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Applying lean thinking in construction and performance improvement

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Abstract The productivity of the construction industry worldwide has been declining over the past 40 years. One approach for improving the situation is using lean construction. Lean construction results from the application of a new form of production management to construction. Essential features of lean construction include a clear set of objectives for the delivery process, aimed at maximizing performance for the customer at the project level, concurrent design, construction, and the application of project control throughout the life cycle of the project from design to delivery. An increasing number of construction academics and professionals have been storming the ramparts of conventional construction management in an effort to deliver better value to owners while making real profits. As a result, lean-based tools have emerged and have been successfully applied to simple and complex construction projects. In general, lean construction projects are easier to manage, safer, completed sooner, and cost less and are of better quality. Significant research remains to complete the translation to construction of lean thinking in Egypt. This research will discuss principles, methods, and implementation phases of lean construction showing the waste in construction and how it could be minimized. The Last Planner System technique, which is an important application of the lean construction concepts and methodologies and is more prevalent, proved that it could enhance the construction management practices in various aspects. Also, it is intended to develop methodology for process evaluation and define areas for improvement based on lean approach principles.

1. Introduction

Since the 1950s, lean production or Toyota production system principles have evolved and were successfully implemented by Toyota Motor Company. Toyota production system had two pillar concepts: (1) Just In Time flow (JIT) and (2) Autonomation (smart automation) as shown in more details in Fig. 1.

The term "lean" was coined by the research team working on international auto production to reflect both the waste

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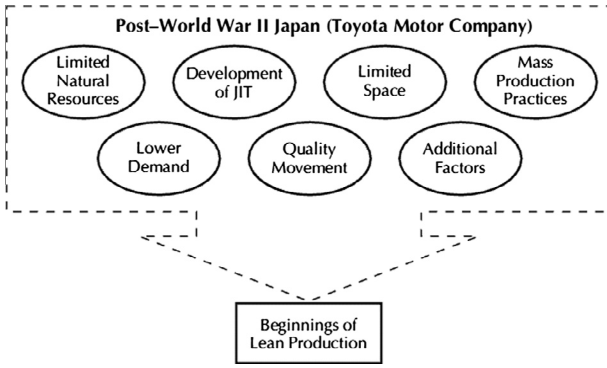

Figure 1 Beginning of lean production [1].

reduction nature of the Toyota production system and to contrast it with craft and mass forms of production [2]. Starting from efforts to reduce machine setup time and influenced by TQM, a simple set of objectives was developed for the design of the production system including to (1) Identify and deliver value to the customer value: eliminate anything that does not add value; (2) Organize production as a continuous flow; (3) Perfect the product and create reliable flow through distributing information and decision making; and (4) Pursue perfection: Deliver on order a product meeting customer requirements with nothing in inventory. Lean production aims to design and make things differentiated from mass and craft forms of production by the objectives and technique, and to optimize performance of the production system against a standard of perfection to meet unique customer requirements. In the beginning of the 1990s, the new production philosophy, which is known by several different names, is as follows: (1) world class manufacturing; (2) lean production; and (3) new production system. This philosophy is the emerging mainstream approach. It is practiced, at least partially, by major manufacturing companies in America and Europe. The new approach has also diffused to new fields, like customized production, services, administration, and product development. Since 1992, Koskela [3] has reported the adaptation of lean production concepts in the construction industry and presented a production management paradigm where production was conceptualized in three complementary ways, namely as (1) Transformation; (2) Flow; and (3) Value generation (TFV) theory of production. This tripartite view of production has led to the birth of lean construction as a discipline that subsumes the transformation-dominated contemporary construction management [4,5]. Managing construction under lean is different from typical contemporary practice because it (1) has a clear set of objectives for the delivery process; (2) is aimed at maximizing performance for the customer at the project level; (3) designs concurrently product and process; and (4) applies production control throughout the life of the project. The first goal of lean construction must be to fully understand the physics of production, the effects of dependence and variation along supply and assembly chains. In lean construction as in much of manufacturing, (1) *Planning*: defining criteria for success and producing strategies for achieving and (2) *Control*: causing events to conform to plan, and triggering learning and re-planning are two sides of a coin that keeps revolving throughout a project. In this research, principles, methods, and the implementation phases of lean construction will be discussed showing the waste in construction and how it could be minimized. The Last Planner System (LPS) technique, which is an important application of the lean construction concepts and methodologies and is more prevalent, proved that it could enhance the construction management practices in various aspects and bring numerous advantages, so that the construction projects will be more stable and less stressful for all involved stakeholders by reducing dependencies and variations to identify and eliminate waste (non-value adding activities).

2. Research background

Construction management and technology are the two key factors influencing the development of the construction industry. Over the past 40 years, although several new and advanced technologies have been applied to construction projects, the efficiency of the industry has remained quite low [6–8]. For example, the productivity of the USA construction industry has been declining since 1964 [9]. A similar decline in construction productivity has also occurred in other countries. Japan, for example, decreased from 3714 to 2731 Yen/Man/Hours over the period of 1990–2004. The main reason for this appears to be that the new technologies cannot effectively reduce the cost of design and construction while, at the same time, improving the management of the construction process. For example, although the Computer Aided Design (CAD) technology has improved the efficiency of drawing, it cannot reduce design errors and these, in turn, can cause the need for rework of construction making it difficult for construction managers to optimize the construction process to reduce cost [10,11]. This is a particularly relevant issue for Design/Build (D/B) projects, where the aim is to reduce cost and increase quality by an improved constructability of the building design. However, the new technologies cannot, as yet, effectively support the implementation of D/B projects. Therefore, the application of both appropriate new technology and contemporary management concepts is likely to be two effective approaches to improve construction industry efficiency. One of the new management philosophies that have been considered for the UK construction industry is that of lean thinking [12]. Lean construction, much like current practice, has the goal of better meeting customer needs while using less of everything, a term coined by the International Group for Lean Construction in 1993, Gleeson and Townend [13] had been investigated by many researchers in recent years. This refers to the application of lean production principles and practices in design–construction processes to maximize value and to reduce waste [14,15]. Some successful experience in implementing lean construction has been achieved. Conte and Gransberg [16], for example, examined the principles used in applying lean construction by over 20 construction companies in Brazil. Similarly, Wright [17] presented several cases involving the use of lean construction. However, the application of lean construction is still in its initial stages. In order to improve the implementation of lean construction, Miller et al. [18] proposed the harmonization between main contractors and subcontractors as a prerequisite, while Thomas et al. [19,20] proposed reducing variability to improve performance and improving labor flow reliability for better productivity as lean construction principles.

Bashford et al. [21] also introduced the production management model into residential construction; it was presented a lean management model for the construction of high-rise apartment buildings, which was developed to LEAPCON that did a simulation of lean construction of high-rise apartment buildings, Sacks et al. [22]. Sacks et al. [23] proposed a building information modeling based on lean production system. Gabriel [24] illustrated through case studies, the developed concept of lean project management, which recognized that the system and philosophy are now better understood by participants, who themselves provide and contribute to the project control mechanisms. The project manager becomes an individual client-based leader of the project team, the source of decision making, and the conduit for communication. The approach had been successful on complex public arts buildings over 10 years and could be of general application on wide range of project management and management by project environments. Al-Sudairi et al. [25] reported interim results of a study to evaluate lean principles when applied to construction using computer simulation. Data for a structural steel erection process were modeled to form the experimental tool for evaluating lean principles. In all cases, the simulated principles improved project performance. Performance improved dramatically when all principles are simultaneously applied. Thomas et al. [26] investigated the lean principle, which more reliable flows lead to better labor performance. Actual data from three bridge construction projects are examined to document the instances of poor flow resource reliability and its effect on labor performance. Inefficient labor hours are calculated. The results showed that there was strong support that more reliable material, information, and equipment availability contributes to better performance. Salem et al. [27] tested the effectiveness of some lean construction tools, in particular, those tools that can be applied in medium size construction firms. Due to the success of the lean production system in manufacturing, the construction industry has adapted lean techniques to eliminate waste and increase profit. A field study was conducted to evaluate the effectiveness of some lean construction techniques. The data collection methods included direct observations, interviews, questionnaires, and documentary analysis. The effectiveness of the lean construction tools was evaluated through the lean implementation measurement standard and performance criteria. It was found that last planner, increased visualization, daily huddle meetings, and first-run studies achieved more effective outcomes than expected. However, the results of implementation of 5S process and fail safe for quality did not meet the expectations of the tool champions and the research team. It was found that there is a need for behavioral changes and training for effective use of lean tools. Most of the lean construction tools, selected for the project, are either ready to use or are recommended with some modifications. Agbulos et al. [28] presented development that involved the improved work methods and engineered productivity standards for the various drainage operations. The work measurement concept was implemented to develop engineered productivity standards for the remaining crews in order to improve their productivity as well focused on six crews. Authors described the application of an industrial engineering philosophy of work measurement of lean production theory and the technique of simulation analysis to capture current work methods, generate and test alternative methods, and develop new productivity standards for drainage maintenance operations crews. Salem et al. [29] proposed a new lean assessment tool to quantify the results of lean implementations. The assessment tool evaluates six lean construction elements including: (1) Last Planner; (2) increased visualization; (3) huddle meetings; (4) first-run studies; (5) five S's; and (6) fail safe for quality. Mao and Zhang [30] developed a construction process reengineering framework and corresponding methodologies that integrate lean principles and computer simulation techniques. Computer simulation techniques are incorporated into the framework to virtually simulate and assess the efficiency and effectiveness of the reengineered construction process that is achieved based on lean principles. Simulation made it easier to quantify and assess the effectiveness and efficiency of the reengineered construction process. Integrating lean principles and computer simulation techniques, the proposed construction reengineering framework was useful and workable in streamlining the construction process for improved productivity, efficiency, and cost effectiveness, which was confirmed by the case study of a tunnel project. Song and Liang [31] observed waste in both project-level contractor coordination and operation level construction performance. A vertically-integrated scheduling system that features location based look-ahead scheduling and graphic weekly work planning was developed to improve project-level contractor coordination. To implement waste elimination solutions at the operation level, construction simulation and 3-D visualization were applied to facilitate lean implementation. Meanwhile, the impact of lean on sustainability was observed and discussed. Deshpande et al. [32] presented the techniques used by a mid-size industrial construction contractor: (1) Purpose built facility; (2) Making decisions at the last responsible moment; (3) Lean audits; and (4) 5S in the design of industrial projects to encapsulate and implement techniques of lean production in the management of design. Shewchuk and Guo [33] proposed a lean approach to panel stacking, panel sequencing, and stack locating, where panels within each stack form a continuous structure and are erected via continuous flow. The objectives were to minimize the quantity of stacks, panel material handling distance, and the work required to position and brace panels. The proposed approach and algorithm result in improved performance have no shape restrictions and always provide feasible solutions. Additionally, computational experiments show that the algorithm outperforms methods being employed in the construction industry today.

3. Research objectives

As a response to the construction problems previously discussed, the research seeks to confirm the following objectives: (1) Determine the implementation of lean ideal; (2) Identify the source of wastes classified under lean construction industry; (3) Examine general perceptions of the construction industry with the lean construction principles of practices; (4) Study reducing and eliminating wastes as classified under development of Last Planner System as a technique of lean construction implementation and to evaluate the effectiveness of implementing last planner to increase plan reliability; (5) Examine the relationship between lean construction and performance improvement programs in construction organizations; and (6) Analyze the characteristics of successful performance improvement programs, and develop a model that identify three critical elements: (a) Time spent on improvement, (b) Improvement skills and mechanisms, and (c) Improvement perspective and goals.

4. Lean journey

Lean implementation begins with leadership commitment and is sustained with a culture of continuous improvement. When the principles are applied properly, dramatic improvements in safety, quality, and efficiency can be achieved at the project level. Improvements at the process and enterprise levels are enablers that make improvements at the project level more successful and allow such improvements to be sustainable [34], Fig. 2.

The lean ideal is to provide a custom product exactly fit for purpose and delivered instantly with no waste to the subsequent actions that may be necessary in order for projects to pursue that ideal [34]. The ability of individuals and organizations to follow this process will vary with position and circumstances, but to the extent possible, the following should be implemented on projects: (1) Select suppliers who are willing to adopt lean project delivery; (2) Structure the project organization to allow money to move in pursuit of the best project-level returns; (3) Define and align project scope, budget, and schedule; (4) Explore adaptation and development of methods; (5) Make design decisions, with explicit alternatives against stated criteria; (5) Practice production control in accordance with lean principles; (6) Build quality and safety into projects; (7) Implement JIT and multi-organizational processes after site demand; (8) Use evaluations and planning on process that transform materials; (9) Use computer modeling to integrate product and process design; (10) Use 5S workshops: a tool for workplace organization and promoting teamwork (S_1) Sort through items, keep what is needed and dispose of what is not; (S_2) Straighten: organize and label everything; (S_3) Shine: clean; which can also expose abnormal and pre-failure conditions; (S_4) Standardize: develop rules to maintain the first three S's; and (S_5) Sustain: manage to maintain a stabilized workplace and initiate continuous improvement when needed and (11) Apply Value Stream Mapping to make visible all the steps in process. These can be organized specially for projects and preceded by a pre-project phase [34].

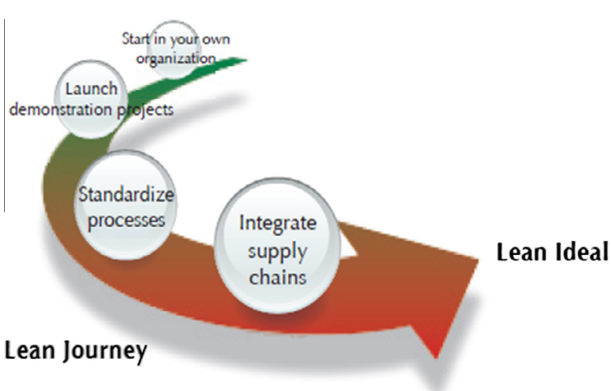

Figure 2 Lean journey to implement lean ideal [34].

5. Construction wastes

Construction management suffers many problems and the majority is practical which need to be solved or better understood. As a result, the construction industry is overwhelmed by delay and often has suffered cost and time overrun. Alsehaimi and Koskela [35] reported that the poor project management was a dominant and common reason for delay in construction projects. Consequently, these problems associated with management, in particular, should be understood, and efforts need to be directed toward developing solutions and more efficient methods of operation [36]. The introduction of new production philosophies in construction requires new measures of performance Koskela [3], such as waste, value, cycle time or variability. UK studies indicated that up to 30% of construction is rework, only 40–60% of potential labor efficiency, accidents can account for 3–6% of total costs, and at least 10% of materials are wasted. The cost of rework in Australian construction projects has been reported as being up to 35% of total project costs and contributes as much as 50% of a project's total overrun costs. In fact, rework is one of the primary factors contributing to the Australian construction industry's poor performance and productivity [37]. In general, a very high level of wastes/non-value added activities is assumed to exist in construction, and it is difficult to measure all waste in construction. Several partial studies from various countries have confirmed that wastes in construction industry represent a relatively large percentage of production cost. The existences of significant number of wastes in the construction have depleted overall performance and productivity of the industry, and certain serious measures have to be taken to rectify the current situation. Waste measures are more effective to support process management, since they enable some operational costs to be properly modeled and generate information that is usually meaningful for the employees, creating conditions to implement decentralized control. Fig. 3 shows the waste percentages of time in manufacturing and construction.

Waste has been defined by Alarcon [39] as ''Anything different from the absolute minimum amount of resources of materials, equipment and manpower, necessary to add value to the product.'' In general, any losses produced by activities that generate direct or indirect costs but do not add value to the product from the point of view of the client can be called ''waste.'' Waste is measured in terms of costs; other types of waste are related to the efficiency of the processes, equipment or personnel, and are more difficult to be measured because the

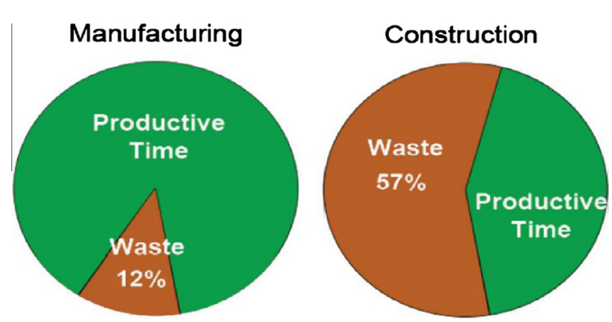

Figure 3 Waste percentages of time in manufacturing and construction [38].

optimal efficiency is not always known. Value adding and non-value adding activities can be defined as follows [39]: (1) Value adding activities: Those which convert materials and/or information in the search to meet client's requirements and (2) Non-value adding activities (waste): Those which are time, resource, or space consuming, but do not add value to the product. Waste in the construction industry has been the subject of several research projects around the world in recent years. However, most studies tend to focus on the waste of materials, which is only one of the resources involved in the construction process. This seems to be related to the fact that most studies are based on the conversion model, in which material losses are considered to be synonymous of waste. Formoso et al. [40] stated that many people in the industry have considered wastes are directly associated with the debris removed from the site and disposed of in landfills, and they suggested that the main reason for this relatively narrow view of waste is perhaps the fact that it is relatively easy to see and measure. The main focus for those conventional material waste studies in construction is seen to be restricted to physical waste or material waste in construction and/or the specific impacts due to the physical waste itself. Formoso et al. [41] had significantly grouped some researches and studies, done by other researchers around the world on the wastes in construction, into two main aspects based on the impacts of the construction waste: (1) Researches and studies mostly focused on the environmental impacts that result from the generation of material waste, aimed to reduce the generation of waste at source and to propose alternative methods for treatment of construction waste in order to reduce the demand for final disposal areas, others concerned with the measurement and prevention of construction waste, regarding sustainability requirements stated by Dutch environmental policies; (2) Researches and studies mostly concerned with the economic impacts of waste in the construction industry and concluded that there was a considerable amount of waste that can be avoided by adopting relatively simple prevention procedures. Other researches also pointed out that storage and handling were major causes of waste, while most of the problems concerning waste on building sites are related to flaws in the management system and have very little to do with the lack of qualification of workers. Basically, Koskela [3] has been looking for the evidences of waste and value loss due to (1) Quality of works; (2) Constructability; (3) Material management; (4) Non-productive time; and (5) Safety issues. Formoso et al. [41] proposed the main classification of waste based on the analysis of some Brazilian building sites they had carried out as (1) *Overproduction*: related to the production of a quantity greater than required or earlier than necessary. This may cause waste of materials, man hours, or equipment usage. It usually produces inventories of unfinished products or even their total loss, in the case of materials that can deteriorate. An example of this kind of waste is the overproduction of mortar that cannot be used on time; (2) *Substitution*: is monetary waste caused by the substitution of a material by a more expensive one (with unnecessary better performance); the execution of simple tasks by an overqualified worker; or the use of highly sophisticated equipment where a much simpler one would be enough; (3) *Waiting time*: related to the idle time caused by lack of synchronization and leveling of material flows and pace of work by different groups or equipment. One example is the idle time caused by the lack of material or by lack of work place available for a gang; (4) *Transportation*: concerned with the internal movement of materials on site. Excessive handling, the use of inadequate equipment or bad conditions of pathways, can cause this kind of waste. It is usually related to poor layout and the lack of planning of material flows. Its main consequences are as follows: waste of man hours, waste of energy, waste of space on site, and the possibility of material waste during transportation; (5) *Processing*: related to the nature of the processing (conversion) activity, which could only be avoided by changing construction technology. For instance, a percentage of mortar is usually wasted when a ceiling is being plastered; (6) *Inventories*: related to excessive or unnecessary inventories which lead to material waste (by deterioration, losses due to inadequate stock conditions on site, robbery, and vandalism) and monetary losses due to the capital that is tied up. It might be a result of lack of resource planning or uncertainty on the estimation of quantities; (7) *Movement*: concerned with unnecessary or inefficient movements made by workers during their job. This might be caused by inadequate equipment, ineffective work methods, or poor arrangement of the working place; (8) *Production of defective products*: it occurs when the final or intermediate product does not fit the quality specifications. This may lead to rework or incorporation of unnecessary materials to the building (indirect waste), such as the excessive thickness of plastering. It can be caused by a wide range of reasons: poor design and specification, lack of planning and control, poor qualification of the team work, lack of integration between design and production, etc.; and (9) *Others*: waste of any other nature than the previous ones, such as burglary, vandalism, inclement weather, and accidents. Alarcon [39] divided the controllable wastes into three different activities, which associate with flows, conversions, and management activities: (1) *Controllable causes associated with flows*: (a) Resources: (i) Materials: lack of materials at the work place; materials are not well distributed; inadequate transportation means; (ii) Equipment: non-availability; inefficient utilization; inadequate equipment for work needs; and (iii) Labor: personal attitudes of workers; rebellion of workers; and (b) Information: (i) Lack of information; (ii) Poor information quality; and (iii) Timing of delivery is inadequate; (2) *Controllable causes associated with conversions*: (a) Method: (i) Deficient design of work crews; (ii) Inadequate procedures; and (iii) Inadequate support to work activities; (b) Planning (i) Lack of work space; (ii) Too much people working in reduced space; and (iii) Poor work conditions; and (c) Quality: (i) Poor execution of work; and (ii) Damages to work already finished; and (3) *Controllable causes associated with management activities*: (a) Decision making: (i) Poor allocation of work to labor; and (ii) Poor distribution of personnel; and (b) Ineffective supervision/control: Poor or lack of supervision. Modeling, evaluation of wastes, and performance in construction projects have been a challenge for the construction industry for decades. Several models and procedures have been proposed for the evaluation of project performance at site and project level. Some of these models focus on prediction of project performance while others focus on measuring. Traditional models offer only a limited set of measures as most of them limit their analysis to a number of measures such as cost, schedule, or productivity (usually labor productivity). The shortcomings of the traditional control systems and models are unable or not appropriate to measure those new performance elements but Alarcon [39] suggested that some of the concepts developed in previous researches can be utilized in modeling new performance elements for construction required for continued improvement. It is worthwhile to point out some opinions of different researchers and authors related to the extent of performance elements in the aspects of construction process. He has characterized performance in seven criteria or elements on which management should focus its efforts on as: (1) *Effectiveness*: A measure of accomplishment of things; (2) *Efficiency*: A measure of utilization of resources. It can be represented as a ratio of resource expected to be consumed divided by the resources actually consumed; (3) *Quality*: A measure of conformance with specifications; (4) *Productivity*: Theoretically, this is defined as a ratio between output and input, and it is primary measured in terms of cost. In the context of the construction industry, the output is the structure or facility that is built or some components of it. The major input into construction process includes work force, materials, equipment, management, energy, and capital; (5) *Quality of work life*: A measure of employee's affective response to working and living in organizational systems. Often, the management focus is on insuring that employees are satisfied, safe, and secure and so forth; (6) *Innovation*: This is the creative adaptation process of product, service, process, or structure in response to internal; as well as external; pressures, demands, and changes, needs and so forth; and (7) *Profitability*: A measure or a set of measures of relationships between financial resources and uses for those financial resources.

6. Lean thinking principles

There are five fundamental principles for lean thinking, which have to be followed step by step to gain the maximum benefit of the lean success: (1) *Specify Value*: Specify value from customer's own definition and needs and identify the value of activities, which generate value to the end product; (2) *Identify the Value Stream*: Identify the value stream by elimination of everything, which does not generate value to the end product. This means, stop the production when something is going wrong and change it immediately. Processes which have to be avoided are miss production, overproduction (repeat production of the same type of product, etc.), storage of materials and unnecessary processes, transport of materials, movement of labor workforces and products, and finally production of products which does not live up to the wished standard of the customer as well as all kind of unnecessary waiting time; (3) *Flow*: Ensure that there is a continuous flow in the process and value chain by focusing on the entire supply chain. Focus has to be on the process and not at the end product. However, the flow will never get optimal until customer value is specified, and the value stream is identified; (4) *Pull*: Use pull in the production and construction process instead of push. This means produce exactly what the customer wants at the time the customer needs it and always prepared for changes made by customer. The idea is to reduce unnecessary production and to use the management tool "Just In Time"; and (5) *Perfection*: Aims at the perfect solution and continuous improvements. Deliver a product which lives up to customer's needs and expectations within the agreed time schedule and in a perfect condition without mistakes and defects. The only way to do so is by having a close communication with the customer/client as well as managers, and employees are between. Fig. 4 summarizes examples of lean tools already used in job sites.

Koskela [3] has summarized lean thinking into eleven principles which are (1) Reduce the share of non-value adding activities (waste); (2) Increase output value through systematic consideration of customer requirements; (3) Reduce variability; (4) Reduce cycle times; (5) Simplify by minimizing the number of steps, parts and linkages; (6) Increase output flexibility; (7) Increase process transparency; (8) Focus control on the complete process; (9) Build continuous improvement into the process; (10) Balance flow improvement with conversion improvement; and (11) Benchmark. There are fourteen principles organized in four categories: (1) Philosophy; (2) Process; (3) People and Partners; and (4) Problem Solving, as seen in Fig. 5 [43].

The fourteen (14) management principles of the lean way are as follows: (1) Base decisions on long-term philosophy even at the expense of short-term financial goals (Philosophy); (2) Create continuous process flow to bring problems to the surface (Process); (3) Use "Pull" systems to avoid overproduction (Process); (4) Level out the workload (Process); (5) Build a culture of stopping to fix problems to get quality right the first time (Process); (6) Standardized tasks are the foundation for continuous improvement and employee empowerment (Process); (7) Use visual control so no problems are hidden (Process); (8) Use only reliable, thoroughly tested technology that serves people and processes (Process); (9) Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others (People and Partners); (10) Develop exceptional people and teams who follow your company's philosophy (People and Partners); (11) Respect your extended network of partners and suppliers by challenging them and helping them improve (People and Partners); (12) Go and see for yourself to thoroughly understand the situation (Problem Solving); (13) Make decisions slowly by consensus, thoroughly considering all options; implement rapidly (Problem Solving); and (14) Become a learning organization through relentless reflection and continuous improvement (Problem Solving).

7. Lean construction techniques

Lean construction is a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value [4]. Lean Construction is using the same principles as lean production to reduce waste and increase the productivity and effectiveness in construction work. The most important determinants of construction are supposed to be workflow reliability and labor flow, but lean construction has changed the traditional view of the project as transformation, and embraces the concept of flow and value generation. Similarly, it shares the same objectives of lean production, e.g., cycle time reduction, elimination of waste, and variability reduction. Continuous improvement, pull production control, and continuous flow have been the direction for the implementation of lean construction. Lean construction is composed of the following techniques [44]: (1) *Concurrent Engineering*: Concurrent engineering can be described as parallel execution of various tasks by multidisciplinary teams with the goal of obtaining most favorable products concerning functionality, quality, and productivity. Many enhancements can be accomplished by using concurrent engineering. Scheduling could be recovered by network analysis

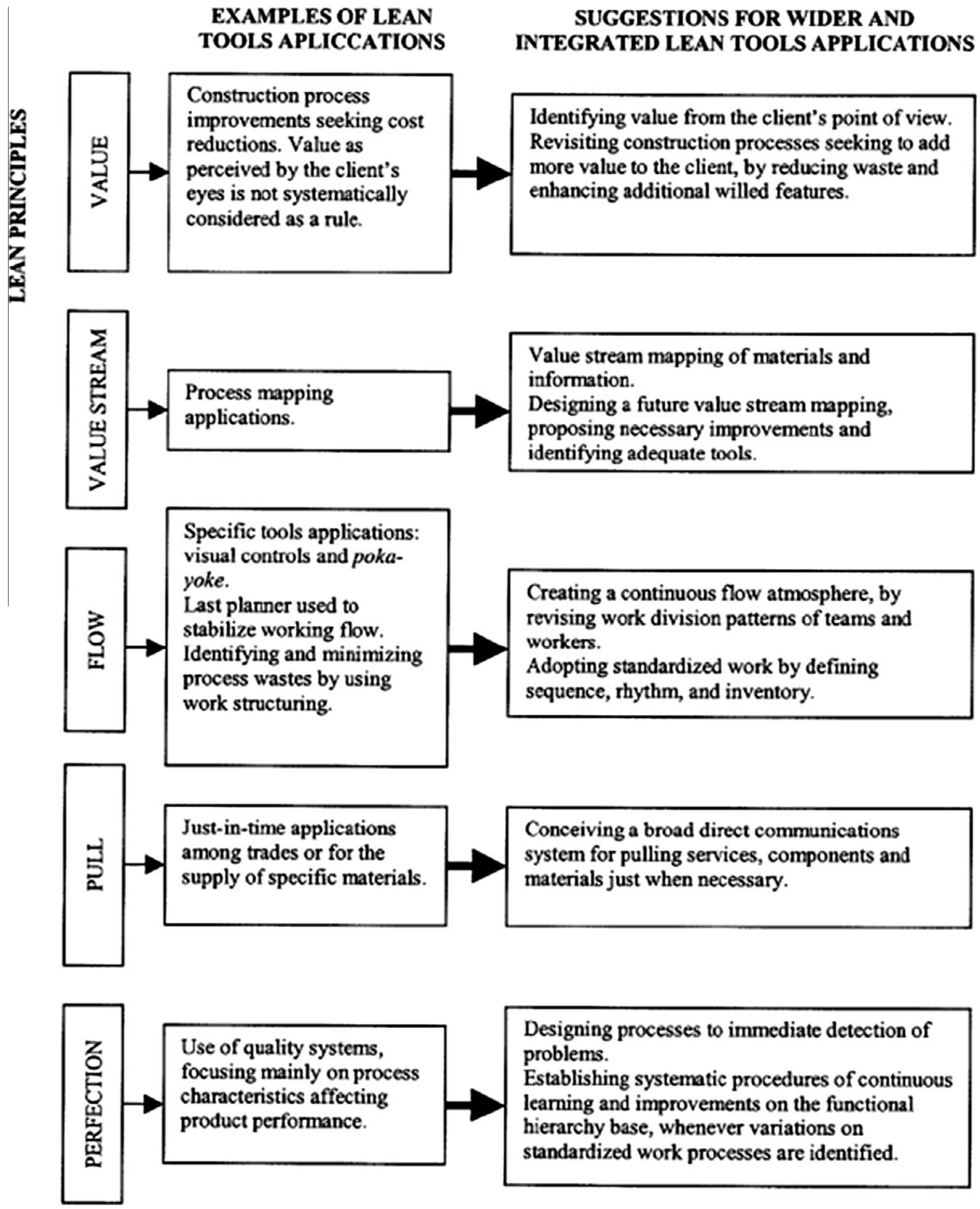

Figure 4 Examples of lean tools in construction implementation and suggestions [42].

(CPM and PERT). Many other opportunities can be achieved through overlapping activities, splitting activities and reducing the transfer time between different activities. The important planning parameters for scheduling concurrent activities are lead time, quantity, and risk under ambiguity. Concurrent engineering is focusing on the team efforts; communication and information sharing are the keys for discovering new ideas. While partnering with subcontractors and suppliers can also be good changes regarding concurrent engineering, the success of lean production is depending on the involvement of all participants in the early stages of the design; (2) *Last planner*: The last planner is the person or group of people responsible for production unit control, which means completion of individual tasks at the operational level. Last planner necessitates work flow control, ascertaining the stream of supply, design, and installation throughout production units. This can only be done by using look-ahead schedule, which determines the progression and rate of work. It carves up the master schedule into many packages, specifying the techniques of check capacity, execution, and establishes a stockpile of standing by work. The scope of look-ahead schedule ranges from 2 to 6 weeks and should be put in order by team work; (3) *Daily huddle meetings*: Daily huddle meetings provides a platform for the team members to share their views and to share what has been achieved, at the same time, discus problems they are facing during the production process; (4) *The Kanban System*: The strategy of Kanban is grounded on key components, i.e., market place, supplier kanbans, collection vehicle, satellite stores, and inventory management system. Market places are site warehouse that allocate different materials and small tools to the workers. Similarly, satellite stores are situated on site, where they get products from market places. Collection vehicle collects materials from preferred suppliers to the operational site. Kanban use plastic bins as a signal to pull materials from

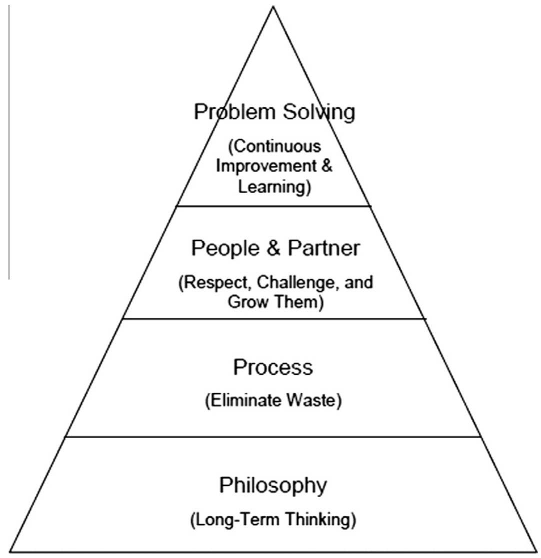

Figure 5 "4P" of the lean way [43].

suppliers to site, using the concept of Just In Time. Request forms are normally used as kanban signals between market place and satellite stores. The system of kanban starts normally with open doors, so that the site can pull materials from the supplier up to certain perimeters. Subsequently, the material requested from suppliers arrives at market, and products are later on picked from the stores, which are usually managed by recorder points; (5) *Plan Conditions and Work Environment in the Construction Industry (PCMAT)*: The purpose is to introduce a plan of health and safety into the project execution, called "Plan of Condition and Work Environment." These safety activities can generate limitations for scheduled tasks and that is why it should be embraced as a part of assignments. All safety practices are therefore amalgamated in short-term planning, which can be analyzed through daily feedback from crew and subcontractors respectively; (6) *Quality Management Tools*: The fusion of quality management tools in the lean construction is based on the change from conformance based quality to the quality at the source. A point system is normally employed to evaluate the execution of planned controls, which will help workers to follow planned controls instead of quality corrections; and (7) *Visual Inspection*: Visual inspection shows the uneven nature of the construction and leads to the application of visual tools for material, work and information flow, etc. Identification of materials can accelerate repetitive processes and diminishes the risk of selecting wrong product. Progress charts and schedules can implement the dedication to the completion of tasks. Information and technology can also improve the communication between decision maker and executer, and can accelerate the process as well. The Lean Construction Institute [38] described how current projects are to be managed and defines the project management as follows: (1) Determine client requirements and design to meet them; (2) Align design to quality, schedule, and budget limits; (3) Manage the project by breaking it into pieces, estimating duration and resource requirements for each piece, and then put the pieces in a logical order with Critical Path Method (CPM); (4) Assign or contract for each piece, give start notice and monitor each piece to assure it meets safety, quality, schedule and cost standards. Take action on negative variance from standards; (5) Coordinate using the master schedule and weekly meetings; (6) Cost may be reduced by productivity improvement; (7) Duration may be reduced by speeding each piece or changing logic; and (8) Quality and safety get better with inspection and enforcement.

8. Application channels of lean construction

8.1. Lean Project Delivery System (LPDS)

The Lean Project Delivery System is a set of interdependent functions, rules of decision making, procedures for execution of functions, and as implementation aids and tools, including software when appropriate, and is a conceptual framework developed by Ballard [45] to guide the implementation of lean construction on project-based production systems. LPDS was depicted as a model with five main phases, where each phase is comprised of three modules; see Fig. 6. The interdependence

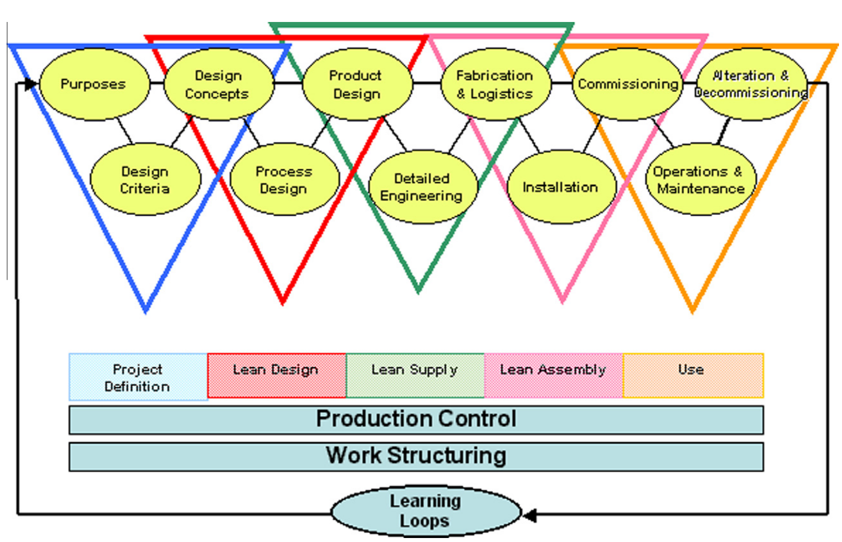

Figure 6 Lean project delivery system [43].

between the phases was represented by sharing one module between two subsequent phases. Production control and lean work structuring were both shown to extend throughout the five main phases. Learning was introduced to underscore the need to document lessons learned from one engagement to another.

The LPDS model consists of 15 modules, 11 organized in 4 interconnecting triads extending from project definition to design to supply and assembly, plus 2 production control modules and work structuring module, both conceived to extend through all project phases, and the post-occupancy evaluation module, which links the end of one project phase to the beginning of the next: (1) *Project Definition*: (a) Needs and Values Determination; (b) Design Criteria; and (c) Conceptual Design; (2) *Lean Design*: (a) Conceptual Design; (b) Process Design; and (c) Product Design; (3) *Lean Supply*: (a) Product Design; (b) Detailed Engineering; and (c) Fabrication/Logistics; (4) *Lean Assembly*: (a) Fabrication/Logistics; (b) Site Installation; and (c) Testing/Turnover; and (5) *Production Control*: (a) Work Flow Control; and (b) Production Unit Control. Work Structuring and Post-Occupancy Evaluation are thus far only single modules. Essential features of LPDS are as follows [45]: (1) Structure and management of a project are aimed at creating value; (2) Cross-functional teams, involved in front end planning and design, include members from all areas of production process; (3) Project control would be a tool executed throughout the project as opposed to reliance on after the fact variance detection; (4) Optimization efforts are focused on making work flow reliable and not to focus on improving productivity; (5) Pull techniques are used to govern the flow of materials and information; (6) Capacity and inventory buffers are used to absorb variability in the production process; (7) Feedback loops incorporated at every level, are aimed at a rapid system adjustment and learning; and (8) Work structuring of the entire process increases value and reduces waste at the project delivery level. Efforts to improve performance at the planning level increases performance at project level.

8.2. Last Planner System (LPS)

One of the most effective ways to increase efficiency of construction industry is to improve planning and control process. In Lean Construction, planning and control are considered to be complementary and dynamic processes maintained during the course of the project. Planning defines the criteria and creates strategies required to reach project objectives, control makes sure that each event will occur following the planned sequence. Re-planning must be done when the previously established sequences are no longer applicable or convenient. Feedback facilitates learning when the events do not occur as planned [15,45]. One of the best known Lean techniques is the Last Planner System which has been demonstrated to be a very useful tool for the management of construction process, and continuous monitoring of the planning efficiency, to assist in developing foresight, smoothing workflow variations, and reducing/removing uncertainties plaguing construction processes. It consists of work flow control and production unit control. Work flow control is accomplished primarily through the look-ahead process, while production unit control is accomplished primarily through weekly work planning. Mossman [46] defined the last planner as a system for collaboratively managing the network of relationship and conversations required for program coordination, production planning and project delivery, by promoting conversations between trade foreman and site management at appropriate levels of detail before issue become critical [46]. Last Planner System aims to shift the focus of control from the workers to the flow of work that links them together. The two main objectives of LPS are to make better assignments to direct workers through continuous learning and corrective action and to cause the work to flow across production units in the best achievable sequence and rate. The last planner integrated components are: master plan, phase planning, look-ahead planning, weekly work planning, **P**ercentage of **P**romises **C**ompleted on time or **P**ercent of **P**lanned **C**ompleted "PPC" (A measure key of the Last Planner System success) and reasons for incompleteness, when systematically implemented can bring many advantages and add major benefits to construction management practice in general and planning practice in particular. PPC does not measure productivity or production, only planning effectiveness. But of course, the values of PPC are related to production and productivity indirectly, it is assumed that when a project team improves its planning it reduces variation, and thus can become more productive by matching its production resources more closely to the demand for them, so reducing waste. When the weekly work plan is executed, an analysis of the previous week report is made, and the PPC is calculated by dividing the quantity of works effectively completed by the total quantity of works that had been planned. A note explaining the reasons justifies any work that had been planned but was not completed. When the PPC is calculated, a re-programming of the services is made, indicating the services that had already been executed and those that had been planned but were not executed. The immediate result of this re-programming is the calculation of a new date for finishing the construction [47]. Companies utilizing the LPS have been able to maintain project on time and at budget, as well as having a stress-free production planning and control process. Fig. 7 illustrates the results of implementation of the LPS on a construction project, which clearly reflects the positive impact of the system on budget and productivity [48]. Fernandez et al. [49] reported benefits attributed to LPS implementation were as follows: (1) smooth work flow, (2) predictable work plans, (3) reduced cost, (4) reduced time of project delivery, (5) improved productivity, and (6) greater collaboration with field personnel and subcontractors. Test case projects also reported certain challenges faced by project participants when applying LPS: (1) lack of leadership, (2) organizational inertia, (3) resistance to change, (4) lack of training, (5) contractual issues, and (6) lack of experience and knowledge, among others. Last Planner System (LPS) has four main elements [46]: (1) *Programming Workshop*: Collaboratively creating and agreeing production sequence (and compressing it if required); (2) *Make-Ready*: Making tasks ready so that they can be done when we want to do them; (3) *Production Planning*: Collaboratively agreeing production tasks for the next day or week; and (4) *Continual Improvement*: Learning about and improving the project, planning and production processes.

Table 1 provides a comparison of the differences between CPM and last planner, identified CPM as Strategic Planning and last planner as production planning.

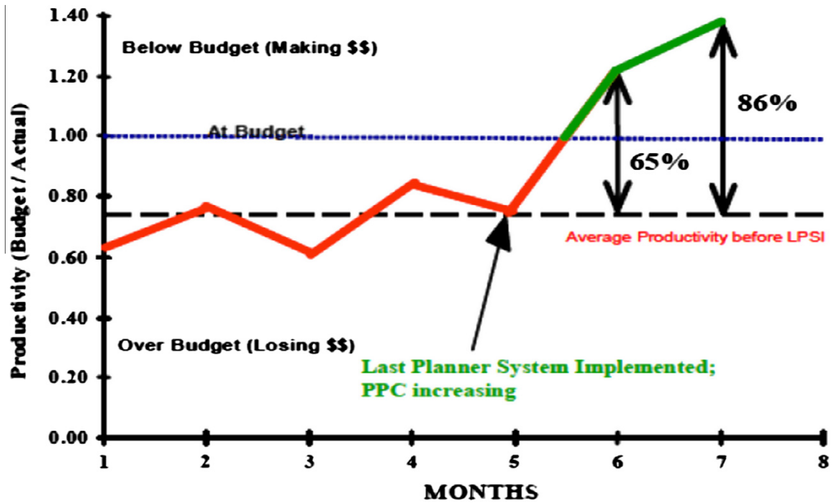

Figure 7 Productivity improvement using LPS [48].

Table 1 Separate strategic planning from production planning.

Critical path method	Last Planner System
• CPM logic embedded in software	• Applied common sense
• High maintenance	• Low maintenance
• Managing critical path	• Managing variability
• Focus on managing work dates	• Focus on managing work flow
• Planning based on contracts	• Planning based on interdependencies

The Last Planner System is based on a traditional planning system, and is performed by field foremen; the condition of (SHOULD-CAN-WILL-DID) is implemented. Figs. 8.1 and 8.2 represented the diagram of the Last Planner System.

A reliable assignment, one that gets done at the required time, determines what WILL be done, after considering both what SHOULD from higher-level schedules and what CAN be done based on the situation at hand. Assignments are likely to get done when they are well defined, resource sound, in the right sequence, and within the capacity of the crew. The last planner's job is to make certain task in the assignment that meets these criteria and to reject assignments that do not. Last planners can reasonably commit to completing the tasks on weekly work plans that meet these criteria. To be effective, production management systems must tell what should be done, what can be done, and what will be done; then, they compare what was done to improve planning [15]. The term SHOULD is considered as: Hopefully; CAN means: Probably; and WILL means: Absolutely. Fig. 9 illustrates the possible relationships among SHOULD, CAN, and WILL.

Diagram (A) in Fig. 9 represents a scenario with the highest probability of task completion, and diagram (B) shows the certainty of failure. Referring to Fig. 8.1, a reliable assignment determines what WILL be done, after considering what SHOULD and CAN get done based on the situation at hand. The assignments in diagram (A) are well defined, sound, in the right sequence, and doable by the crews. Thus, the task is likely to get done at the required time. In contrast, the assignments in diagram (B) are out of plan and have much variability to be controlled. Thus, the probability of task completion decreases. The Last Planner System has four levels [50]: (1) *Master*

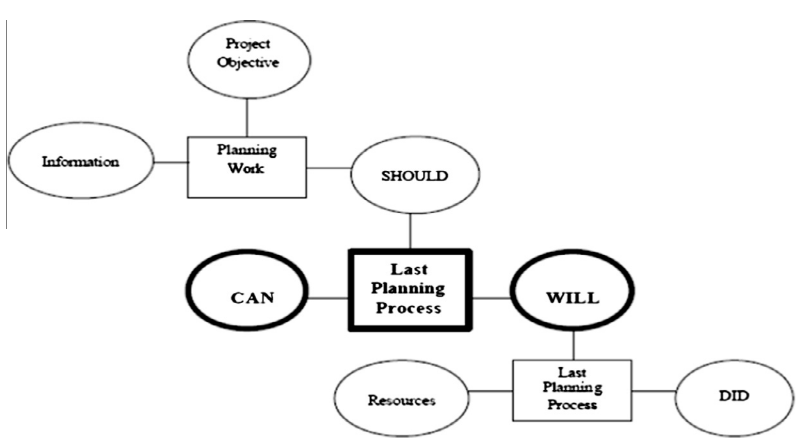

Figure 8.1 Last Planner System [15].

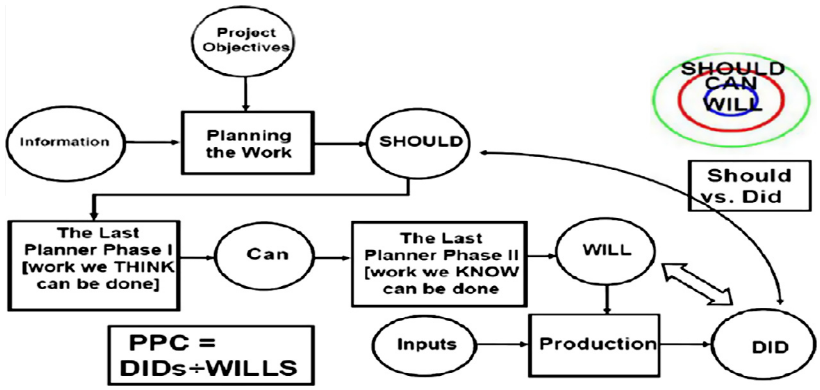

Figure 8.2 Last Planner System [38].

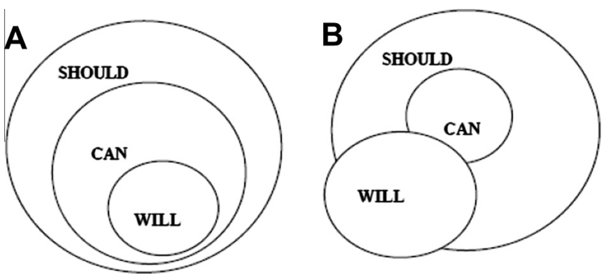

Figure 9 Diagram of SHOULD-CAN-WILL [15].

Schedule: setting milestones and strategy identification of long lead items; (2) *Phase Schedule*: Pull|| planning (specifies hand-offs; identify operational conflicts); (3) *Look-ahead Plan*: Make Work Ready Planning (to ensure that work is made ready for installation; re-planning as necessary); and (4) *Weekly Work Plan (WWP)*: commitments to perform work in a certain manner and a certain sequence, and Learning (measuring percent of planned completed PPC), deep dive into reasons for failure, developing and implementing lessons learned. Fig. 10 describes the detailed processes of LPS.

Fig. 11 illustrates the sequence of implementing the Last Planner System, and Fig. 12 illustrates how Last Planner System achieves lean concept.

Wambeke et al. [51] provided quantitative data that demonstrated how using the LPS method reduced and/or eliminated variation for the mechanical contractor involved in construction project. Also they used a risk assessment matrix as a new and effective means of prioritizing which causes of variation should be targeted first for reduction. Kim and Ballard [52] investigated the theories implicit in two prevalent project control systems: (1) Earned Value Method (EVM) and (2) Last Planner System (LPS). They introduced two fundamental and competing conceptualizations of management: (1) Managing By Means (MBM) and (2) Managing By Results (MBR).

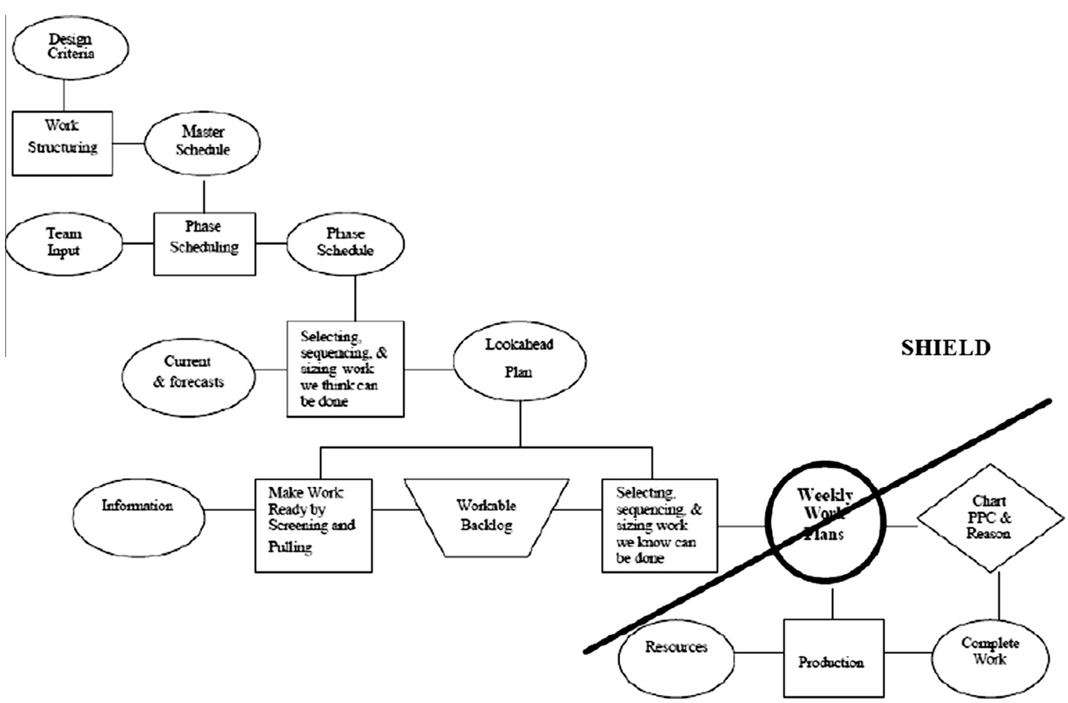

Figure 10 Process of Last Planner System [50].

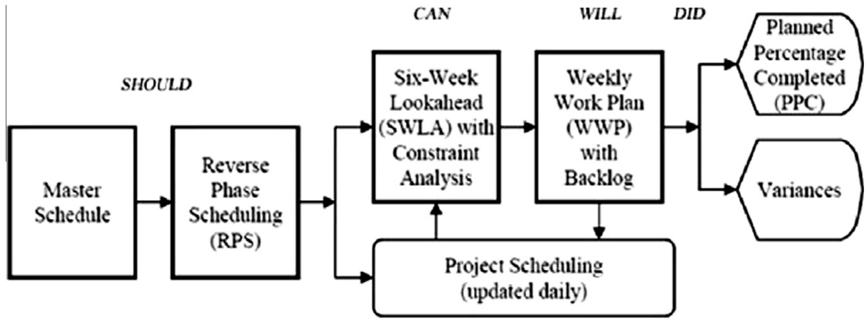

Figure 11 The sequence of last planner process.

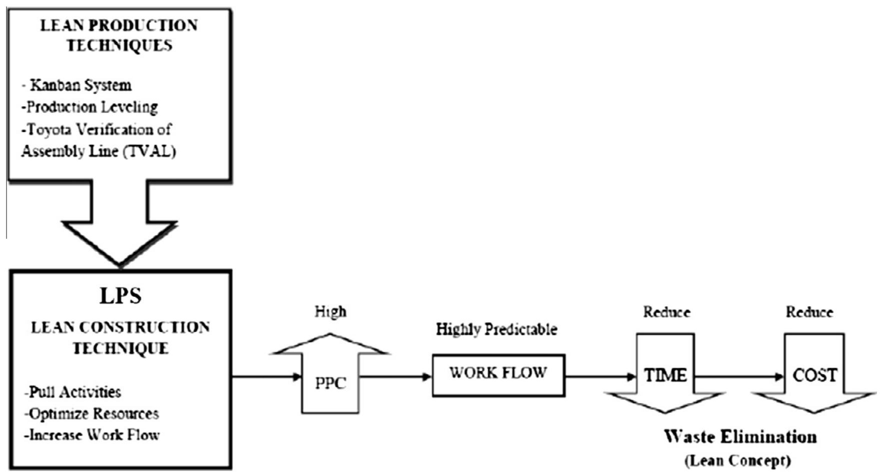

Figure 12 How Last Planner System achieves lean concept.

The EVM is found to be based on MBR. However, project control based on MBR is argued to be inappropriate for managing at the operational level where tasks are highly interdependent. The LPS is found to be based on the MBM view. The empirical evidence from case study suggested that the MBM view is more appropriate to manage works when it is applied to the operation level where each task is highly interdependent.

9. Performance improvement process model

Fig. 13 shows the key factors that determine the success of improvement process. The model is depicted as a causal loop diagram and illustrates the interactions between key factors.

An arrow between factors means that factor X affects factor Y. A positive sign indicates that if factor X increases, then factor Y also increases. A negative sign indicates that if factor X increases, then factor Y decreases. A double line indicates a time lag. When more than one arrow converges to a diamond, then ALL of conditions need to be present for the resulting factor to occur and must ALL be present for effective (Operational Improvements) to occur. The development of (Operational Improvements) depends on three key factors: (1) Time spent on improvement; (2) Performance Improvement skills and Mechanisms; and (3) Perspective and Goals. Operational Improvements are the changes implemented by the organization. These improvements result in (Improvement Results) but with a time lag.

9.1. Time spent on improvement

9.1.1. Time spent on production

(Time Spent on Production) reduces (Time spent on improvement); (Work Load and Project Pressures) increases (Time Spent on Production); (Market Conditions) increase the (Work Load) because of the increased volume of work, and the difficulty to hire qualified people in a growing market, project staff is spread (thin) and cannot allocate much time to improvement; and (Time Spent on Production) increases the (Organizational Performance). This illustrates the managerial dilemma between (Today Performance) versus (Future Performance).

9.1.2. Management support

(Management Support) increases (Time spent on improvement). The construction literature considers senior management support critical for the success of improvement effort. (Management Support) is indicated by the following: (a) Personal involvement in improvement efforts; (b) Acknowledging and rewarding the efforts and successes; (c) Hiring employees who can contribute to improvement; (d) Evaluating middle management (project managers and superintendents) based

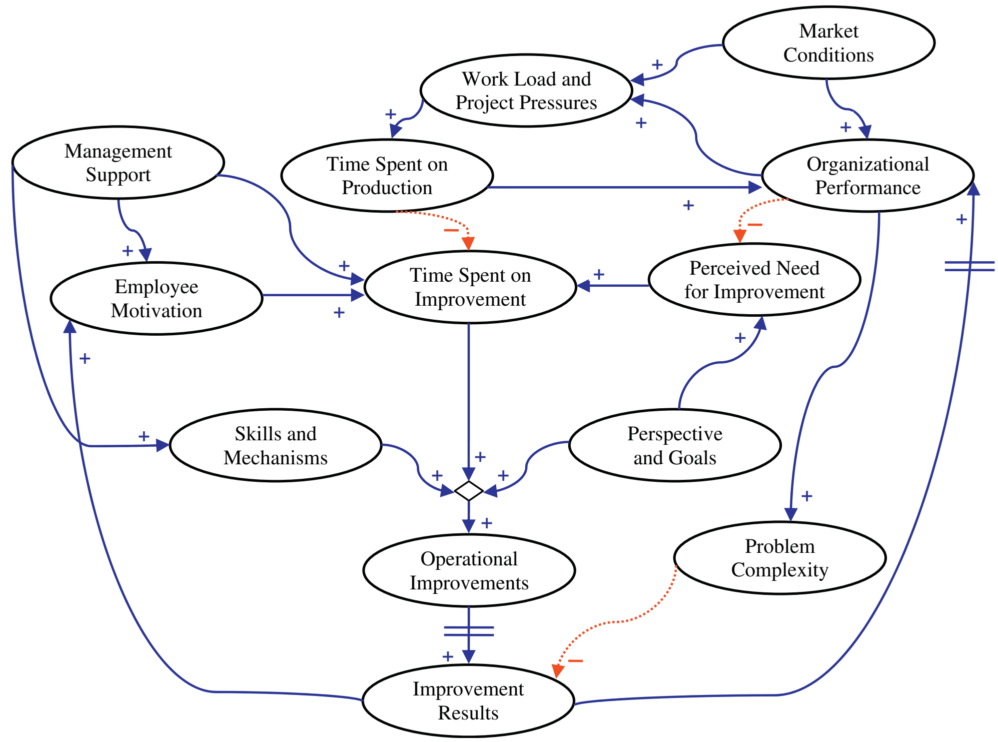

Figure 13 Model of performance improvement process.

partially on their contributions to improvement efforts; and (e) Providing resources for training and bringing in external experts as needed. Management commitment is also reflected in the approach to risk taking and experimentation. (Management Support) also increases (Employee's Motivation). Employees are less likely to be involved in an improvement effort if their supervisor does not support their involvement. Many supervisors discourage their subordinates to spend time on improvement because it diverts employee attention from real work.

9.1.3. Employee motivation

(Employee Motivation) increases (Time spent on improvement). In every organization having a typically small percentage of employees who are actively looking for ways to improve work and initiate improvements. These are the champions who put a lot of personal time in improvement. Another group of employees is willing to try new ideas even if they do not make any particular effort to initiate changes. And finally, there is group that is not interested in improvement. (Improvement Results) increase (Employee Motivation) (a) if efforts and successes are acknowledged and rewarded; and (b) if the positive results come fast. If the results take a long time, the participants' motivation is reduced. However, many of the complex production problems may have a longer time lag between the start of improvement effort and the result (the easy/fast solutions typically have small effect and do not bring substantial change). Both management and employees involved in improvement process need to understand this.

9.1.4. Perceived need for improvement

(Perceived Need for Improvement) increases (Time spent on improvement). The (Perceived Need for Improvement) is the gap between organizational performance and target performance. Thus, (Organizational Performance) reduces the (Perceived Need for Improvement). Good (Market Conditions) increase (Organizational Performance). In a good market (when the work volume and profit are good) managers perceive less need for improvement even without equally-good operational performance. Furthermore, in a market where the demand is high, the project budgets have higher contingencies, which reduce the pressure for high process performance. Finally, (Improvement Results) increase (Performance) thus reducing the (Perceived Need for Improvement), as they reduce performance pressures. The (Need for Improvement) is directly affected by the (Perspective and Goals) of improvement process. First, improvement goals create a pressure for improvement when the gap between goals and performance widens. Thus, managers can increase the (Perceived Need for Improvement) by setting high performance goals. Benchmarking against (world class) companies is one example. However, it is not only the level of goals, but also the type of goals that generate need for improvement. Even more important, the managerial perspective (and mental models) of the construction process affect the interpretation of the root causes of problems. This issue is discussed later under (Perspective and Goals).

9.2. Performance improvement skills and mechanisms

9.2.1. Performance improvement mechanisms

The mechanisms for learning can be grouped in three categories: (1) *Learning from Experience*: Such mechanisms include observation and analysis of existing processes (office or field), after action reviews, and any methods for review and evaluation of organizational activities. Work methods improvement developed systematic approaches to analyze production operations; (2) *Gathering Intelligence*: Another way to identify potential improvements is by monitoring the external environment. This includes exploring developments outside the company, keep up with new designs, methods and technologies that take place outside the company; and (3) *Learning through Experimentation*: Experimentation includes the usage of new untested methods and techniques. These could be production technologies, management methods (e.g., last planner), new information systems, incentives systems, etc. Two important issues related to experimentation are: (a) The extent that management supports risk taking (otherwise, no real risks will be taken); and (b) How can we reduce/better control the risk involved in construction experiments? (e.g., it may be necessary to team-up with owners to conduct some experiments). The use of learning mechanisms increases the organization's ability to identify problems and improvements. However, the ability to identify effective changes also depends heavily on the available skills.

9.2.2. Performance improvement skills

Every performance improvement process includes three major steps: (1) Acquiring information, when the organization collects measurements, observations, and data (such as statistical data of defects, market data, and productivity data); (2) Interpreting information, when the organization analyzes data to understand what it means, and what are the cause-effect relationships at work, and what are the real causes of observed data; (3) Applying information, when the organization develops and implements improvement initiatives. To perform these steps effectively, the organization needs skills in acquiring relevant and meaningful information, as well as skills in analyzing the information, and creating effective changes. Process Analysis Skills and Root Cause Analysis are essential in order to discover the key factors affecting performance, and develop effective interventions. Without such skills, solutions tend to address symptoms near the problem, rather than root causes. (Management Support (is essential for the development of (Improvement skills and Mechanisms) as they provide the resources for development of Improvement skills through internal training or external experts, and forums for intelligence gathering, after action reviews, and process analysis. Furthermore, experimentation directly depends on the extent that management supports risk taking.

9.3. Improvement perspective and goals

The term (Perspective) refers to whether the improvement process is Result-focused or Process-focused. The Critical Success Factors are an example of a (Result-focused) approach. Critical Success Factors are those result areas (such as Schedule, Safety, Estimating, Quality, Cost, and Change Management) that directly affect the performance of the organization. TQM and Lean Construction are (Process-focused). The different focus of the improvement process has important implications for the direction of improvement efforts as it leads to the following differences.

9.3.1. Different goals

Different goals regarding what the improvement teams are trying to accomplish. Result-based goals are typically oriented toward customer expectations. For example, the schedule improvement goal in a result-focused approach is expressed as (Complete all project on or ahead of the promised schedule) versus (Reduce cycle time of process X) from a process-focused perspective. Quality goal may be (Zero Punch list at time of completion) (result-focused) versus (Eliminate Defects and Rework) (Process-focused). Result-focused goals and process-focused goals are both needed, but at different organizational levels. At the strategic level, management needs to establish result-focused strategic improvement goals in the areas that are critical for competitiveness (such as schedule and cost reduction and safety and quality improvement). But in order to meet the strategic improvement goals, the improvement efforts need to focus on the production processes. Traditional management systems do not focus on production processes, but are result-oriented. However, a results attitude emphasizes fixing problems and fighting fires, rather than preventing problems, planning and learning. The key point is that result-focused goals emphasize results with or without process improvement. Such goals have limited effect on (Perceived Need for Improvement) when the results are satisfactory. On the other hand, process-focused goals continue to drive process improvement even if project results are satisfactory. It was suggested that management must focus on process improvement first and results second.

9.3.2. Different perspectives

Different perspectives regarding the root causes of performance problems. The simple truth is that when there is no explicit focus on the process, the direction of improvement efforts is determined by the prevailing mental models of the participants. The prevailing perspective (mental model) in construction considers project work as a collection of (activities) rather than a flow [3]. People who hold this perspective believe: (1) Sources of the problems are (outside the process) the owner makes changes or adds scope, the design is incomplete, the subcontractors were late, did not provide manpower when needed, etc.; (2) Performance problems are typically attributed to individual factors, such as responsibility, motivation, and skills, rather than systemic factors (how the work is managed, coordinated, etc.); (3) Delivering a project is just like skinning a cat. There are thousand ways to do it, all pretty much the same. Process-focused approaches (such as TQM and lean production) emphasize both the components of the process (activities, crews, etc.) and the interdependencies between components of the complex production system [53]. Sources of the problems are (inside the process) interdependence and variation, and the incentives, behaviors, and work rules that generate and propagate them. Consequently, different perspectives lead to different directions of improvement efforts. In other words, the definition of the problem drives the solutions.

9.4. Operational improvements

Depending on the (Time spent on improvement), (Skills and Mechanisms), and (Perspective and Goals), the amount and type of operational improvements vary. Result-focused programs are more likely to focus on responsibility and accountability, skills and motivation. Applied in a general contractor organization, these programs lead to greater emphasis on contractual clauses (allocate responsibility), pushing the contractors harder (hold them accountable), training project personnel in identification of defects, or increasing efforts (e.g., having more inspections earlier). Similarly, subcontractors may focus on workers' skills, and efficient equipment. This perspective usually does not aim to change the way by which the work itself is done; rather it changes the context within which work is done. On the contrary, process-focused efforts emphasize the interdependencies between process participants, requirements and the work processes themselves. This leads to very different solutions. Result-based improvement efforts may even increase the (waste) in the process (e.g., by adding inspections, and increasing tracking of defects, rather than reducing waste by preventing defects). Finally, the different perspectives also lead to different participation in the improvement process. Result-focus efforts do not lead to continuing cross-functional or cross-organizational efforts because they do not emphasize the interdependencies between process participants. Cross-organizational cooperation is typically limited to project-level initiatives, but there is no long-term cooperation between contractors, designers and owners to continuously improve work processes.

9.5. Problem complexity

(Problem Complexity) reduces (Improvement Result) assuming that the perspective and skills remain the same. The problems that the improvement effort addresses, have different levels of complexity. Simple problems involve few organizational units/functions and have a simple methodology. An example of a simple system is a crew that performs a relatively simple operation under conditions of low variability, e.g., painting. There is only one organizational unit involved (the painting crew) and the operation has few steps. The factors affecting the performance are relatively few and easily identified (e.g., crew skills, tools and equipment, etc.) The impact of such changes is immediate. The complexity of problems increases as the number of organizational units and their interactions increase, and as the number of steps required and their variability increases. For example, the construction of foundation includes layout, excavation, forming, rebar installation, concrete pour, and stripping the forms. This is a relatively complex operation that involves several different organizational units, and multiple steps and interactions. Improving performance of complex operations requires cross-functional (or even cross-organizational) changes in the way the work is organized and managed (in term of sequence, interdependencies, technologies, incentives, control mechanisms, etc.). Thus, complex problems require process-focus and cross-organizational efforts. As a result, as problem complexity increases, it becomes harder to achieve improvement results.

9.6. Improvement results and feedback loops

(Improvement Results) increase (Organizational Performance) although with a time lag (for example, the results of training will be observed in later phases or following projects). (Improvement Results) also increase (Employee Motivation) as well as management support, which leads to spending more time on improvement. This creates a positive feedback loop. On the other hand, when organizational performance increases, the work load typically increases because the organization is more successful in getting more work. In addition, the perceived need for improvement also declines. Increased work load and reduced need for improvement reduce the Time spent on improvement. Thus, a negative feedback loop is created that (regulates) the process. (Organizational Performance) increases (Problem Complexity) that is, as the organization performance increases, further improvements require solutions to more complex problems. Effective improvements are harder to identify and implement, with fewer and slower improvement results. This creates another negative feedback loop. That means if improvements are based on training, motivation, and extra work load (such as additional inspections), the organization will have to increase its efforts simply to maintain the same level of performance. However, when improvements are incorporated in work processes (rather than people or inspections) they can be sustained with fewer efforts.

10. Conclusion

This research seeks to confirm the following objectives: (1) Determine the implementation of lean ideal; (2) Identify the source of wastes classified under lean construction industry; (3) Examine general perceptions of the construction industry with the lean construction principles of practices; (4) Study reduction and elimination of wastes as classified under development of Last Planner System as a technique of lean construction implementation and to evaluate the effectiveness of implementing last planner to increase plan reliability; (5) Examine the relationship between lean construction and performance improvement programs in construction organizations; and (6) Analyze the characteristics of successful performance improvement programs, and develop a model that identifies three critical elements: (a) Time spent on improvement, (b) Improvement skills and mechanisms, and (c) Improvement perspective and goals. The authors identify different ways to structure improvement program: outcome focused (such as Critical Success Factors) and process-focused (such as Lean Construction). The paper discusses the implications of the different perspectives and argues that they lead to different improvement approaches each reflecting different paradigms for the nature of the change. The authors propose that result-focused improvement programs may be a barrier to the adoption of Lean Construction. The paper proposed a dynamic model of performance improvement process. The model examined the factors affecting the process and their interactions. The paper proposed that: (1) Direction of the improvement effort is strongly influenced by the structure and goals; and (2) Result-focused programs have limited ability to address complex systemic problems. One question for future research is what drives a contractor to establish a result-focused or a process-focused program. It appears that specialty contractors are more familiar with the process-perspective because of their familiarity with productivity improvement studies (which is a process analysis of a relatively simple problem). On the other hand, general contractors are more likely to emphasize overall project results. Future research also needs to (1) Develop and validate a more complete model of performance improvement; (2) Further examine the behavior of improvement process over time; and (c) Use the model as a starting point for system redesign by adding loops and breaking links.

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