

TOYOTA PRODUCTION SYSTEM ADOPTED BY BUILDING CONSTRUCTION IN JAPAN

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ABSTRACT

This paper explains the lean construction system that adopts Toyota production system that is applied to building construction in Japan. The introduction of this system to construction site is limited. Only a few contractors and house building companies are introducing this lean construction system.

First, the paper explains the reasons why only a limited number of companies are introducing the lean construction system. The paper then describes the outline of this lean construction system, the effects of this adoption, and compares the details of this lean construction system, car production system, and the conventional construction system in Japan. How to eliminate waste and implement the PDCA cycle in this system are also shown. Finally, the paper explains the importance of education and incentive and motivation in order to obtain useful suggestions that will enhance lean construction.

KEY WORDS

Lean construction. Toyota Production System. PDCA. JIT. Motivation. Incentive. Posting control board. Standard operating procedure documents

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1. IS LEAN CONSTRUCTION NECESSARY FOR CONSTRUCTION PROJECT IN JAPAN?

The national government's budget deficit and economic depression have decreased construction investments to 62% of those in peak periods in Japan over the last decade. Project owners are working on construction cost reductions to implement construction projects with efficiency within limited financial resources. With the size of projects and the unit prices of construction costs reduced, construction companies are in a dire financial condition. Reflecting this situation, about 6,000 companies a year have gone bankrupt from 2000 onward or about twice the figure during the 10-year period between 1990 and 1999. This figure is equivalent to about 1% of the total number of construction companies a year.

Under these circumstances, the construction companies are fighting for survival by making the construction work procedures more efficient and slimming down their organizations. The authors here introduce the building construction projects for which the Toyota Production System was adopted for the first time in Japan to make the construction lean.

2. FUKUDA PRODUCTION SYSTEM (FPS)

2.1 OUTLINE OF THE FPS

The construction companies that adopted the Toyota Production System on a large scale in Japan are Fukuda Corporation in the field of building construction and a couple of companies in the field of housing construction. Fukuda Corp. is a Niigata-based construction company, having annual sales of \$946 million (in 2003). With the objective of making construction work more efficient and reducing construction costs, the company introduced the system into construction work in 2002. In order to introduce the system, the company received guidance from consultants (CULMAN CO.LTD) who were former employees of Toyota Motor Corp. This building production system is called the Fukuda Production System (FPS). The flow of the FPS is shown in Figure 1.

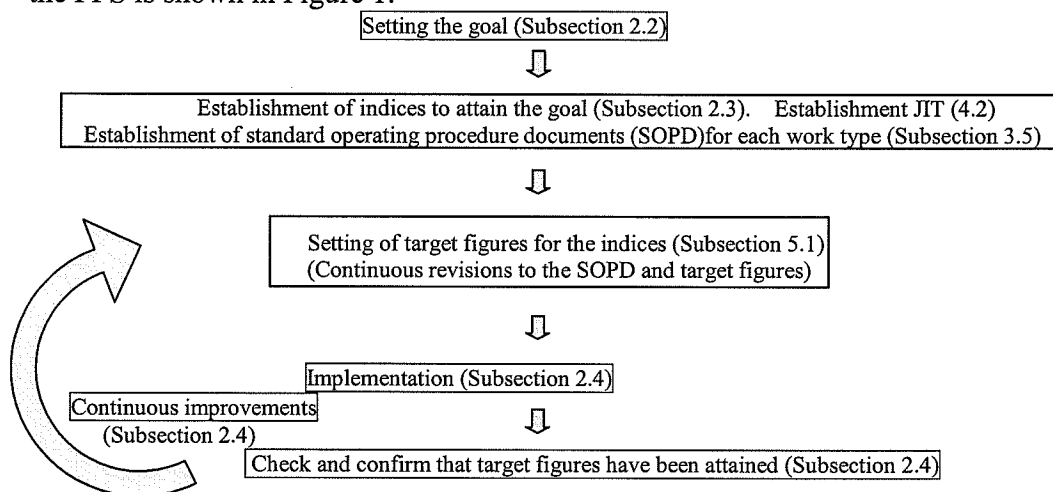


Figure 1: Flow of the FPS

2.2 SETTING THE GOAL

The primary goal of the FPS is to achieve a high level of customer satisfaction. To attain the goal, the following four policies were established:

- (a) Individual perfection of quality assurance;
- (b) Substantial cut in construction lead time (by 30%);
- (c) Establishment of cost standards and then continuous cost targets reducing activities; and
- (d) Continuous improvement by the company and company staff.

2.3 ESTABLISHMENT OF INDICES TO ATTAIN THE GOAL

Conventional cost standards did not always need to make clear the details and duration of activities. So the cost standards are sometimes not very clear. To clarify them, the following three indices were introduced;

- (a) Separation of material and labor costs: in the conventional cost standards for construction work, material and labor costs were in most cases combined. For this reason, there was not much need to make the details of activities clear. Consequently the cost structure was unclear and it was hard to find where waste was present (in material or labor costs). For this reason, the combined costs were separated into material and labor costs. Particularly the costs of materials to be purchased were separated into net material cost, shop fabrication cost, transportation cost, overhead cost and profit to elucidate the presence of waste.
- (b) Review of standard units: conventionally, standard units, such as ton, m, m², m³ and set, were used. Taking structural steel work as an example, ton was used as a standard unit for both large and small structural members. However, it was difficult to understand the work volume using this unit. To make the work volume clear, the unit ton is revised to the unit piece. In addition, the unit m² for interior boards is revised to the unit board for clarification.
- (c) Change of the measure of time for activities: conventionally, the measure of time for activities was working day. However, it was difficult to find wasted time when working day is used for the measure of time. For this reason, the measure of time is changed to working time (by the hour, minute, and second).

2.4 IMPLEMENTATION TO ATTAIN THE GOAL

The waste during construction work is classified into nine types and the policies for continuous reduction of waste are determined, as shown in Section 4.1. This system models after the Toyota Production System.

Checks and confirmation are necessary to see whether the goal is attained. If the goal is not attained, the cause is examined. If the goal is attained, the procedural steps are standardized. In order to set the target figures to a higher level, a factor analysis is also carried out. Major check and confirmation items are as follows:

- (a) Improvement of construction procedure and construction flow
- (b) Man-hour analysis: standardization of procedural steps
- (c) Establishment of individual perfection of quality assurance
- (d) Inspection of reduction of generated volume of construction rubbish

3. BASICS TO ATTAIN THE GOAL

Basically, construction work consists mainly of the physical movement of materials from the origin to design coordinates. Taking concrete work that forms a large proportion of construction work as an example, only the hydration step is a chemical reaction and other steps are nothing but physical movements. Most of other types of work, such as formwork, rebar arrangement work, structural steel erection work, interior finishing work and building frame work, consist of physical movement of materials.

Accordingly, ordinary construction work does not contain many difficult activities. The presence of waste can be found by not only specially trained workers but also by the workers who are experienced in the type of the work if the workers are given incentives and are motivated to reduce waste. What is most important in reducing waste is not the excellent operating ability of a genius but to give incentives to and have motivate all the project members, including contractor and subcontractors, to attain the goal. The following Subsections 3.1 to 3.4 and 3.7 are implemented to increase motivation and Subsections 3.5 and 3.6 are continuously reviewed and improved to attain the goal.

3.1 TRAINING OF WORKERS

When construction workers enter the construction site for the first time, they receive training on the harm of waste, the importance of standard operation procedure and suggesting improvements, and the procedural steps of improvement. In this case, the 9 types of waste (presented in section 4.1) are explained concretely to give them a sense of involvement.

3.2 KEEPING CONSTRUCTION SITE CLEAN LIKE A SHOWROOM

It is necessary for construction companies to make a good impression on the visitors of not only the current customer but also potential customers. The construction site that is clean like a showroom makes a good impression on the visitors and creates a business opportunity. The construction workers who are praised for the clean construction site are motivated to aim at further improvements. For this reason, the following measures are taken:

- (a) Straighten and clean up the construction site and practice good manners (including greetings). The implementation of these activities is checked and shown daily on the inspection board.
- (b) Post a worker working position board to help the workers clearly understand the location, the number of workers, and their activities in the field.
- (c) Post a work schedule and progress control board (Figure 2) to help the workers clearly understand the work progress.

WORKING ITEMS and PERFORMANCE of TODAY

No.	Group name	No. of workers	Morning time			Afternoon time		
			Working items	Target figures	Performance	Working items	Target figures	Performance
1	A	10	5 F Column, Wall form setting	60 m ²	100%			
2	B	8	6 F Shoring	80 m ²	80%			
3	C	4	5 F Beam Rebar Prefabrication	3 T	110%	SAME AS LEFT		
4	D	5	2 F Sash Installation	5 units	100%			
5	E	6	2 F Piping underfloor	20 m ²	90%			

Figure 2 Typical daily work schedule and progress control board

- (d) Post a quality control board (Figure 3) to help the workers clearly understand the quality control conditions.

Interior finishing work quality control board (Room No. 203)

Item	Date	Cleaned	Quality control	Item	Date	Cleaned	Quality control
Installation of sash				Setting tiles on entrance floor			
Fill gap around frames				Laying plaster boards			
Repair of walls and ceiling				Opening holes in boards			
Frame				Installation of kitchen units			
Glass				Hanging cloth wall covering			
Installation of unit bath				Installation of equipment			
Installation of raised floor boards				Flooring			
Installation of furniture				Installation of doors			
Vertical piping and installation of boxes				Sweep/Cleaning up			

* Inspect the quality, straighten and clean up the site after completion of the work to hand over the workplace to the next process. Put the inspector's signature to the board.

Figure 3 Typical interior finishing work quality control board

3.3 POSTING CONTROL BOARDS IN A PROMINENT PLACE

It is important for the workers to share with each other the information regarding target figures and working conditions. If they cannot share identical information, they might carry out work differently from the planned one. Further, misunderstanding often arises between people. If they can obtain information instantly on these occasions, the misunderstandings can be easily corrected. The control boards, such as daily, weekly and monthly work schedule and progress control boards, quality control board, and JIT material delivery control board, are posted in a prominent place. Displaying the control items for each worker raises the worker's awareness that he is playing a leading part in the construction work, which increases the worker's motivation. Further, posting control boards in a prominent place can bring out the presence of waste. For this purpose, the following three measures are adopted:

- (a) Target figures are entered on the work schedule board (Figure 2). The foreman enters the work progress twice – as compared with the target figures of the day – in the morning and in the afternoon. The workers can view and confirm their

work progress at any time, and therefore they can take immediate actions to make up for the delay at their discretion.

- (b) Weekly and monthly work schedule boards are posted to help the workers grasp the work schedule to be attained.
- (c) The quality control board describing the quality control items (Figure 3) is posted at the workplace for the workers to readily check the items. This makes it possible to see whether the conditions constraining the next work step are removed.

3.4 INCENTIVE TO REDUCE WASTE

The company adopted an incentive payment system to give the worker who has reduced waste or suggested an improvement a monetary reward. Although the payment is small, \$ 10per item, many improvements have been suggested. Excellent suggestions are standardized at the head office and applied to construction sites on a nationwide scale. Not only are problems solved but good control methods are adopted. If improvement suggestions are adopted in the field, even if the payment is small, it will give the workers an incentive to suggest improvements.

3.5 ESTABLISHMENT AND REVIEW OF SOPD

Standard operating procedure documents (SOPD) is a manual describing standard operating steps for each work type (including the rebar assembly, setting and removal of forms, installation of sashes, etc) to minimize waste in construction work. In the manual, working method, precautions, and activity duration (by the hour, minute and second) are also described for each work element, including movement, preparatory work, main work and sweeping at the end of the working day. The working method is explained in an easy-to-understand combination of figures and photos. The precautions are described for quality, safety and others. The activity duration is determined from the data accumulated for each work type. If the data is unavailable, the activity duration is determined by timing the duration of work element in the conventional construction system.

3.6 PERFORMANCE OF QUALITY CONTROL ACTIVITIES

The quality control activities are performed in the following four stages:

- (a) At the daily meeting, the field engineer and foreman examine the results of "improvements to reduce waste" and "planned quantity and actual progress" of the day. They discuss measures to improve defective work as well as further increase the efficiency of good work.
- (b) A comparative analysis of planned quantity and actual progress is carried out weekly. The engineer and foreman discuss the necessity for improvements.
- (c) Branch office managers inspect the construction site once a month. Quality control activities at the site are reported, and discussions are held among the site

manager, engineer, and foreman regarding the measures for productivity improvement.

- (d) A summary meeting of quality control activities is held at the head office biannually in the presence of contractors and subcontractors (including executives) to report improvements as well as to motivate the participants to increase productivity.

3.7 GIVING SUBCONTRACTORS AN INCENTIVE TO IMPROVE

Contractor performs improvement activities jointly with subcontractors to build the subcontractors' awareness by showing figures that their profits will increase.

4. FINDING OF WASTE AND CONTINUOUS REDUCTION OF WASTE

4.1 FINDING AND REDUCTION OF WASTE

The 9 types of waste and waste reduction examples are explained below. First 7 types have been proposed by OHNO (1988):

1. Waste of defective production and waste in correction

Defects incur waste because they must be corrected. To prevent the waste, following the Toyota Production System, the workers build quality into products during construction. More exactly, good use is made of the quality control board. Both the field engineer and foreman give a final check for defective quality to eliminate the waste in correction.

2. Waste of overproduction

Waste in the use of materials, equipment and manpower is caused by an ill-considered plan. To prevent waste, a meeting is held to discuss construction methods before commencing the work and the plan is reviewed in the field every day, week, and month, as shown in Figure 5.

3. Waste in processing

Processing in the field often involves waste of fabrication spaces and surplus materials. To reduce waste, pre-cut structural elements are fabricated outside the field.

4. Waste in haulage and walking

Much time is taken to haul and move materials in the field. To prevent the waste in haulage and walking, rules are set so that the materials can be delivered to necessary locations JIT and the flow lines of workers and materials are minimized.

5. Waste of inventory

To prevent an unnecessary inventory, necessary materials and equipment are delivered to the necessary locations at the site JIT. The space for storage of the materials and equipment are minimized and the wasteful motion of looking for materials and equipment in stock are eliminated by the JIT inventory system.

6. Waste of motion

There is waste of net activity duration during the work, such as installation of tiles as an example, the net activity duration can be reduced by the using a rule and jig.

7. Waste in waiting

The waste in waiting is caused when taking over the work to the next work step. To reduce the waste in waiting, the JIT system is adopted, multi-skilled workers are employed and

improvement suggestion activities are carried out. Fig. 4 shows an example of the reduced waste in waiting and the leveled number of workers by these activities. The building construction taken as an example is a 12-storied one-room condominium with a total floor area of 2,300 m².

As shown in Fig. 4, the rebar arrangement work for beams and columns was improved by changing from field assembly to prefabrication and from pressure welding to mechanical jointing of the rebar. The standard activity duration per floor was decreased from 13 days to 8 days by reducing the waste in waiting. However, setting the standard activity duration per floor to 8 days caused the peak of the number of rebar workers on the sixth day in the work cycle, which forced the subcontractor to work too hard. For this reason, by prioritizing unvarying number of workers at all times, the standard activity duration per floor was set to 9 days. The performed quantities per unit of rebar and form works were improved by the reduction of waste in waiting.

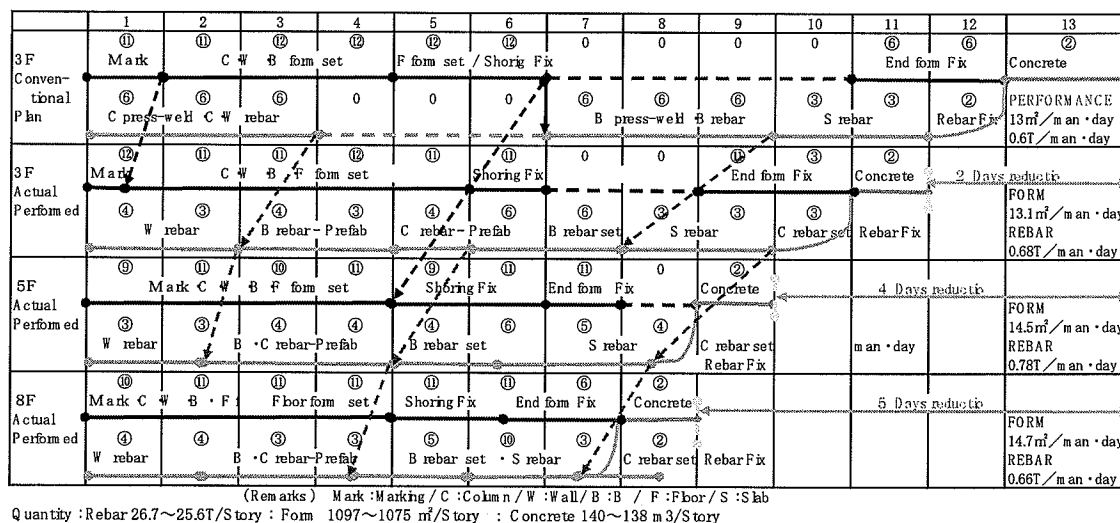


Figure 4 Typical reduction of activity duration

8. Waste in disposing of rubbish

Construction rubbish entails not only cost for disposal and treatment, but also causes waste in storage and haulage. To reduce the rubbish, the following measures were taken.

- To reduce the volumes of rubbish, including packaging materials, the type of packing materials to be delivered to the site is designated.
- The recyclable rubbish generated at the site (such as light gauge steel and particle boards) are loaded onto the trucks, which came from material distribution facilities, for transportation on the return route.
- Target waste emissions are set, weekly emissions graphed and posted in a prominent place to motivate the workers to reduce waste material.

9. Waste in management and planning

Due to an ill-considered plan, time was being wasted in guessing the plan at site, making field adjustments, and doing the work in a haphazard fashion. The waste can be minimized by making a detailed plan, as described in Subsection 2) above.

4.2 JIT(JUST-IN-TIME) SYSTEM

The material distribution facilities were established so that materials can be delivered to the site JIT. In addition, the JIT material distribution network was set up to link the field office, branch offices, and material distribution facilities. Necessary materials are delivered to the predetermined location (Room C on Floor B at Site A, for example) in time. To visualize the JIT delivery process, the JIT delivery system board is posted to boost the awareness "Time is money" among the workers.

5 CYCLE OF PLAN, DO, CHECK AND ACTION (PDCA)

5.1 PDCA FLOW

The cycle of PDCA is important in performing lean construction at the site. The flow diagram of the PDCA cycle is shown in Figure 5.

1) Plan

After contracting the construction work, the site manager prepares the execution plan and a budget using the work quantity and activity duration database at the head office. The site manager, field engineer, and the project members at the head and branch offices get together at the branch office to hold a meeting. The items to be discussed at the meeting include construction method, construction cost, quality, safety and the environmental matters. At the meeting, the figures of the targets to be attained at the site are determined.

The field engineer uses the SOPD in the database at the head office. The field engineer prepares jointly with foreman daily schedule, instructions, weekly and monthly schedules.

2) Do

The flow of construction management of a day is explained below.

- (a) In the morning, the field engineer and workers do the exercises and attend morning assembly. The contractor's engineers provide instructions about the day targets and safety precautions as well as explain the example improvement activities to motivate the workers to improve. After the assembly, the foreman and workers hold a Tool Box Meeting to confirm the contractor's instructions. (Do)
- (b) The work is carried out in accordance with the SOPD. The quantity, specifications and arrival time of the materials and equipment to be delivered to the site are designated for the JIT delivery. (Do)
- (c) During the morning, the site manager and engineer make a site inspection tour to grasp the working conditions. The foreman enters the work progress during the

morning on the daily work schedule and progress control board (Figure 3) before lunch break. (Check)

- (d) The field engineer and foreman hold a meeting in the afternoon. At the meeting, the work schedule of the day and problems are discussed, and remedial measures are decided if there are problems. Defective parts, if any, in the SOPD are corrected. (Action) Considering the remedial measures, the daily schedule and instruction of the following day are prepared (Plan).
- (e) During the afternoon, the site manager and field engineer make a site inspection tour to grasp the working conditions. After completion of the work, the foreman enters the work progress of the day on the daily work schedule and on the progress board. (Check) After completion of the work, the field engineer and foreman hold a meeting to discuss the work progress of the day, problems, and improvements. (Action)

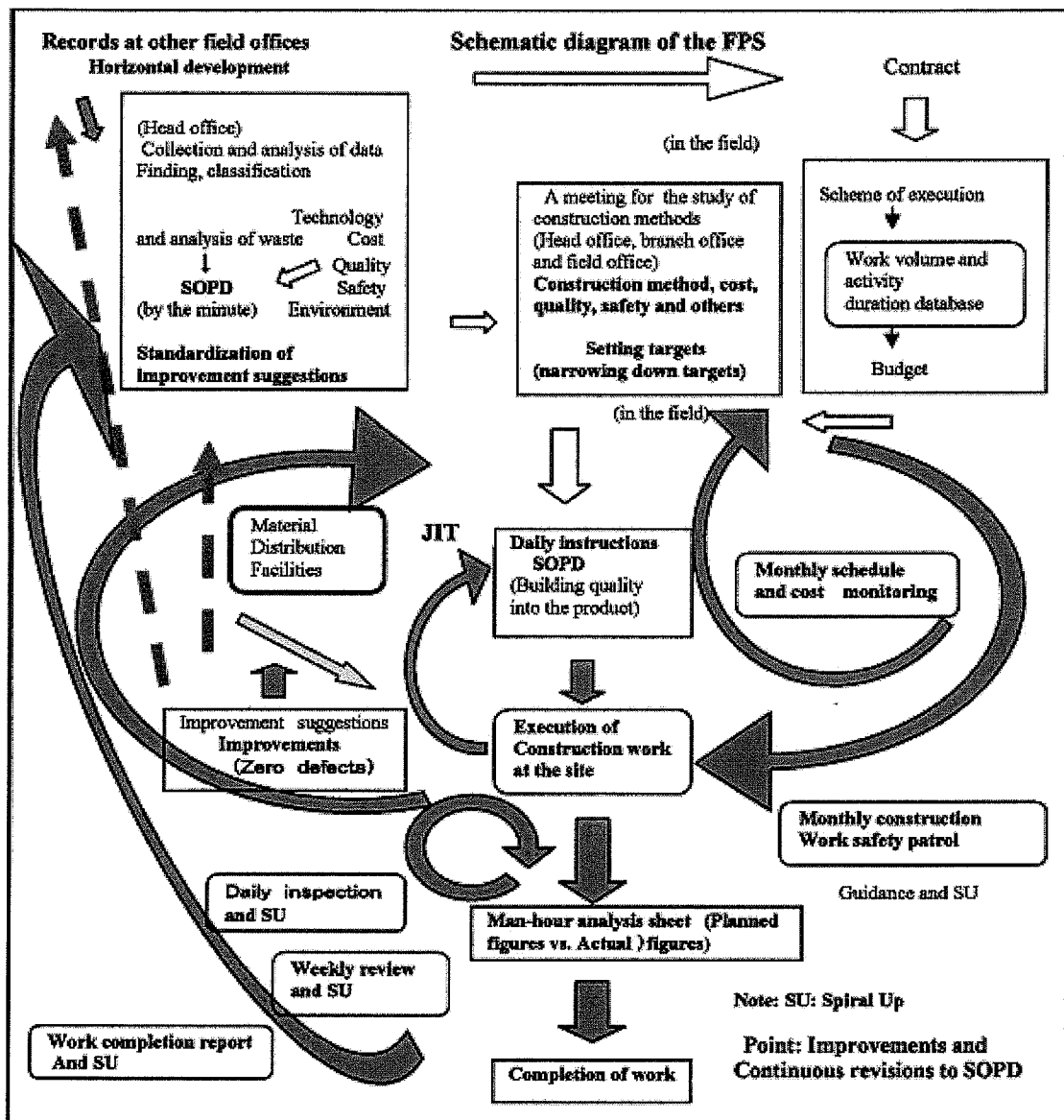


Figure 5 Schematic diagram of the FPS

3) Check and action

- A man-hour analysis sheet is prepared every week based on the planned and actual man-hours for each work type for factor analysis.
- A quality control board is used for quality control.
- Improvement suggestions at the site are reported to the head office. The suggestions judged useful are standardized at the head office and applied to other field offices.

- Branch office managers make a site inspection tour once a month. On this occasion, schedule, man-hours, quality and safety are inspected. The site manager submits a report on improvements concerning the instructions given during the tour of inspection.
- After the work is completed, the man-hour analysis sheet, factor analysis sheet, and improvements to the SOPD are submitted to the head office. At there, these documents are reviewed and deliverables judged useful are standardized for use as a database.

5.2 WORK PROGRESS CONTROL BOARD

The work progress control board is posted so that all workers can clearly see the percentage of completion of the work as compared with the planned progress based on the SOPD. Shown on the board are: (a) SOPD, (b) work location plan, (c) planned and actual progress graphs, and (d) cumulative planned and actual progress graphs.

Displaying the planned and actual progress enables quick understanding of profits and losses as well as boosts the workers' motivation. The contractor and subcontractors probe the cause of the difference between the planned and actual progress, which is helpful in preparing better SOPD.

6. IS CONSTRUCTION WORK SPECIAL?

6.1 PECULIARITIES OF CONSTRUCTION WORK

Table 1 lists the differences between the characteristic features of factory car production and construction work. As can be seen from the table, the construction work involves many uncertainty factors, including outdoor work, single product manufacturing, on-site production, and a strong likelihood of a worker's changing from one construction site to another. For this reason, it has been commonly said that it is difficult to introduce the manufacturing industry's production system into the construction work. To cope with the uncertainty factors, importance has been attached to the experience (know-how: tacit knowledge) of experienced site managers and foremen.

Table 2 compares the major construction companies' conventional construction system with lean construction (the FPS). As can be seen from the table, the FPS makes different efforts from the conventional construction system to eliminate waste: that is (a) standardization of operating procedures, (b) subdivision of SOPD, (c) clarification of target levels, (d) speedy evaluation of planned and actual figures, and (e) raising worker's awareness by posting control boards in a prominent place. This means the disclosure of experienced person's know-how, not tacit knowledge but explicit knowledge.

Table 1 Differences between the characteristic features of factory car production and construction work

	Production volume	Natural conditions	Location of production	Workers
Manufacturing work	Large quantity	Mainly indoor	Factory	Regular workers are in many cases employed for the long term.
Construction work	Single product	Mainly outdoor (susceptible to natural conditions: uncertainty)	Construction site	Workers often change from one construction site to another.

6.2 CAN LEAN CONSTRUCTION DEAL WITH UNCERTAINTY FACTOR?

As previously described in Chapter 3, the construction work consists mainly of the physical movement of materials from the origin to design coordinates. To surmount the uncertainty factors of the construction work, the following assumptions can be made.

- (1) If the scheme of execution is well thought out, the construction method is not changed by the uncertainty factors. What is changed by the factors, such as natural conditions and change of workers at each site, is only the speed at which the work is carried out.
- (2) More specifically, if the procedures of operation are well studied and the SOPD are prepared in such a manner that the flow lines of workers, the sequence of operation, materials and tools become identical (no difference is made in the procedures of operation to the workers → the factors to be judged by the workers are minimized), the difference in the activity duration is dependent on the worker's net operating and moving speeds (= capabilities.)
- (3) Assuming that there is hardly any difference in the worker's net operating and moving speeds among skilled workers, the planned operating efficiency can be readily attained by any worker if a carefully studied standard operation procedures are available.

Table 2 Differences between the FPS and conventional construction system

	Conventional construction system	Lean construction system (FPS)
Cost standards	Material and labor costs are separated, but the cost is not broken down in detail.	Material and labor costs are separated. The costs are broken down in detail.
Relationship between contractor and subcontractors, and between subcontractors	Highly independent of one another in the implementation of work. (Each subcontractor carries out its work responsibly.) The buffer taken for each work type is large.	Closely related to each other in the implementation of work. The buffer taken for each work type is small.
Keeping construction site clean like a showroom, and posting control boards in a prominent place	The workers straighten and clean up construction site and practice good manners. However, they have a little awareness of the importance of keeping construction site clean like a showroom and post control boards in a prominent place.	The workers straighten and clean up construction site and practice good manners, and have growing awareness of the importance to keep construction site clean like a showroom and post control boards in a prominent place.
SOPD	The procedures emphasize work safety.	The procedures emphasize not only safety work but also increased speed and waste elimination. Planned activity duration for each work element is described.
Dissemination of information about planned target figures	The planned target figures are made known to the foreman.	The planned target figures are made known to every worker in a visible form.

Evaluation of planned and actual figures	Planned and actual figures are evaluated and countermeasures worked out at a daily meeting.	The planned and actual figures of the day are made known to every worker in a visible form. The figures are evaluated and countermeasures worked out in detail at a daily meeting.
JIT delivery system	The system is adopted.(In case of urban renewal construction)	Material distribution facilities are set up and the usability of the system is improved.
Improvement suggestions	Workers are encouraged to make suggestions about improvements, and useful suggestions are applied to other field offices.	Same as left. Included in the standard operating procedure
The PDCA Cycle	The PDCA Cycle is held every day, week and month. Safety, schedule, and quality are emphasized.	The PDCA Cycle is held every day, week and month (as shown in Fig.5). Improvement activities in addition to safety, schedule and quality are emphasized.

There is a learning curve (Line A in Fig. 6) showing that the operating efficiency generally increases with time. When a worker changes, the new worker restarts working from the origin (Point ①) of the learning curve, which is undesirable. If workers having similar level of work ability understand the SOPD and target levels and do their work, the effectiveness of lean construction can be inferred by evaluating how the operating efficiency is changed.

Line A is learning curves of conventional systems. If line A (between ②~③) can be instantaneously obtained by lean construction, the effectiveness of the lean construction is proved. Fig. 6 plots the activity duration when four work teams (A, B, C and D) carried out the same work of sheeting. Team A first started operations by the conventional method, the SOPD were prepared when Team A completed the 6th work, and the target activity duration was set to 907 minutes. After Team A completed the 8th work, Teams B, C and D started operations. According to the figure, Team C attained the target activity duration at the second time, and Teams B and D at the first time. Accordingly, it was proved that there was almost no decrease in operation efficiency due to the change of workers and that the above-mentioned assumptions are correct.

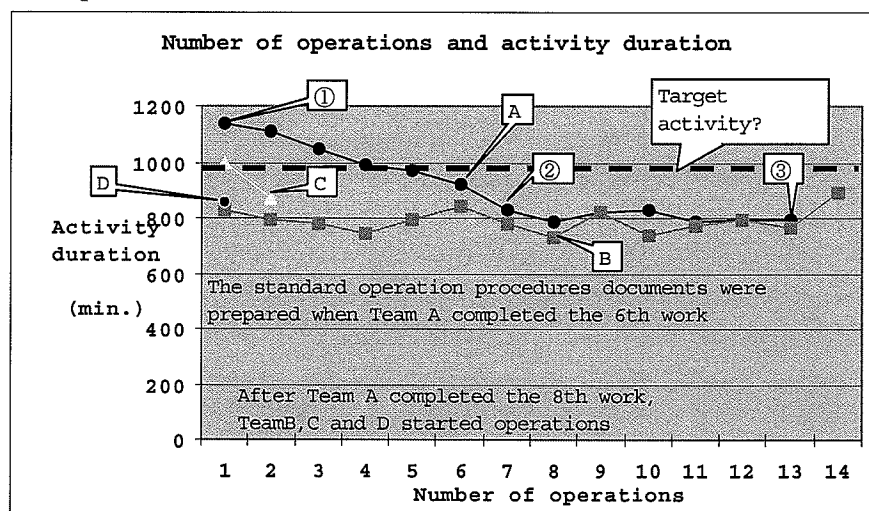


Figure 6 Relationship between the number of operations and activity duration (work of sheeting over a floor and wall: approx. 50 m²)

7. CONCLUSIONS AND DISCUSSIONS

Focusing on the FPS, the authors have compared the conventional construction with lean construction and the factory car production system in Japan, and clarified the following.

- (1) It is effective to introduce the Toyota Production System into the construction work.
 - Construction time can be reduced and the number of workers leveled by eliminating waste.
 - Every worker can easily understand target levels by posting control boards in a prominent place, which leads to increasing the worker's motivation to work.
 - Stable operating efficiency can be promptly obtained by preparing detailed SOPD.
- (2) On the other hand, the daily workload of posting control boards in a prominent place increases. Because repetitive tasks particularly in the construction industry make up a small proportion as compared with the manufacturing industry, the point of importance is how to reduce the workload of collecting data and posting control boards every day. For this purpose, database creation becomes indispensable.
- (3) In the manufacturing industry, even the lowest level worker is on the payroll in general, whereas the workers on a payroll are seldom seen in the construction industry. Accordingly, improvement activities are easily disseminated to every worker in the manufacturing industry, whereas in the construction industry, the activities are disseminated to foreman but it is hard to disseminate the activities to every worker. The important point is how to increase the motivation of every worker.

8. ACKNOWLEDGEMENT

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