Lowland Technology International 2018; 20 (2): 87-94
International Association of Lowland Technology (IALT): ISSN 1344-9656
Special Issue on: Green Technology for Sustainable Infrastructure Development

Research Paper

Building with the on-site manufacturing process

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ARTICLE INFORMATION

Article history:

Received: 30 November, 2016
Received in revised form: 15 January, 2017
Accepted: 21 July, 2017
Publish on: 07 September, 2018

Keywords:

Lean manufacturing process
Construction Cost
Construction period
Building design

ABSTRACT

In general, the process of building construction makes the inevitable wastes such as nails, formwork, steel and concrete. In order to reduce these wastes, parts of building have therefore been produced by using the manufacturing process. This process can improve construction process with minimum wastes and time of construction. However, the manufacturing process is not completely effective for building construction. There is also an additional cost for the transportation from manufactory to the construction site. For this reason, to set the exact time of the construction process, to avoid material waste and to effectively reduce the construction cost, all the production processes of manufacturing building should be started and ended at construction sites. This research has studied the Lean Manufacturing Process (LMP) and applied to the process of the construction which is called “the building with the on-site manufacturing process, BMP” to reduce instable human resource by machines which provides three advantages as follows: 1) the better quality, 2) minimum constructing cost and 3) minimum constructing period.

1. Introduction

The construction paradigm is cost and schedule. It had been focused on getting it done fast and cheap, usually at the expense of one or the other: accelerating schedules would inevitably escalate the cost, while forcing cost reductions usually extend schedules. There are some types of construction projects that the buildings are repeatedly constructed at one construction site such as town-house and multi-unit housing. These projects require long-term construction time and numerous labors (Brioso, 2015). There are many factors that affect the productivity of labor in construction. They are several types of impacts that may occur on a project and then, for each impact, assigns as a percentage loss of labor productivity for minor, average, and severe impact events. Based on the Mechanical Contractors Association of America manual, the subcontractor’s president in Clark Concrete concluded that the company sustained a 60 percent loss of productivity in its work (Gerson, 2011). The impacts considered included: stacking of trades (20 percent loss), concurrent operations (15 percent loss), dilution of supervision (5 percent loss), site access (5 percent loss), out-of-sequence work (10 percent loss),

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Note: Discussion on this paper is open until March 2019

and competition for labor (5 percent loss). Manufacturing and other industries have realized significant improvements in productivity through automation and greater use of information technologies. In construction industry, large Japanese construction companies invested significant resources to automate and integrate processes and technology, using modularization, just-in-time delivery, robotics, rigid supply chain management, and innovations in connections and assembly methods (Ibbs & Sun, 2016). Integrated automatic systems composed of numerous robots and other automated components were used to construct steel and reinforced concrete high rise buildings, among other tasks (Dave et al., 2016). However, the cost of buying and using some of these technologies much higher than the costs of using existing practices. As a consequence, robotics and other types of automated systems were not adopted by the construction industry and are not used widely.

Lean construction is a way to design production systems to minimize waste of materials, time, and effort (Marhani et al., 2012). It aims to optimize the project activity by activity; assuming customer value has been identified in design. Production is managed throughout a project into pieces, i.e. design and construction, then putting those pieces in a logical sequence estimating the time and resource required to complete each activity and therefore the project. Each piece or activity is further decomposed until it is constructed out or assigned to a task leader, foreman or squad boss. Control is conceived as monitoring each contract or activity against its schedule and budget projections.

In addition to employing LMP to reduce the amount of waste and project cost, the research also demonstrates how LMP can improve and develop the efficiency involved in building 2-storey townhouses as the details in **Table 1** below:

Table 1. Tools used to resolve construction problems.

Set	Lean Tools	Objective
1	**Continuous Improvement** - Design of experiment - Root cause analysis	 - Used to find desired information. - Used to identify the causes of problems.
2	**Flow** - Visual control	 - Used to reduce miscommunication.
3	**Flexibility** - Cross trained workers	 - Used to increase flexibility.
4	**Throughput Rate** - Flow cells - Point of used material	 - Used to arrange a plan of action for the building. - Used to reduce the time involved in the building construction.

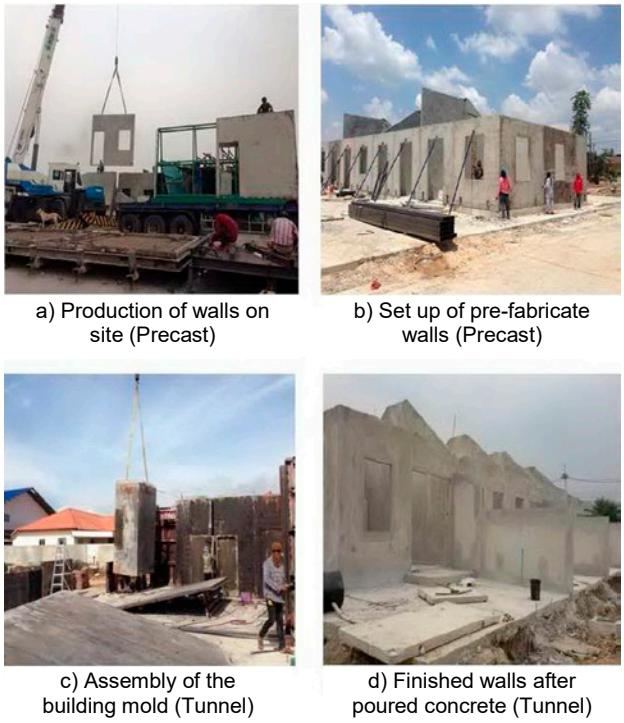
The LMP tool collects all necessary information from the actual day-to-day building construction on site. The information is not edited and Non-Experimental Research was chosen as the basis for the equation:

$$E\text{-}group = NATURE \quad [1]$$

E-group refers to a selection of desired information such as quality information, material information, construction technique, time information, and price information

Nature refers to factual matters about construction information as happens in real-time without additional analysis or alteration.

Once on-site construction begins (Figure 1) the project is separated into Precast System and Tunnel Form System in order to collect building information from these two systems. Collected data will include: time information, price information, and other related information that becomes available throughout the course of the building project



a) Production of walls on site (Precast)
b) Set up of pre-fabricate walls (Precast)
c) Assembly of the building mold (Tunnel)
d) Finished walls after poured concrete (Tunnel)

Fig. 1. On-site Application of LMP.

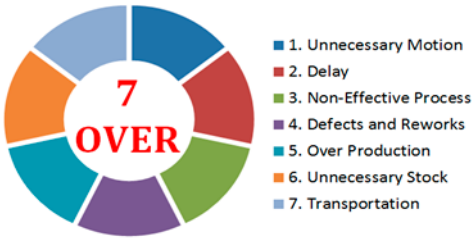


Fig. 2. Waste of Lean.

After which information gathered is classified into 7 LMP types of problems (Figure 2): Unnecessary Motion, Delay, Non-Effective Process, Defects and Reworks, Over Production, Unnecessary Stock and Transportation.

Furthermore, an in-depth analysis all the problems was conducted as outlined in the Case Studying Research (Figure 3). LMP processes were used to solve construction problems and achieve the desired results by the following 5 methods:

Step 1: Grouping

Collecting information, a collector needs some basic knowledge in development and ethics as a researcher and tries to cover all the information data and throughout every step of the development and also collect the data in many different ways from trustful sources: by interview, by related stuff and by document etc.

Step 2: Analyze

The collected information is considered to make an assumption. This is a great way that the researcher to find involved theories to solve the problems

Step 3: Diagnose

Determine causes of each behavior and what happened during the research but if the researcher cannot diagnose the causes of the problems. It is necessary to recollect or regroup the information or the data of the research again.

Step 4: Recommended

After diagnosing the causes of the problems, finding or searching for resolutions which need to be systematic means and be efficient.

Step 5: Follow & Evaluation

This is a process to improve and integrate the resolutions to solve the problems as expected. Following and evaluating helps to measure how the resolutions are working and solved the problems systematically as planned.

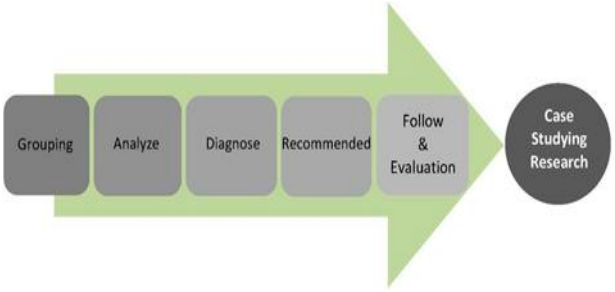


Fig. 3. Case Studying Research.

When the practice of Lean works correctly, there will be three group that get advantages: the group of performance, the group of administration and the group of strategic adjustment. Nowadays, many organizations or companies adapt Lean to make work useful in many ways as following:

- The group of performance of the survey of NIST Manufacturing Extension Partnership, more than 40 companies use Lean and adapt it in their work due to its advantages: Lean time, it decreased 90%, Productivity, it increased 50% and Work in Process Inventory, it decreases 80%.

-The group of administration, Lean reduces the error of ordering, the staff, quitting of the staff as the result that the employment costs less and make sure that the staff has a good performance because they created the standard of performance.

-The group of strategic adjustment extremely reduces the time of work and the goods in the cargo are efficient and Lean eliminates the waste of materials and the cost is much less.

BMP. system helps working better because it eliminates a lot of waste during productivity however everything depends how well to integrate Lean into work.

Table 2. Comparing the advantages and disadvantages of Production.

Philosophy of Scale	Production system	Advantages	Disadvantages
- Economy of scale	- Produce in a great number	-The cost is low - Easy planning and production control. - The highest use of machinery and tools.	- Other waste. - No flexibility when there is a change. - Late resolution.
- Waste-free Production.	- Lean Production	- No cost waste in cargo. - Flexible and simple process. - Immediate resolutions.	- Being complicated for planning and production control. - Need for collaboration from outside suppliers. -Need the variety of skill labor.

This research aims to present the way to apply industrial manufacturing processes to produce some parts of building at the construction area to reduce time of construction, waste of materials and cost of transportation. This research is divided into two parts including; 1) the study of improvement of construction methods to reduce the time, cost and waste by using the principle of the production of industrial goods and; 2) the application of the improvement method to the real construction projects. The selected projects are located in three provinces in Thailand, including Phra Nakhon Siayutthaya Province, Prachin Buri Province and Saraburi Province. Each project includes more than 400 units of two floors townhouse.

2. The producible industry

The principles used in the manufacture of industrial products can be summarized into the following two principles.

2.1 Production Process

Production is a mechanical or chemical process used to produce an object, usually repeated to create multiple unit of the same item. Generally, it involves the use of raw materials, machinery and manpower to create a product. There are three main factors:

1) Input is that all the things must be brought to produce a product. They are divided into three categories including a) materials mean concrete, and wire mesh; b) resource means land, budget, labor, staff, and energy; and c) environment means weather, the laws, tradition.
2) Conversion process is to change the inputs to yield a desired result. This means that a steel binder, assembling a formwork, pouring concrete for building up, tiling a roof and a bathroom installation etc.
3) Output is the final result of production into products. They have already been through the final check completely. It is the time to delivery products to customers with customer satisfaction and feedback before and after the delivery of the building.

2.2 Lean Manufacturing

Lean Manufacturing is using a set of principles to identify and eliminate waste in order to deliver the products that customers want in time or the lean system is a philosophy in production: it is considered that the waste is taking a long time of producing (Shah & Ward, 2003). It should therefore have various techniques to eliminate waste away. The focus of this study is to eliminate losses which occurred during the following processes.

1) Unnecessary motion is such as restricting the movement of formwork and heavy machinery. For the move, it needs to follow the pattern only.
2) Time or delay is to make the system work-flowing continuously such as, preparing materials ready for work on each day. In plus, the replacement of heavy machinery is available in case of any problem happening.
3) Non-effective process is finding ways to make buildings effectively such as, choosing a material for a floor in the building. It needs to use ceramic tiles that require workers with high skills and take much time to do it. So it is unable to avoid humid damage to the tiles. However, on the second floor, it can be compensated with the laminate flooring types at the same price, whose quality can be easily checked and spend less time on building up.
4) Defects and Reworks are the selection of building materials which would be applied in other works or recycle itself such as, the use of a bolt to the formwork tack. The bolt can be reused for multiple times again and again but the nails are only used once and then they must be thrown away. The use of ready-mix cements is mortared for plastering walls to reduce the loss of material abundance.
5) Over Production is a plan to define a target group of client before building by doing a survey and a research of market demand in every time and make sure that before starting to build up, a construction has the sufficient capital for it.
6) Unnecessary Stock is that a construction of the project is required to store the necessary materials in the warehouse properly and enough for the current requirements such as steel bar and wire etc. Some materials are no longer needed to be kept for many; especially, the cement which should be planned to send to a work site daily on a basis.
7) Transportation is a plan to convey materials to the agency continuously. Particularly, the transportation of ready mixed concrete will require a monthly planning as the main plot. Moreover, there should be sub-plans weekly to ship products to achieve a maximum efficient work. As a result, the construction is able to work without disruption. Therefore, there are four indicators being used to evaluate the construction work such as Time Index, Cost Index, Material Index, and Lost Index.

3. Case studies

The structure of the building, in research, is designed in form of flat pieces of the floor and walls. The construction will take concrete forming which combined with the reinforcement of wire mesh as same as the Tunnel form but the difference is that the building in the research will be built in a clear and systematic pattern. Using the technique of reinforced (dowel), the construction is quickly and securely made. Therefore, it is not necessary to masonry-plaster in the building anymore. The research project was located at Ayutthaya province

about 300 units and Saraburi province about 60 units the construction shear wall model.

4. Building with the on-site manufacturing process: BMP System

The definition of a building using building with the on-site manufacturing process: BMP System is, “An eliminating the waste of all kind resources that is in the construction process, whether it could be money, goods and time, those will be eliminated as much as possible until they do not exist anymore". Therefore, a manufacturing system, it is the stage of construction which is concluded the before and after systematic construction process with resources and time fixed. The building will have to be based on the following five processes.

4.1 Structure Design Process

There is a technique in the structural design under the building by the Building Control Act (DPT, 2010), laws and the theories below:

- Design of foundation using Working Stress Design method (ACI 318-14, 2014).
- Design of slab using Flat Slab method (ACI 315-99, 1999).
- Design of wall using Bearing Wall method (Aboul-Ella, 1993)
- Using specially designed steel reinforcement, Subgrade drag and Dowel bar ACI 315-99, 1999).

Once the design is completed, the building will have a feature of structured format bearing unit. The walls and floor structure will have a reinforced concrete slab. The importance is to focus on the added special steel to make a stability of the building and reduce the cracking. Another advantage of the steel special reinforced concrete can be stopped safely.

4.2 Mold Steel Process

A formwork for the construction of townhouse resembles with the formwork system of tunnel form. There is no more the masonry building. Workers can assemble immediately as soon as the casting machines are placed in the desired position without wasting time on lifting the complete formwork. The formwork for the construction can also be used for another building BMP System construction. It is designed to be numerous pieces and lighter for weight of each piece. Therefore, it is increasing efficiency in the narrow workplace. The formworks can be separated into following groups.

4.2.1 Table group: To engage in concrete wall on first layer and second layer.

4.2.2 Frame group: To leave space concrete doors and concrete windows.

4.2.3 Wall group: To engage in fresh concrete exterior walls and interior walls of the building. At once, it can pour concrete for only two rooms. After assembling the plaster formwork, it will be completed in all layers.

4.2.4 Blocked space structure group: To be used for stopping concrete, this mold is used to stop pouring

4.2.5 Special equipment group: To create features to the buildings for beauty such as a gable roof in the front building etc.

4.2.6 The scaffolding and bracket group: To be used for the construction of the wall in the second layer which is bracketed between the outer wall and the inner wall.

4.3 Plan Management process

In general, a building is planned in a schedule, but for the BMP System, it is planned in the equilibrium line throughout the project. Because of the great ability of eliminating the losses and risks in the construction process. The Curve Blue is a S-curved plan which varied during the process of construction. The green line is an equilibrium plan line which eliminates the variability during the construction process. It is able to save construction costs and shorten construction time (Figure 4). The BMP System can also make sub-plans in each of the activities from the main plan as well. So each group of staff knows the exact date and time when they need to work on. The Bar chart at the worksite is able to reduce the conflict in operations. However, the supervisor needs to know well all the plan construction. Due to the construction, any unexpected problem could occur regularly. Therefore, the plan needs to be adjusted appropriately depend on situation.

4.4 Managing Construction Equipment Process

In this study, the two of four-wheel crane with a capacity of 20 tons were moving along the planning system as shown in lines A and B in Figure 5. This ensures the efficient performance.

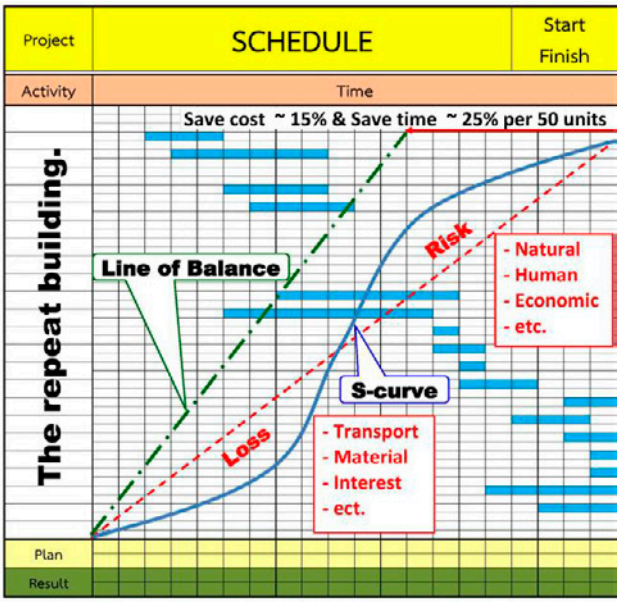


Fig. 4. Compare construction plans.

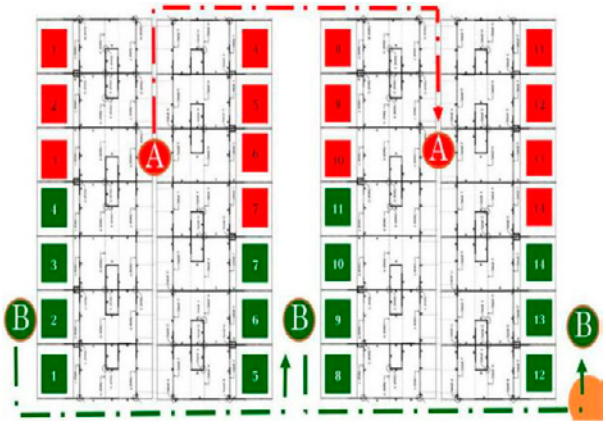


Fig. 5. The movement of the machines along the building.

4.5 The construction process of town house of 7 rooms can be set into five stages.

4.5.1 Constructing the foundation, at this stage, it is not counted as the work. Since there is variety of obstacles during operating such as a pile in incomplete condition or if the problem occurs with the construction foundation, it will spread to the soil erosion or underground water etc.

4.5.2 Pouring concrete on the first layer: the first stage is counted as the period of construction. It will take 7 days at this stage: working on covering soil, pouring lean, the steel reinforcement etc.

1) The area is set in 2 levels: the lower level includes a garage parking space and the space behind the building, the high level is the inner area in the building. Then placing all tubes for sanitation system is completed and some concrete is poured and put some reinforced steel in order to pour concrete on the ground level.
2) Pour the concrete to the ground level then reinforce with steel on the high level.
3) Before pouring concrete on the ground level, the special steel should be inserted exactly as designed.

4.5.3 Pouring the concrete into first layer for the wall and the second layer for the ground. At this stage, it is composed of steel for pouring concrete into walls and floors, all together in one time. In this process, it takes 10 days. There is a working sequence as following stages.

1) Assembling the first layer with steel reinforcement.
2) Assembling the second layer into a block on the floor and a formwork to stop pouring concrete by leave a space about 0.10 meters to pour concrete for the second layer of the wall. For the wall, it is blocked for the door space and the window space.
3) Reinforcement of main and extra steels and placement the block out in order to pour concrete to the ground layer. In this case, it needs to block for pouring concrete to the ground layer because if the internal walls are poured by concrete along the same time, they will not be able to remove the mold.
4) The concrete was required to be with good workability, slump of 16 – 18 cm, the cement has a 28-days compressive strength of about 3500 MPA . For example, the cylindrical (stone 3/8 inch) concrete was made by the head pendant whose size is not larger than 25.4 mm in size. The concrete for the building starts from the middle towards the edge of the building. When the concrete was poured in the ground level, then some more concrete began to pour in the edge of formwork through each steel form and toward the space stop then the concrete stopped. For the space that was blocked for the stairs, the steel reinforcement was needed to prevent tearing of the structure for this segment.
5) Removing the concrete must be taken after at least 12 hours. After removing the formwork, it must be cured with concrete curing compounds immediately. Moreover, find a backing up thing to support under the second level immediately in order to prevent the deflection of concrete which is over standard.
6) When removing the form of a wall and the floor from the first pour, reinforcing steel should be made in order to pour concrete for the door and windows then they will install a framework.

4.5.4 Pouring the concrete for the second level, this stage is assembling steel for using in pouring concrete the second level of the wall. It takes 9 days.

4.5.5 This is the final stage of construction in the building townhouse. The construction of the roof and finishing of the job in this process take 14 days. After removing the first formwork, a frame roof with roof material cover and then plaster some thin concrete are constructed. Next, a sanitary, an electric system, a plumbing, a door, windows and a tiling, etc. were set. This includes all other details of the building until it was complete. The amount of spent time during the construction from the second step to the fifth step 5 takes totally 40 days (Figure 6).

Fig. 6. 2-story-Townhouse Building in the process.

To have the construction completed, there is a need to give the task to each group for the most efficiency. The steps are described by the flow chart, as shown in Figure 7, the number of workers and artisans have been categorized as shown in Table 3, a series of surveys before starting a construction, leads to the pile and the ground level floor.

After that, the foreman will give the task into three teams (Teams A, B and C). Team A's job is to knot the steel through the placement of sleeves until the completion then convey the work to Team B who has to pour the concrete and Team C's job is to assemble and remove the formwork of the building of three teams (Teams A, B and C). The Team C will work and make it possible to deliver the building to the contractor in the other six days at a time. The contractor will have various types, such as tiling the floor, ceiling tiles and painting job. And the contractor will work for another eight days and then deliver a building. For the duration of building a work, it was calculated from the team who used a series of mold. To shorten more time, it can be added more formwork for and more staff team into the system construction.

Table 3. Classification of workers and artisans to follow BMP.

The process of building a town house per one set of formwork	Operator (People)	Period (Day)
1. Footing, Cast Stanchion (Excluding pile)	4	0.50
2. Adjusting floor, Place the steel floor, Pipelines, Casing pipe.	4	0.50
3. The concrete floor	3	0.75
4. To set a formwork the façade the ground floor and floor building two second town.	4	0.50
5. Place the steel floor, Pipelines, Casing pipe the second floor.	4	0.25
6. Work concrete walls of the ground floor and second floor of the building.	3	0.50
7. Place steel wall and install a cast wall for second floor.	4	0.50
8. The two-layer concrete wall with decorative panels.	3	0.50
9. Installation of roof and roofing.	6	2.00
10. Paint, Tiled interior, Bathroom town house.	10-15	8.00

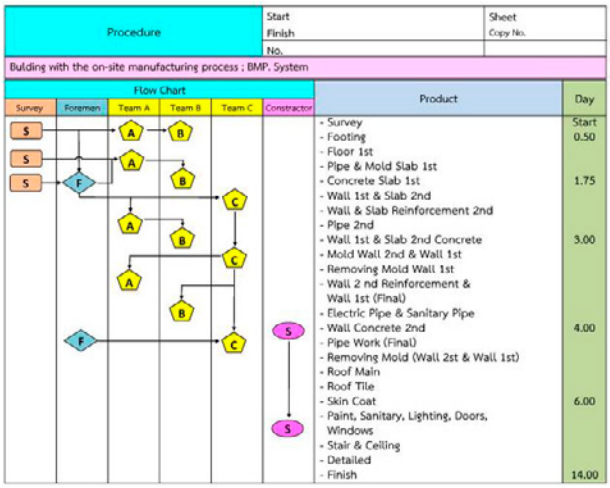


Fig. 7. The control plan building with BMP.

5. Comparison between BMP system and Regular system (RC).

5.1 Time

5.1.1 Regular system

- The construction period takes from 150 to 180 days.

5.1.2 BMP. System

- The construction period takes 49 days.

5.2 Cost

5.2.1 Regular system

- Labor structure needs essentially about 15 to 20 people. The structure is multi-dimensional. It requires

several formworks to assemble up. The skilled workers are required so it leads to employment with a high price. For one unit, the fixed price costs 970,000 baht.

5.2.2 BMP System

- The labor structure takes between 4-6 people. The structure resembles into a flat plate. There is a formwork which has been assembled and it can replace workers effectively.

- The price of building per unit costs from 820,000 baht to the lowest price is 690,000 baht (Information 2015 A.D). The price is variable depend on the amount of construction. Due to the cost of the construction, one mold is used for 150 units (1-series with 2 rooms). The details are as follows.

- The first 50 units of the building construction costs 820,000 bath/unit.
- 51 to100 units of building construction costs 740,000 bath/unit.
- 101 to 150 units of building construction costs 690,000 bath/unit.

5.3 Material

5.3.1 Regular system

- Using building materials such as prop, formwork (wood, steel, PVC), steel, stone, sand, plaster, nails, bolts, bricks for construction. There is a problem of quality control.

5.3.2 BMP System

- The three main types of materials are used in the construction of structure such as concrete, wire mesh and the steel. It makes the good building material management.

5.4 Loss

5.4.1 Regular system

- The loss of building materials costs between 3-5% of the construction price.

5.4.2 BMP System

- The loss of building materials costs less than 1% of the construction price.

6. Conclusion

A construction project begins with drawing and designing a plan and then find a contractor to complete the construction of the building without knowing how contractors will construct a house and the only thing we know is letting them to complete construction as the plan. Therefore, there is a risk of the failure or any other problem like the contractors leave the unfinished construction job etc.

The BMP system process includes a building design and a construction design. By creating a process with step by step, the contractors know therefore the designs and make them happen within the expected time and conditions.

The contractors will not process the construction in the wrong way as a plan that the employer had expected whether the building materials or the machinery that are used in the project. Several projects in Thailand has been successfully constructed by BMP system. The concept of BMP system might be applied as a design method for constructing the other projects with duplicating structures such as the bridge, pipes, road, prevent-erosion bank works etc.

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