks for problem solving and sustained improvement to effectively adjust and accommodate resources, ensure common understanding among personnel, and continuously eliminate barriers organizational learning.

2. Literature Review

2.1. Toyota Production System

The Toyota Way is the managerial core of the Toyota production system. Toyota was founded in 1937 by Sakichi Toyoda as a textile company. Toyoda later visited the United States where he recognized the future market potential of the automobile industry. He began recruiting talent in the automotive field and established the Toyota Motor Corporation. Toyota managers investigated car production manufacturing processes and examined various sources of wastage with an eye towards fully eliminating waste and ensuring that the required amount of the correct materials was available at the right time for every process. This approach, later called "lean production" aimed to increase product quality and customer satisfaction. Waste indicates a failure to meet the standard performance of the production system, and anything that does not contribute to creating product value is viewed as waste. The champion of lean production, Taiichi Ohno, identified seven forms of production waste (Ohno, 1988): over-production, waiting, transporting, inappropriate processing, unnecessary inventory, unnecessary/excess movement, and defects.

The phrase "The Toyota Way" was first coined by Toyota Motor Corporation president, in 2001, and popularized in Jeffery Liker's 2003 book, "The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer". The book explicated Toyota's 14 management principles and the 4P model of the Toyota Way, which is illustrated in Fig. 1 (Liker, 2003).

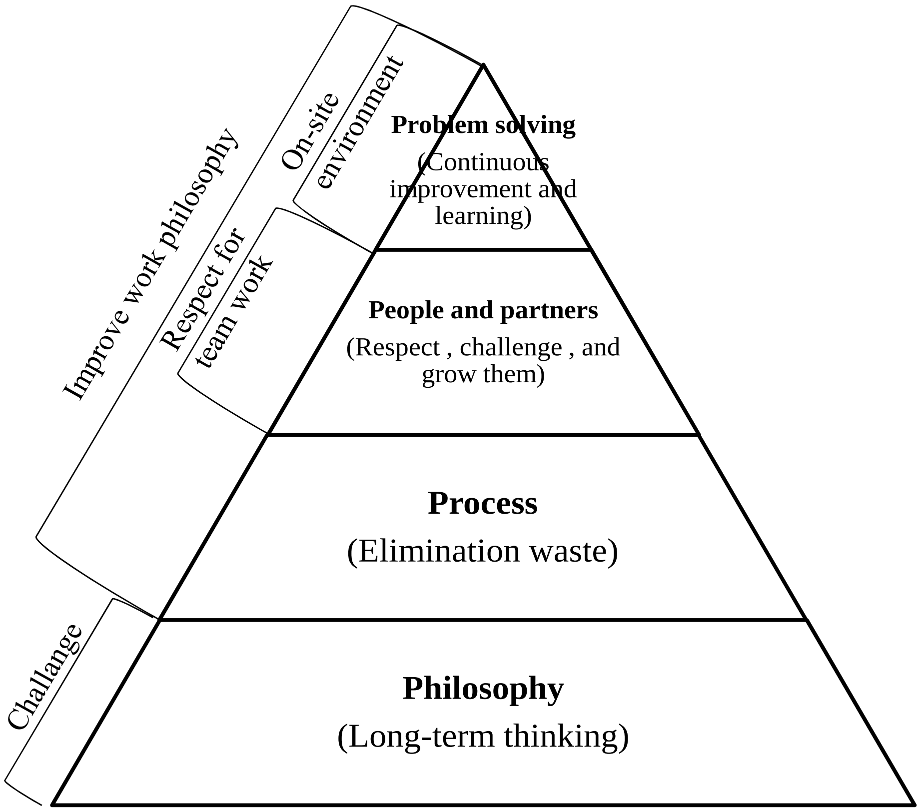

Fig. 1. 4Ps and 14 principles

2.2. The Toyota Way

Fig. 1 illustrates the 4Ps of the Toyota Way. Philosophy, Process, People/Partners and Problem Solving – these are the fundamental principles of the Toyota culture.

- Philosophy:

At the most basic level, the leader of Toyota viewed the company as a tool for generating value tool for customers, society, communities, and individuals. Sakichi Toyoda began by trying to invent an improved loom to help rural women improve their quality of life. Later, he asked his son, Kiichiro Toyoda, to establish a car company to contribute to the world. Through the company's history, all the leaders of Toyota firmly adhere to this philosophy, and it is the basis for all the company's other principles.

- Process:

Toyota believes that correct products are the results of correct processes. A value stream map is thus drawn to represent the value of each stream. Non-value-adding activities are eliminated to reduce obstacles and waste. Most production activities take the Batch and Wait approach: regardless of manufacturing, machining or assembly status, production is usually restricted by batching. In a production system, goods have to be moved as a batch. Moving goods from one station to another creates delays and waste. Operational time is thereafter cut into blocks, resulting in errors going undetected (Liker and Meier, 2006). Toyota's production processes pull components as required, ensuring fluid flow, thus decreasing waiting time and creating a continuous and uninterrupted production process.

- People and Partners:

Challenging workers and business partners to pursue growth and create value for organization is one of Toyota production principles. Toyota's production regulations include many tools aimed at forcing problems to the surface, challenging employees' intellect and initiative.

- Problem Solving:

Continually solving root problems is a way to promote organizational learning. When root problems go unchallenged, the same mistakes will reoccur. Solving root problems and ensuring a common understanding of problems among personnel can promote organizational learning for the team and company.

2.3. Fourteen Managerial Principles

Following Liker (2003), this study divides the above-mentioned 4 Ps into 14 principles, taking "the team that locks on a goal of team spirit to cultivate employee and concentrate each individual force" as a key concept. This study emphasizes that human intelligence and skills are the most valuable resources of any enterprise. The 14 principles are described as below:

- Philosophy:

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

- Process:

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 (Work like the tortoise, not the hare).

Principle 5: Build a culture of stopping the production line to fix problems, to get quality right 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 that serves your people and processes.

- People and Partners:

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

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

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

- Problem Solving:

Principle 12: Go and see for yourself to thoroughly understand the situation.

Principle 13: Make decisions steady by consensus, thoroughly considering all options; implement decisions rapidly.

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

3. Introduction of Formwork Engineering

This section first introduces the administration style of formwork engineering and onsite operations. A value stream map is then drawn by applying the second level "process" of the Toyota Way.

3.1. Introduction on Formwork Engineering

In Taiwan, almost 87% construction projects take the form of labor and material bidding. Only 5% of bids are self-implemented (Song, 2008). The formwork bidder with the lowest price would win the bid. After re-evaluation costs, the formwork bidder would then subcontract out the job to an even lower-priced work crew in order to maintain or increase formwork bidder's profit. However, to maximize their wages, the work crew would then greatly discount the specification. In addition, to keep operational costs down, construction companies are unwilling to invest in improved construction or managerial techniques, driving a vicious cycle that results in anti-selection where the worse drive out the better.

The advantages of subcontract management include reduced subcontracting costs, increased work performance, lower labor costs, and increased labor flexibility. However, the disadvantages include loss of key technology, suppression of creative development, difficult in implementing quality control, schedule restrictions imposed by subcontractors, difficult cost control, poor safety awareness, poor work quality, inadequate adherence to regulations, and high fluidity in subcontracting personnel.

Approximately 30% of construction projects are repeatedly subcontracted among many subcontractors. Approximately 75% of technical work is re-subcontracted, and the re-subcontracting duration varies. This results these types of subcontracting work being subject to high levels of uncertainty. In addition, subcontractors require high personnel mobility and prefer to hire large numbers of workers on a temporary basis, with temporary workers on average accounting for more than half of contractors' total workforce. In addition, 80% of contractors prefer to use temporary staff mainly because of variable work content demand, and secondly due to financial concerns. Temporary workers have high flexibility in terms of job content and job location. This also indicates the uncertainty faced by temporary workers is greater than that of long term workers. Their income sources and average wages are also significantly lower than those for long term workers. Thus they experience higher financial pressures than long term workers, along with complete lack of job security and lower job satisfaction levels. Their views for the future tend to be more negative (Chang, 2007).

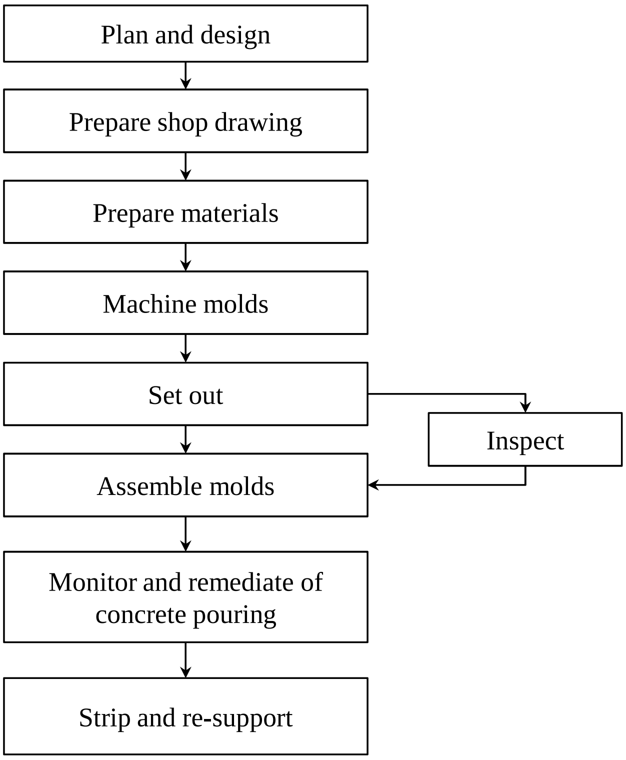

Fig. 2. Traditional formwork operation process

3.2. Formwork Operation Process

Many types of molds are commercially available. Molds for building, factory, and civil engineering work have different functions. They can also be classified as "traditional wooden mold" and "systematic mold" (Liyan and Yang, 2004). The materials used include wood, steel, aluminum, plastic, and FRP. The main jobs of formworkers are indicated in Fig. 2 (Shen, 1992): design and plan the mold, draft shop drawings, prepare materials, machine molds, set out, inspect layout, assemble mold, monitor and remedy mold during concrete pouring, and remove mold and re-support operations. Therefore, formwork operations are more complex than those required for rebar and concrete pouring. Planning and formwork scheduling are performed by the formwork foreman. The required formwork personnel are arranged in advance according to the construction schedule, structural height, shape, implementation difficulty, and material. As shown in Fig. 3, in current practice, molds are placed randomly without proper arrangement. The cut molds are also improperly categorized. For example, form workers would cut 60x180 cm wooden boards with electric saws into 45x60 pieces, leaving the remainder unusable. This is an example of procedural waste in action and processing. Adapting the Toyota Way of long term management and waste elimination would thus create new efficiencies within the construction industry.

3.3. Formwork Value Stream Mapping

A traditional formwork value stream is draw by using the Toyota Way's second step to identify current operational processes (Rother and Shook, 2006). The current-state formwork value stream map is shown in Fig. 4. The operational flow of formwork engineering can be divided into two categories, viz. material flow and information flow. In material flow, when a formwork subcontractor receives an order from a general contractor, the formwork foreman and superintendent will discuss the master construction schedule, and verify the stock status of molds, mold supports and accessories. If the stock is insufficient for the implementation of the project, the formwork subcontractor will place an order to material suppliers. The subcontractor transports all related formwork material to the project storage yard when above-mentioned preparation work is complete. On information flow, the formwork master schedule is elaborated by the general contractor. The formwork target completion date is determined by the superintendent and the foreman. The foreman then categorizes jobs and manages his labor force according to the formwork schedule. Fig. 4 shows waste to exist between major operations: from storing formwork materials in the project yard to setting out mold positions, assembling and processing molds, stripping molds, arranging molds, and transporting molds. A formwork section is considered to be complete when the molds are transported to storage or to the next project. The foreman reports his progress to the superintendent once the sectional progress has been completed.

Fig. 3. Actual site of formwork implementation

4. Toyota and Construction Industries

This section compares the growth of the Toyota Motor Corporation and construction industry, exploring differences in growth patterns and management philosophy, and describing how operational philosophy can influence enterprise development.

4.1. Comparison of Toyota and Construction Industry

Between 1981 and 1997, the total annual production value of Taiwan's construction industry increased from USD8.848 billion to USD36.326 billion (DGBAS, 2011), as shown in Fig. 5. From the onset of the Asia Financial Crisis in 1997 until 2000, however, annual production value decreased to USD30.215 billion (Tao, 2000), with many construction firms and subcontractors going out of business. The government provided stimulus in the form of the "New Ten Construction Projects" (CEPEY, 2004), increasing annual production output increased to USD44.139 billion in 2008 before dropping again to USD37.556 billion in 2009. Annual production value of Taiwan's construction industry follows changes in the general economic climate. Construction companies responded to bad times by cutting expenditures and manpower, depriving them of vital human resources and changing the core value of their organizations.

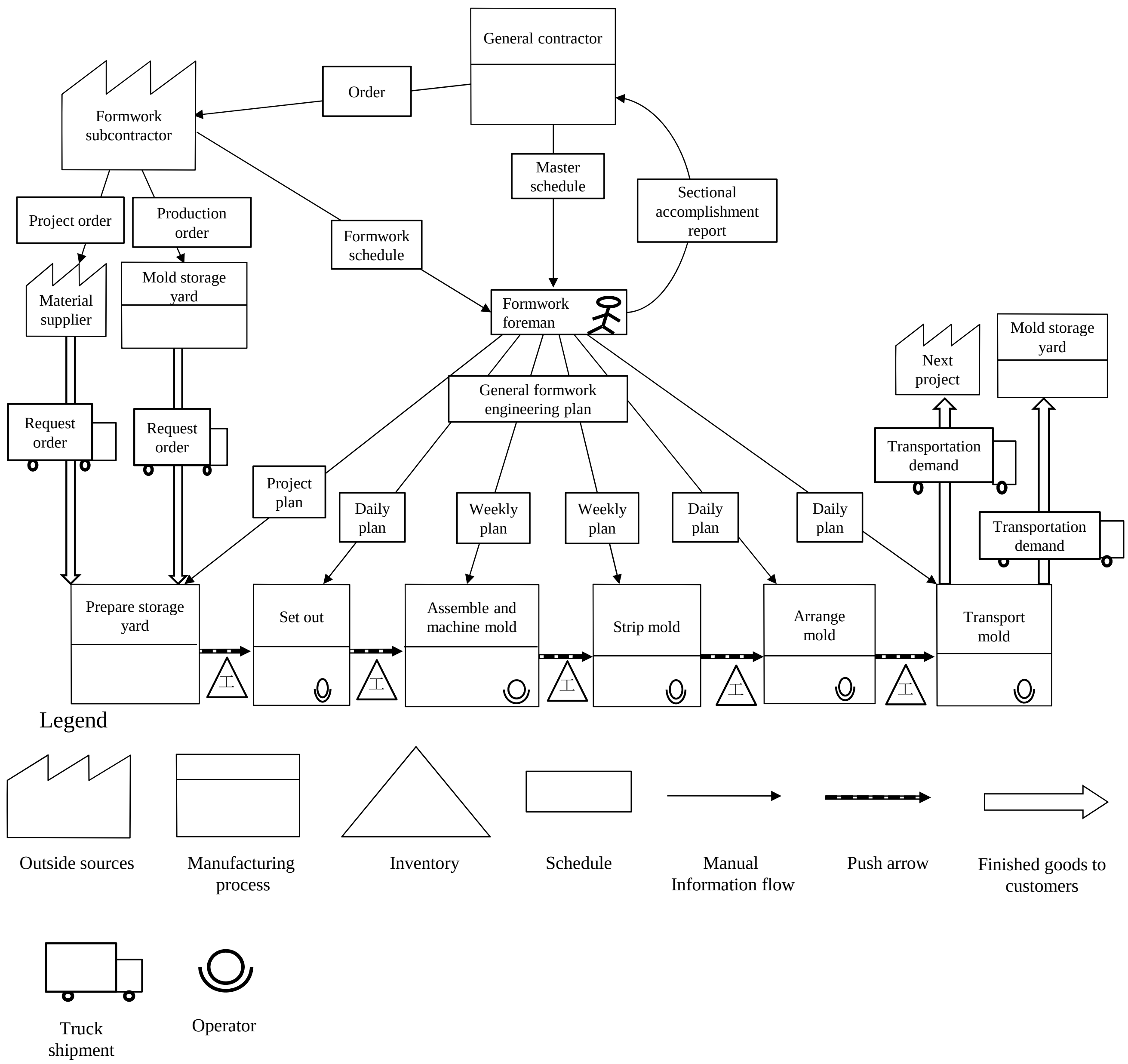

Fig. 4. Formwork current state map

By the contrast, between 1981 and 2008, Toyota Motor Corporation increased its production from 3.51 million to 8.97 million vehicles (Toyota in The World, 2008), as shown as in Fig. 6. Despite Japan's poor economic performance in the 1990s and the Asian Financial Crisis of 1997, Toyota's annual production volume maintained steady growth, and the Toyota Way withstood all external economic impacts. The key difference in the performance between these two industries is that Toyota's core production system is a "complete system" which integrates product development, distribution and sales, rather than on production alone (Womack et al., 1990).

As shown in Fig. 7, growth in Taiwan's construction industry decreased from 28.18% in 1992 to -11.83% in 2001, for a total decline of 40.01% over 10 years, and an average annual rate of decrease of 4.00%. Growth of -11.83% in 2001 increased to 3.43% in 2008, for a total increase of 15.26% over 8 years, and an average annual growth rate of 1.91%. This volatility changed the industry's core value, increasing employee turnover and resulting in the loss of valuable skills which otherwise would have been kept in the companies, leading to a failure to improve product quality. In contrast, Toyota's growth rate decreased from -1.63% in 1992 to -2.27% in 2001, a gap is 0.64% over during10 years for an average annual decrease 0.06%. Growth then increased from -2.27% in 2001 to 2.78% in 2008, a gap of 5.25% over 8 years, equals to an average annual growth rate of 0.63%. Overall Toyota exhibited more stable growth, and this can be attributed to differences in attitude toward operations

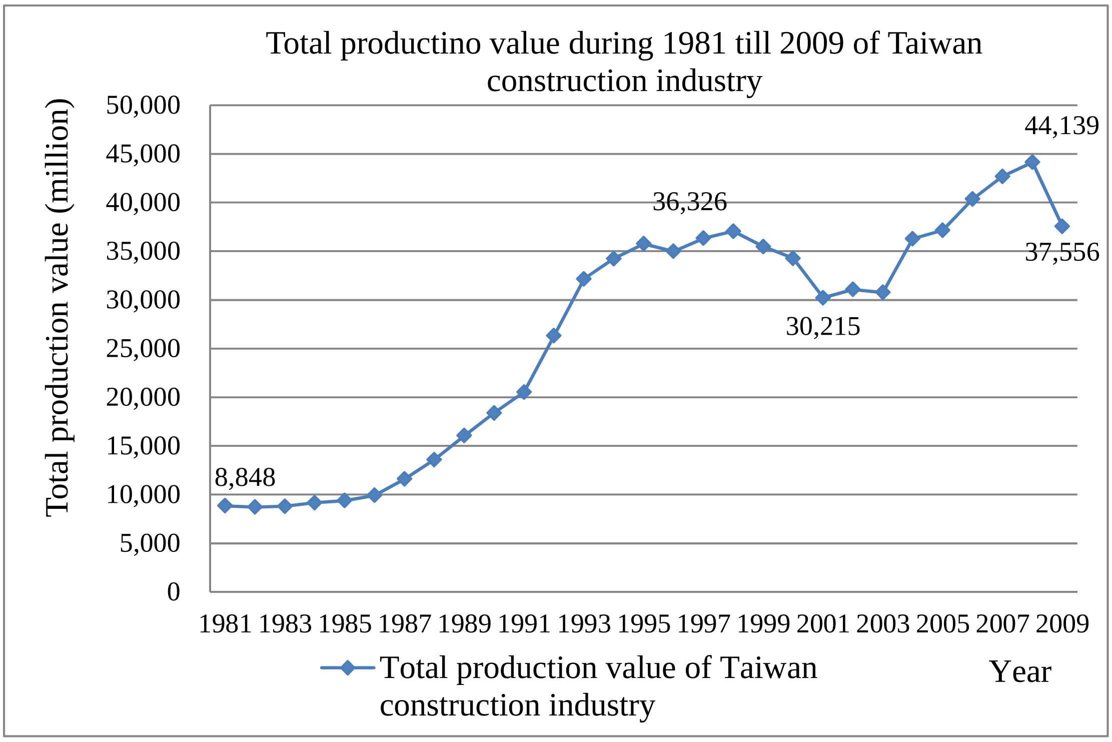

Fig. 5. Total production value of Taiwan's construction industry, 1981 to 2008

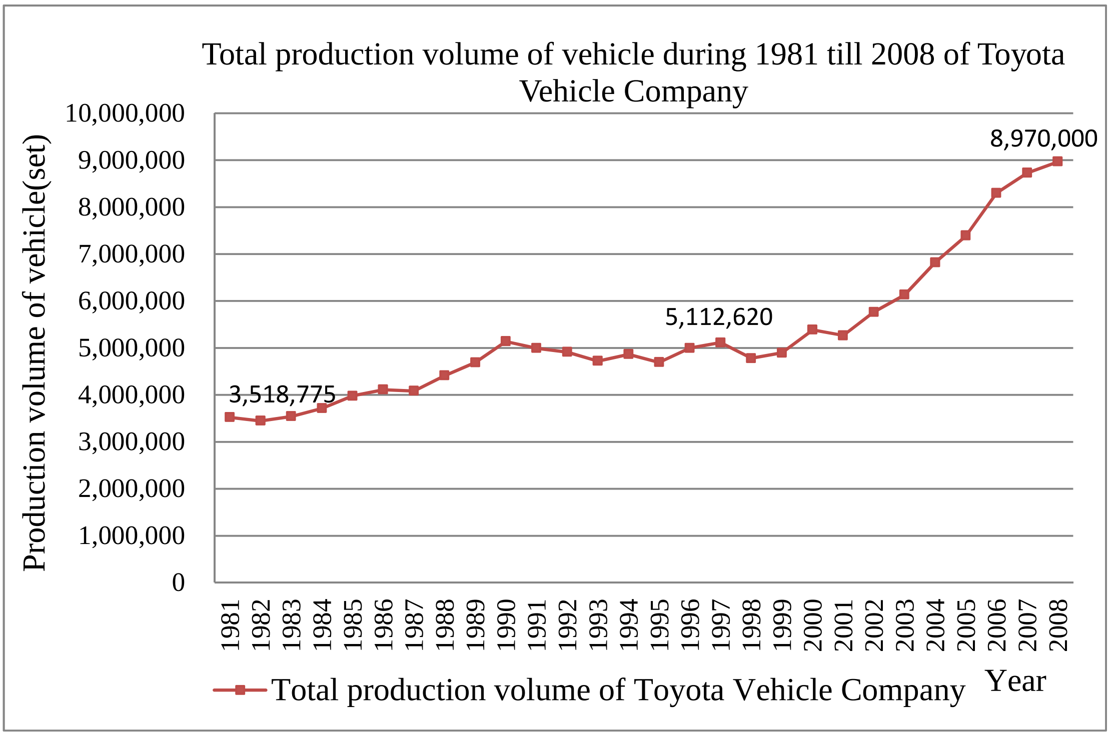

Fig. 6. Toyota total production volume, 1981 to 2008

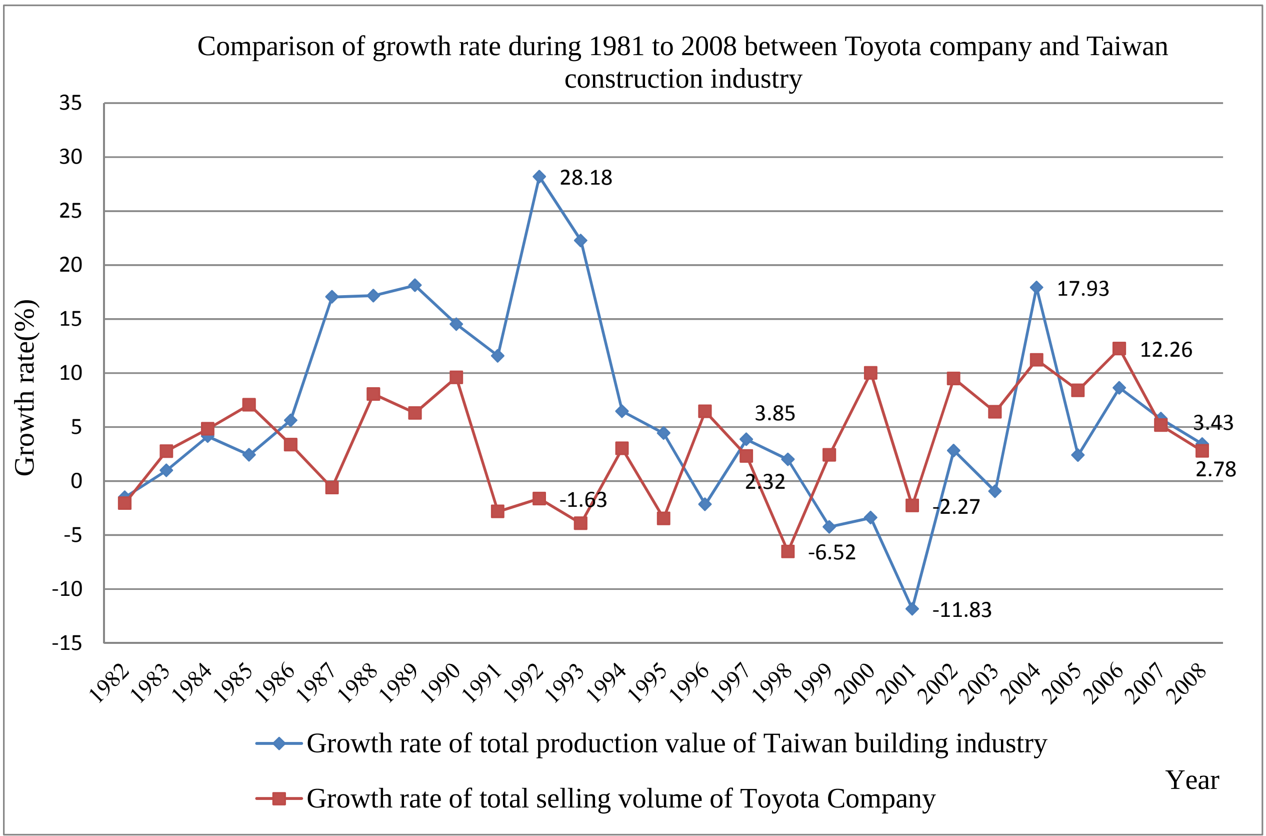

Fig. 7. Comparison of annual growth rate between Toyota and Taiwan's construction industry

4.2. Management Method Analysis for Toyota and Taiwan's Construction Industry

The construction industry's traditional administration model tends to encourage subcontracting. Management focuses on minimizing costs while completing projects on schedule. Most decision making is made by administrators and tends to be project-specific. Formwork engineering relies on techniques which are passed on from master to apprentice, leaving little room for a culture of continuous improvement. Formwork quality is highly variable and difficult to control. Moreover, most construction companies subcontract out formwork. While this saves direct short-term costs, derivative quality problems resulting from the subcontractor's low unit price usually results extra costs and time spent on repairing defects. Furthermore, construction projects are complex and subject to many uncertain factors such as weather and uneven implementation quality. Therefore, improper management practices may result in delays, forcing the contractor to rush the schedule.

In contrast, Toyota bases its enterprise culture on team spirit, cultivating employees and concentrating on individual talent to create uninterrupted processes and reduce inventory levels (Koskela, 1992). Toyota concentrates on continuous process improvement, working in small batches and continuously tuning the production system. Management actively solicits input from every employee, continuously improving its administration model in the context of a long-term vision. Toyota continuously examines every technique and process for potential improvement, in pursuit of stable and repeatable production methods to maintain predictable, regular cycle times, and throughput. In addition, Toyota has established a culture of knowledge sharing, which helps standardize best practice. The Toyota production system encourages all employees to think creatively about how to achieve improvement. This reduces product variability and may compress the production cycle times so as to reduce overall costs required to fulfill operation strategy. Table 1 presents a summary comparison of Toyota's approach to continuous improvement and traditional construction management (Imai, 1986).

A company's stable growth and profitability originates from the firm's operating philosophy and product value. Each project requires a manager who can bring his team to a concrete consensus. The team needs to be able to work together closely to correctly price the project, calculating backward from a suitable profit. Three steps are used to rectify key managerial procedures to ensure a smooth flow: 1) deleting unnecessary activities, 2) reorganizing manpower to compose a multifunction team, 3) continuously seeking team improvement so as to reduce total costs for manpower, space, equipment, and time by at least half. Connecting together isolated improvements throughout the value chain upgrades the whole performance to a high value level.

5. Lean Formwork Construction Process

This section applies the 4Ps and 14 principles of the Toyota Way to improve formwork engineering. A strategy for improving framework is established accordingly, and a future-state value stream map is drawn.

5.1. Application Procedure

This study applies the Toyota Way's 4Ps to establish an improvement strategy for formwork engineering.

Table 1. Comparison of continuous improvement and traditional construction management

	Continuous improvement by Toyota	Traditional construction management
Focus on	Process and people	Minimizing costs and progress
Target	Small batches and tuning	On schedule delivery
Exploration range	All staff and management	Management
Time frame	Continuous and gradual	Project item
Technique tends to	Optimize internal knowledge and skills	Create working experience
Motive	Decrease cycle time variability	Survive to the next project
Practical request	Requires little investment, but great effort to maintain it	Requires large investment and great effort to maintain it

Step 2: Establishing valuable processes

The correct process leads to the correct result (Liker and Meier 2006). Thus, shortening production lead times helps to achieve the lowest cost and shortest schedule for a construction project. The core value within this process is to eliminate waste and to establish a value stream by applying this concept. Three activities are carried out in this process: 1) examining the value of each construction process with a view to eliminate waste, 2) understanding current production waste through the current state value stream map, 3) improving the state value stream map by applying principles 2 through 8. Devoting administration resources to support the construction process could result in interrupted implementation when any abnormality arises, thus forcing problem to the surface.

Step 3: Setting up an implementation team

Applying principles 9 to 11 develops the core values of team cooperation. The process begins with cultivating excellent workers who are then organize into an excellent implementation team. The implementation system is designed to support the team in creating added value. The main purpose of coordinating team work is to encourage mutual support and skill sharing among formwork crew members.

Step 4: Establishing a culture of continuous improvement

This study presents a value stream map for problem solving and continuous improvement. Principles 12 to 14 are adopted to efficiently re-deploy calibrated resources. Practical, onsite understanding is critical to overcoming any obstacles met in the pursuit of perfection. In addition, a culture must be developed that works against the holding of pre-conceived ideas, but rather encourages in-person, detailed observation of practical operation flows as a basis for decision making and problem solving. This step emphasizes looking into the cause and effect chain of the root problem rather than simple "problem acknowledgement". After thoroughly understanding the root problem, possible options are considered. The strategy in this step is to form a team consensus for each potential influencing factor to arrive at a solution that benefits the team. Reaching a consensus between decision makers and crew members increases the likelihood of successful implementation.

5.1. Formwork Improvement Methods

The core value of formwork engineering is the creation of an uninterrupted construction process. In terms of external value, formwork subcontractors are expected to accomplish their work on time with consistent quality and correct assembly, and without ruptures. Internal value emphasizes decreasing construction costs by eliminating non value-adding activities and waste. This research applies 4P application procedure to identify methods for improving formwork. Traditional and improved formwork engineering approaches are compared in Table 2.

Note 1: A is production surplus waste; B is transportation waste; C is waiting waste; D is inventory waste; E is defect waste; F is movement waste; and G is production waste from operation processes.

As shown in Table 2, seven kinds of waste can be reduced using the Toyota 4P. The purpose of this study is to creating an uninterrupted implementation process, which can be achieved by eliminating waste. To eradicate waste in the process, 12 waste reduction items can be deleted from the Step 2 "process" in Table 2. This waste reduction is illustrated in greater detail by presenting an analysis of analyzing movement and waiting waste in a real case of traditional framework.

5.2. Background Information

Table 2 summarizes the case: a 4-storey RC school building with a single basement level and a total floor surface area of 2185 square meters. This research examines the formwork for the 3rd floor, established on the 2nd floor. Total working days is 35 and the total mold area is 1646 square meters, using wooden molds and supports of wood, steel tube and section steel. The formwork team consisted of a foreman and 10 workers, both foreign and local. The scaffolding, steel bars, machinery, and concrete are supplied by other subcontractors. The anticipated mold labor requirements are 8 hrs/person/day. The working time is calculated by the total available labor force times 8 hours, thus it equals the time value that each laborer produces. Table 3 presents work status over the 35 day construction period.

Table 2. Improvement strategy comparison

4P (14 principles)	Traditional formwork management	Lean formwork management	Waste reduction[1]
Philosophy (1)	Completing formwork	Increasing customer value	A、E
Process (2-8)	No evident construction instruction. Machining specifications communicated orally. Adjusting subcontractors progress by rule of thumb. Construction scheduling performed by formwork foreman. Unused molds kept at construction site.	Using construction instruction card to establish a "pull" construction flow. Machining specifications written on the production card. Applying the supermarket method to support formwork engineering that fits the target of proper time and proper quantity. Production leveling (*heijunka*) implemented to gauge progress. "First in, first out" (FIFO) ensures unused molds are kept offsite.	A、B、C、D E、F、G F、G C C、D
Employee and business Partners (9-11)	High mold worker flow rate. Unreasonable subcontracting price.	Emphasis on cultivating consistency in formwork. Reasonable subcontracting price helps co-working subcontractors form a team.	E E
Problem solving (12-14)	Technical issues are solved by the foreman. Problem solving approach from a technology viewpoint.	Emphasis on solving root problems and continuous improvement. Solve construction problems by increasing customer value.	E E

5.3. Current Formwork State

Fig. 8 shows the value stream map from Fig. 4 based on the data in Table 3. The Fig. shows a total of 20 hours of waste waiting for the steel bar subcontractor from project start to storage yard preparation. Another 32 hours waste resulted from waiting for the scaffold subcontractor from storage yard preparation through mold assembly and machining. Mold assembly and machining required a total of 140.5 work hours. The total mold assembly was 1646 square meters. The average productivity (quantity of mold used divided by working hour equals productivity of plate mold per worker per day) per worker per day is 11.72 square meters (Chang, 2007). A total of 26.5 hours was spent on mold stripping. The overall formwork productivity was 62.11 square meters per worker per day.

The most important production value during the formwork flow is assembly, machining, and stripping. However, the process includes waste due to waiting and movement. According to ABRI (1998), in the traditional mold process "waiting" time accounts for 31.2% of total time spent stripping molds, while "walking" and "searching" respectively account for 10.8% and 17.7% of the total assembly and machining process time. This movement waste is mostly due to materials being improperly laid out on the site, requiring workers to search for required materials.

The total worker hours and total value times (Table 3) are multiplied by the action ratio (Table 4) to obtain a current state action analysis (Table 5). This research defines "stripping," "prying," "walking," and "moving" as value-adding activities, while "waiting" is waste which occurs during mold stripping. "Measuring," "pulling," "cutting," "pass on," "nailing," and "repairing" are actions that produce value, while "walking," "searching," and "waiting" are waste during mold assembly and machining.

Table 2. Case summary

Type of building:	School
Location:	Taiwan
Total floor area:	2185 square meters
Number of floors:	1 floor underground, 4 floor on the ground
Height of each floor:	4 meters
Construction duration:	Start in August 2010 and end in March 2012
Total mold quantity:	6584 square meters
Unit price of plate mold:	USD 9.33/square meter

Table 3. Construction Status

Activity	Total mold labor	Total value time (hr)
Set out (mark)	0.5	4
Prepare storage yard	2	16
Assemble and machine molds	140.5	1124
Strip molds	26.5	212
Arrange molds	14.25	114
Transport molds	35	282

5.4. Future State Formwork Engineering

To eliminate actions that do not produce value (i.e. “wait,” “walk,” and “search”) and to increase onsite working efficiency, this paper intends to create operation zone for formwork engineering. As shown in Fig. 9, this research organizes seven zones: complete mold (A1), support and accessories (A2), mold first grade (A3), mold second grade (A4), discarded mold (A5); the interior is a mold machining zone (B), and the external zone for outgoing material (C). Workers go to the material yard to find the various molds or material they require for assembly or machining. This layout could decrease the mold for “walking” and “searching” by 15.17 and 24.87 mold labors, respectively. Production leveling (*heijunka*) is used to reduce waste caused by waiting for the transport of material during the mold stripping process. The 8.27 mold labor units and 66.14 hours of non value adding time can be reduced by eliminating “wait.”

This study shows that eliminating three types of waste action (i.e. “wait” in mold stripping, and “walk” and “search” in mold assembly and machining) can improve average daily per worker productivity. Productivity per worker for mold stripping increases from 62.11 to 90.28 square meters per day, or 45.35% (Fig. 10). Productivity for mold assembly and machining increased from 11.72 to 16.39 square meters per day, an increase of 39.86% (Fig. 11).

The main cause of waste is found to be a lack of attention to formwork processes on the part of traditional task administration. As a result, workers focus on job completion. In addition, formwork foremen are not concerned with having an uninterrupted implementation process or building team consensus. Thus each mold worker approaches the implementation process as an individual rather than as a member of a team. After the waste of “waiting” in mold stripping and “walking” and “searching” in mold assembly and machining had been eliminated, the future state value stream map was re-plotted, as shown in Fig. 13.

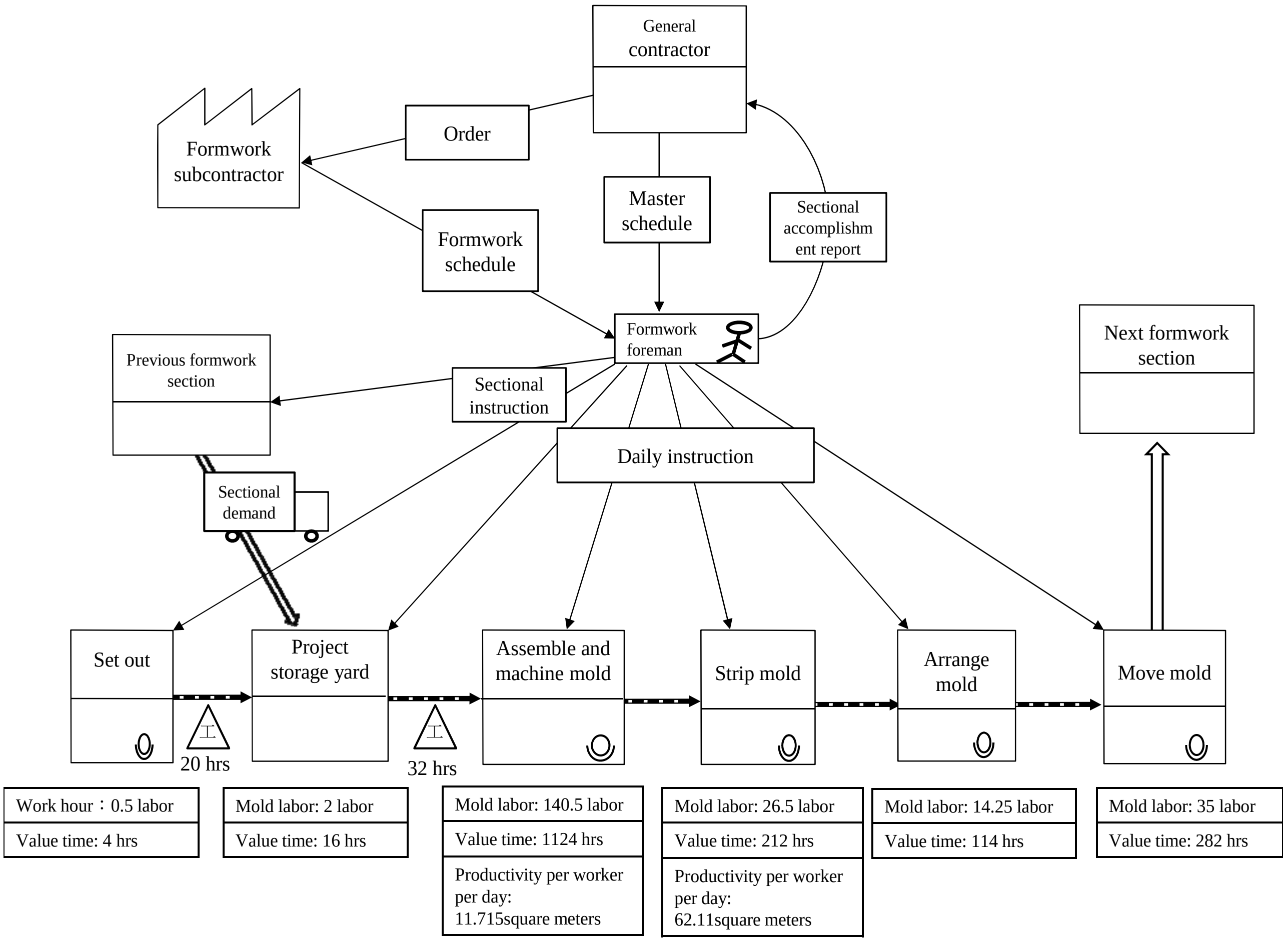

Fig. 8. Current state value stream map

Table 4. Traditional formwork action analysis

Activity	Action	Description	Rate of action
Strip mold	Dismantle	Dismantle back support from panel	9%
	Pry	Pry out panel from concrete surface	19%
	Drop	Drop panels after dismantling	2%
	Walk	Walk to next site for mold dismantling	6.25%
	Move	Move molds to implementation floor from veranda	35%
	Wait	Waiting for material transport	31.2%
Assemble and machine on mold	Measure	Measure the required mold dimensions	5.4%
	Walk	Walk to fetch for plate mold	10.8%
	Search	Search for required mold material	17.7%
	Pull	Pull nails from molds	3%
	Cut	Cut the material	1.8%
	Pass on	Pass on the mold to worker who nails mold in place	7.2%
	Waiting	Wait for assistant to fetch material	6.3%
	Nail	Nail plate mold in position	25%
	Repair	Repair holes caused by deviation	2.9%

Table 5. Action analysis for current implementation state

Formwork activity	Total mold labor	Total value time (hour)	Average productivity per day per worker (m^2)	Action	Ratio of action	Mold labor (labor)	Value time (hour)
Strip mold	26.5	212	62.113	Dismantle	0.09	2.39	19.08
				Pry	0.19	5.04	40.28
				Drop	0.02	0.53	4.24
				Walk	0.06	1.66	13.25
				Move	0.35	9.28	74.2
				Wait	0.31	8.27	66.14
Assemble and machine on mold	140.5	1124	11.715	Measure	0.05	7.59	60.70
				Walk	0.11	15.17	121.39
				Search	0.18	24.87	198.95
				Pull	0.03	4.22	33.72
				Cut	0.02	2.53	20.23
				Pass on	0.07	10.12	80.93
				Wait	0.06	8.85	70.81
				Nail	0.25	35.13	281
				Repair	0.03	4.07	32.60

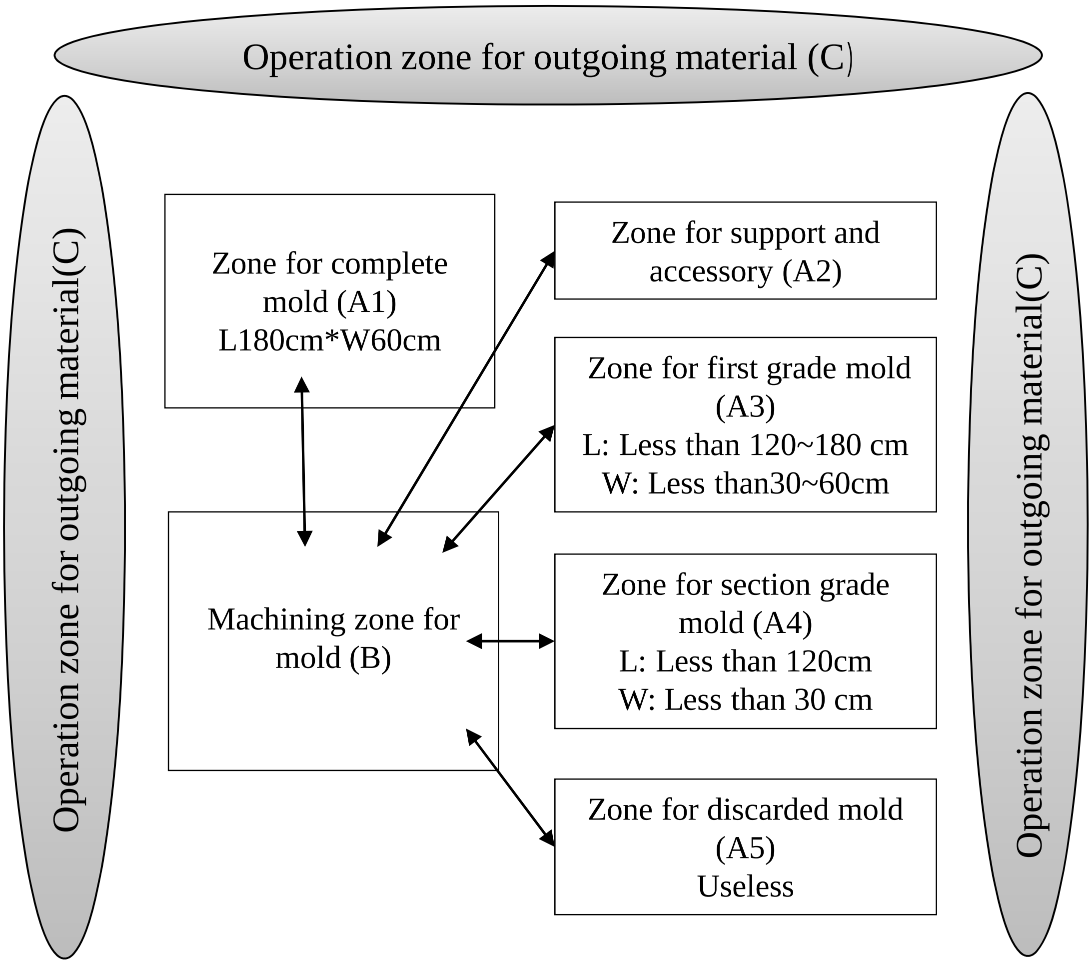

Fig. 9. Formwork operational layout

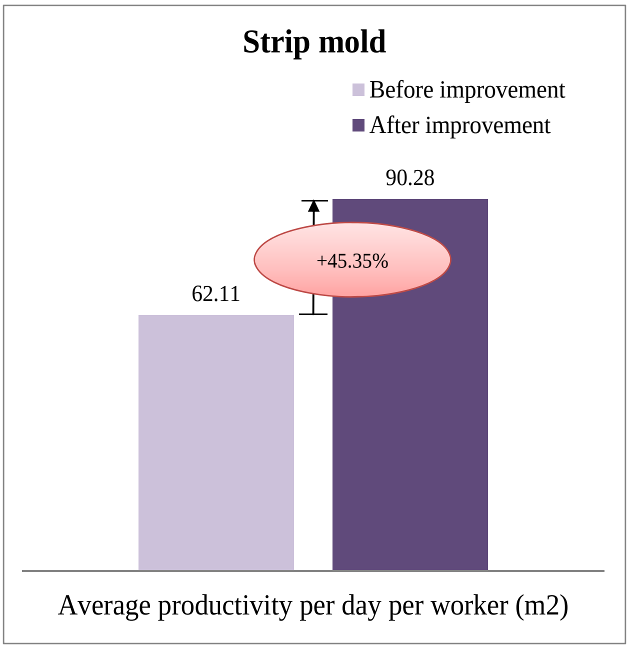

Fig. 10. Mold stripping

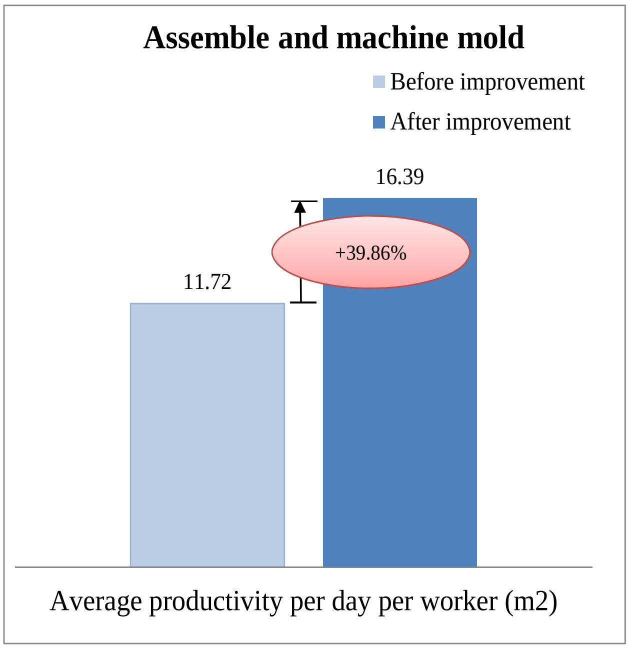

Fig. 11. Mold assembly and machining

Fig. 12 shows that 20 hours of waste in the steel re-bar process can be eliminated by applying production leveling (*heijunka*), along with 32 hours of waste in scaffold processing. These two types of waiting waste are caused by general contractors failing to coordinate with other subcontractors. Fig. 13 shows the general contractor placed an order to the formwork subcontractor. The subcontractor then followed the tota implementation process in sharing out the work load for mold assembly, thus increasing the work load consistency (i.e. leveling the production). The foreman should collaborate on the work content for all support operations including scaffolding, machinery, steel bar and concrete. Drastic fluctuations in construction team demand will cause difficulty in re-deploying manpower and resources, resulting in waste and a failure to achieve uninterrupted processes. To decrease process waste, launch activity can be pulled by the work load of mold assembly and machining. In terms of material supply, considering the demand of mold assembly can allow supermarket method to be adopted. The mold assembly work team lists out all dimensions required on a card to initiate formwork activity. Only work on the construction card is allowed to proceed, thus decreasing waste in the work process. Board machining is a predictable and highly repeatable operation, suitable for standardization. The foreman should respond immediately to any assembly or machining errors.

In mold stripping, the time for dismantling molds on pillars, beams, or walls can be obtained by checking building code standards. A dismantling bulletin board should be posted before and after the concrete pouring operation. A card or other form should be sent to advise the implementation team to dismantle the mold. For instance, the minimum time necessary to dismantle non-support functions like side molds for pillars, beams or walls is 12 hours. This means that stripping work is allowed 12 hours after concrete pouring finishes. If another floor in the building requires mold assembly, the dismantled mold can be moved to that floor for the next assembly job; otherwise, the dismantled mold should be immediately arranged and transported to the next project or mold yard on a first in first out (FIFO) basis, or reused in the same project.

6. Conclusion

This study applied the 4Ps and 14 principles of the Toyota Way to formwork engineering to establish an improvement strategy. Before and after comparisons were made to illustrate the feasibility of the developed strategy. This paper analyzes waste from both action and waiting in traditional formwork engineering. A real example is used to illustrate improvement strategy in practice. Results show that applying the Toyota Way can effectively decrease the mold labor requirements and waste caused by “walking” and “searching” in mold assembly and machining. In addition, “waiting” waste and mold labor requirements can be enhanced in mold stripping.

The Toyota Way and its 14 principles originated in the vehicle manufacturing industry, where the Toyota Motor Corporation spent more than 75 years to establish a culture of continuous improvement. The company goes beyond employee training to cultivate an attitude of introspection, which is at the core of the continuous improvement process. Adopting the Toyota Way could transform formwork engineering by instilling a vision of long term operation and waste eradication. This study describes actual improvements to formwork processes by applying Toyota’s production concepts. Value stream maps identify waste in the formwork engineering, and thus increase operation value. This study offers a growth platform for continuous improvement and learning, allowing construction firms and their extended network of business partners to cultivate excellent individual workers and build excellent implementation teams. This research creates a new philosophy for formwork improvement.

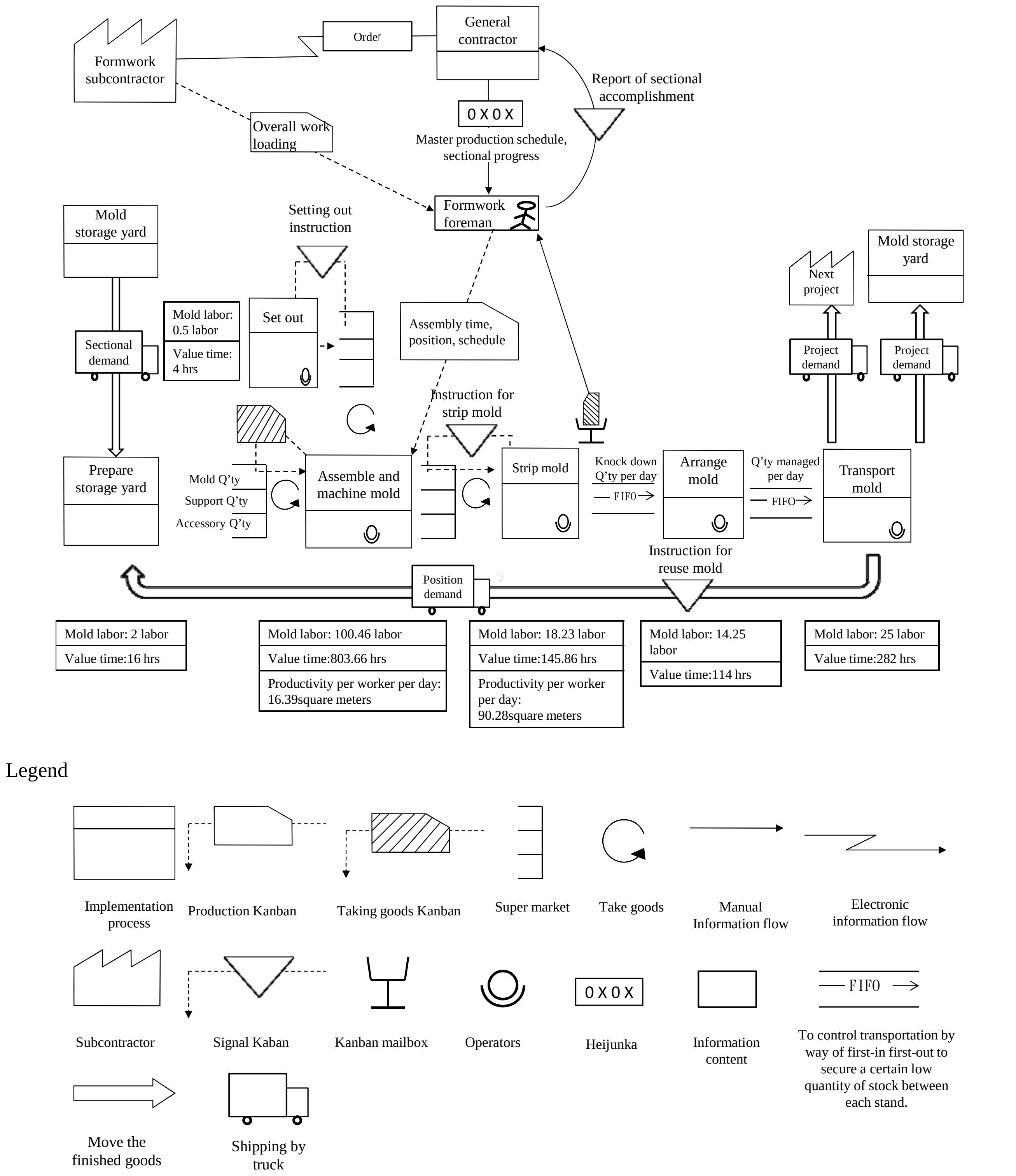

Fig. 12. Future state value stream map

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Dr. Chien-Ho Ko is currently an associate professor in the Civil Engineering Department at National Pingtung University of Science and Technology. He was a faculty member in the Industrial Engineering and Technology Management Department at Da-Yeh University. Prior to this profession, Dr. Ko conducted his postdoctoral research at the University of California at Berkeley, sponsored by government funds of Ministry of Education. He is a registered professional engineer of fire protection. His research encompasses around project production management, robotics, artificial intelligence, and fire protection.

Wei-Chieh Wang is currently a graduate student in the Civil Engineering Department at National Pingtung University of Science and Technology. His research interests are lean construction and system dynamics.

Jiun-De Kuo is a graduate student in the Civil Engineering Department at National Pingtung University of Science and Technology. Before this graduate study, he was an engineer in a professional construction management company. His research focuses on improving formwork engineering.