THE IMPACTS OF PRODUCTION THEORIES ON CONSTRUCTION PLANNING EFFICIENCY

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Construction industry suffers from the lack of efficiency and practicability in the planning process. In this paper, the reasons standing behind construction planning problems are investigated. It is claimed that the conventional production theory (mass production), which the construction management techniques stand on, is the source of planning inefficiency and impracticability. Accordingly, the new production theory (lean production) is reviewed, and its techniques of this theory must be transformed from other production domains to the construction industry at a high level of abstraction, and a powerful modeling tool must be used, instead of the traditional network techniques, in order to implement the lean principles and concepts.

1. INTRODUCTION

Construction planning process can be considered the backbone of construction management. The following definition of the planning process can indicate its importance:

"Planning is the process of determining appropriate strategies for the achievement of predefined project objectives. In construction projects, the objective of planning is the completion of a prescribed amount of work within a fixed time, at a previously estimated cost, and to specified standards of quality" [Faniran et. al. 1998].

Therefore, research efforts have tried always to enhance planning capabilities with improved or even new methods and techniques. Currently, construction practitioners mainly use the principles and techniques of the well-known project management approach in preparing their plans. According to this approach, the main planning principles include:

- Work breakdown structure (WBS): The work content of the project is decomposed into a set of main activities, and each of those in turn is decomposed into a set of sub activities.
- Dependency analysis: The project activities established by WBS are ordered according to the dependency relationships between them.
- Duration estimates: The time required to achieve each activity is calculated.
- Network development: Using one of the networking techniques (mainly CPM or PERT), activities are graphically presented. Details regarding activity durations and precedence relationships are illustrated on the network.
- Resource allocation: The appropriate type and size of resources are committed to each activity, taking into consideration the time span along which the resources are needed.
- Cost estimations: The cost of each activity is calculated, depending on its work content, duration and resource needs.
• Project budgeting: allocates project development costs spread over project duration.
• Other planning issues: such as organizing the project team, and setting a coordination mechanism between subcontractors.

When the construction phase starts, the attention is focused then on monitoring the implementation of the original plan, measuring the progress of work in terms of time, cost and quality, and comparing planned versus actual performance. If any departure from the original plan is realized, corrective actions must be adopted to bring back the work progress to the desired performance.

It can be recognized that construction planning affects most of the project life cycle, and thus, project success is related, to a great extent, to the efficiency of construction planning. Nevertheless, research studies have indicated that “construction planning efforts usually fail to achieve their objectives” [Faniran et. al. 1998]. Neither the project schedule, nor its cost can be controlled accurately. Wastes arise along the project life cycle. The role of planning is transformed from initiating and directing action before it takes place to influencing and regulating operations while in progress and to follow-up and status reporting [Laufer & Tucker 1987] (cited in [Koskela 1999]). It has been concluded that uncertainty is not an exceptional state in the otherwise predictable process of construction work. On the contrary, uncertainty is the permanent feature in construction [Ben-Haim & Laufer 1998]. Fig. 1 shows some variables that cause uncertainty in activity duration.

The interpretation of the failure of conventional construction planning in dealing practically with site problems was the subject of numerous research studies. Considerable portion of these studies attribute planning shortcomings to the used planning tools; mainly network techniques [Kavanagh 1985], [AbouRizk & Wales 1997] and [Senior & Halpin 1998]. Other studies went further by criticizing the theoretical basis that the whole conventional construction management stands upon. [Koskela 1992], [Tommelein 1997], and [Howell & Ballard 1998]. This direction in research studies claims that construction industry must adopt the principles of a new production theory, namely lean production. Cogent evidences are provided to prove the validity of this direction. Currently, increasing research efforts, in various managerial aspects are directed towards the establishment of the scientific foundations of lean construction; the construction version of lean production. Lean construction principles were implemented by some of the civil engineering companies in their projects [Junior et. al. 1998] and [Conte 1998]. The implementation achieved remarkable success, which provides evidence on the applicability and significance of lean construction principles.

In this context, the present work introduces the conventional production theory, and discusses its impacts on conventional construction planning process. Also the principles of the lean production are introduced, as well as some of the lean techniques, and the benefits and the needs of adopting it are discussed.

2. CONSTRUCTION PLANNING AND THE CONVENTIONAL PRODUCTION THEORY

What is a Production Theory and What is its Importance?

A theory can be defined as “a condensed piece of knowledge which consists of fundamental truths, rules or laws, and aims to provide explanation of observed behavior of a system by the means of scientific procedures” (Derived from [Koskela 1992]).

However, the term “theory” can indicate other meanings, namely: non-practical, hypothetical speculation. On the other hand, many other terms, such as: “philosophy, foundation, paradigm, doctrine, and model” can be used instead of the term “theory”. Derived from Koskela’s discussion [1999], an explicit practical theory of production must have the following functions:

- Principles of a new production theory, namely lean production. Cogent evidences are provided to prove the validity of this direction. Currently, increasing research efforts, in various managerial aspects are directed towards the establishment of the scientific foundations of lean construction; the construction version of lean production. Lean construction principles were implemented by some of the civil engineering companies in their projects [Junior et. al. 1998] and [Conte 1998]. The implementation achieved remarkable success, which provides evidence on the applicability and significance of lean construction principles.

Figure 1: Significant uncertainty variables [Ahuja & Nandakumar 1985]
Providing a prediction of future behavior.

- Giving direction in pinpointing the sources of further progress.
- On the basis of the theory, effective tools for analyzing, designing and controlling can be built.
- Providing a common language through which cooperation of practitioners in a common field of knowledge is enabled and facilitated.
- From the point of view of production management practice, the theory provides an ultimate benchmark for practice.

2.1 The Conventional Production Theory

Conventional production theory was introduced in the end of the 19th century [Koskela & Vrijhoef 2000]. It views production process as a conversion (or transformation) of an input to an output. Some of the main aspects of the conversion model can be found in [Koskela 1992]. The main conversion process can be decomposed into subprocesses, which in turn can be decomposed into smaller subprocesses. Each of the subprocesses is considered also a conversion process. Minimizing the cost of the subprocesses can minimize the total cost of the process. Each conversion process adds value to the product. The output value is associated with the costs (or value) of the process inputs. To enhance the output value, better input quality must be used.

Conventional production theory, which is also known as mass production, was the prevalent theory of production in the 20th century. The term “mass” gives an indication to one important principle of this theory of production. This principle states that machines must continue to work as much as possible so as to maximize production and thereby reduce production costs. In car manufacturing, for example, the assembly line must be kept moving as long as it can. On the basis of its principles, many managerial approaches have been developed. Example of these approaches is scientific management, modern corporation and project management [Koskela 1999].

2.2 Construction and the Conventional Production Theory

Comparing the above definition of conventional production theory with the steps of constructing a construction plan mentioned previously shows that construction is currently viewed as conversion process. The project (the main conversion process) is decomposed into activities (subprocesses). Each activity (subprocess) converts an input (or a set of inputs) to an output. That is, each activity consumes an amount of resources (e.g. sand, cement, bricks, and labor efforts) to produce an output (e.g. built walls). The cost of the project (production process) can be reduced by minimizing the cost of its activities. Network techniques (mainly CPM and PERT, the main tools used in conventional planning) are true representatives of conversion models. Activities, which are conversion subprocesses, are used as the basic planning unit in the network techniques.

2.3 Wicked Impacts of Conventional Production Theory on Construction Planning

Conversion models do not consider activities rather than conversion activities. Flow activities such as: moving, inspection, waiting and feedbacking are completely neglected. This abstraction of production details imposes great limitations on the effectiveness of construction planning. The following problems can be observed:

1- Neglecting flow activities leads to the great failure in dealing with resources, the most important element in the planning process. Resources are not devoted to execute only, conversion activities. They also, carry materials, drive equipment, stay idle waiting for logical conditions to be realized, inspect the work, …etc. In fact, many of the resources at construction sites are directed to achieve non-conversion activities. All of these activities are completely neglected in the network diagram (which is a conversion model). Thus, there is not any chance to model resources, and therefore, resources are absolutely absent from network diagrams, just as the link between activities is absent in the simplified bar chart technique.

2- The inability to pinpoint the cause of variability in construction operations, and deal with it, is another wicked impact of neglecting flow activities. Consider for example an ordinary site situation where a resource is shared by many activities (e.g. a crane). Primarily, the conventional plan will not be able to assess the potentials of sharing conflicts because activities that model the resource movement and idleness are absent. Thus, precautional actions will not be taken to avoid a sharing conflict before it occurs. Has this sharing conflict arises, the planning role will be limited to assess the results of the problem, updating the original plan, and coping with the results by either increasing the resources (e.g. use another crane), or extending the execution time. Furthermore, no attempts will be made to trace the problem causes, because there is not any mean that enables such a trace. Simply put, variability is a chronic problem in conventional construction management because there is not any mean to predetermine the causes of variability, nor is there any mean to trace the variability reasons, whenever it occurs.

3- Cycling and feedbacking are types of flow activities that are also not considered in the conversion model. The absenteeism of these activities made network techniques such as CPM and PERT poor tools in modeling construction projects of repetitive nature, such as: high-rise buildings, housing projects, and tunneling. Activities in such type of projects are
repeated from unit to unit. Since network techniques represent each activity in the project with a graphical element (an arrow, or a box), the resulting network, which models a repetitive project, will be a voluminous one. Obviously, such a voluminous network will be disturbing, and will not do its job in clarifying the project stages to the executor. Furthermore, network techniques give no idea about the work continuity for crews and resources that are involved in repetitive activities. In such projects, the planning efforts must concentrate on scheduling the repetitive activities in a manner so that their required resources flow continuously from unit to unit.

4- Network techniques, which are conversion models, employ resource allocation and leveling technique to solve the problem of resource limitations. Resource leveling main work is to alter the initial schedule, taking advantage of activities float to make optimum allocating of resources, depending on the unrealistic assumption which states that resources can be hired and fired freely, whenever the schedule wants. Work is going on at site in a different manner. Activities cannot be shifted between their earliest start and latest finish as leveling algorithms impose, because of work continuity requirements. Besides, work crews can not be employed to achieve an activity or a set of activities and then fired, or remain idle, until the time of another activity has come, as the inconsistent, CPM or PERT schedule states. The plan must be concerned, first of all, with scheduling work so as to make crews flow continually from activity to another until they continue their work. In other words, work continuity must be accomplished to make the best practical utilization of resources.

5- CPM and PERT techniques do not offer the chance of making decisions related to project variables, even by simple means such as decision nodes. This may be referred, to a great extent, to the basic assumption which states that all activities in a network diagram must be achieved because all of them are value-adding activities, and the project will not be completed if one of its activities is not achieved. Thereby, there is no need to make decisions related to project activities. Nevertheless, there was an attempt to incorporate decision nodes in the CPM network. This trial introduced the DCPM (Decision Critical Path Method) [Naaman 1974]. But instead of solving the problem, DCPM compounds it by posing problems related to the critical path determination and resources leveling.

6- In addition to the previous deficiencies, which were mainly outgrowths of the inconvenient theoretical basis, there was also a problem related to the way of specifying activity duration. CPM considers all the activities’ durations deterministic, and therefore, gives a refused representation of the reality.

On the other hand, PERT does not offer a true probabilistic estimation of activity durations. It converts the probabilistic estimates of time into a most likely value and supposed optimistic and pessimistic values. These values, then, are used to provide a deterministic value to determine the critical path. The problem with this method of estimation is that the critical path may be a misleading evaluation of the project completion. That is because the variation of time, which occurs in other paths, may be greater than the variation of time occurs in the mean critical path. Many researches examined this problem and found out that the actual project duration can be 50% greater than the PERT mean critical path value [Crandall 1976]. Another defect in PERT probabilistic analysis of activity durations can be recognized. In construction site, activities may share crews, equipment, and other resources. Because of this sharing, the randomness in various activities’ durations is not independent of each other. Probability system in PERT assumes the opposite. It treats the activity durations as independent random variables.

Some trials were made to develop network techniques so as to avoid their shortcomings. The development of GERT (Graphical Evaluation and Review Technique) was one of these trials. GERT is a technique for the analysis of stochastic networks, which is best used in the situations that do not require achieving of all the activities to complete the project. It incorporates the concepts of PERT and DCPM with flow graphs (a planning technique that doesn’t enjoy a widespread use) [Naaman 1974]. GERT tries to avoid the faults of the previous techniques. Some types of flow activities can appear in GERT networks. GERT provides the ability to represent feedback and self-loops. Its graphical elements give the power for decision making. GERT probability system is more convenient than PERT system. Theoretically any probability distribution can be used, not just Beta distribution, which PERT uses. Each activity can take a different distribution. Despite these advantages, GERT is much more sophisticated than other techniques. Also GERT suffers from the main problem of network techniques, which is related to resources flow and utilization and work continuity. It does not offer much in this field. This fact illustrates why GERT was not met with welcome in construction industry.

3. LEAN PRODUCTION

3.1 The Evolution

The flow view of production was first introduced by F.B Gilbreth and L.M. Gilbreth in 1922. They categorized flows into four types of activities: processing, inspection, waiting and moving. Just the processing activity is a conversion one (value-adding activity), and other types of flows are waste (non value-adding activities) [Koskela 1999].
The Gilbreths’ principles were first practiced, to a limited extent at car manufacturing by Ford Corporation, but the real incorporation of these principles into production management was made in Japan by Toyota in the 1940’s. Toyota production system (TPS) led by engineer Ohno, focused its efforts on waste reduction by the elimination of non value-adding activities such as: reducing the machine startup time, producing a car to the requirements of a specific customer, deliver it instantly, and maintain no inventories [Howell 1999]. Stated briefly this production system, which was named JIT (Just-In-Time), aimed to manufacture “only the necessary products, at the necessary time, in necessary quantity” [Toyota production system 2002].

Simultaneously, the notions of quality were being developed, also in Japanese industries. The concepts were gradually developed from mere inspection of raw materials and products using statistical methods, to total quality control TQC [Koskela 1992]. Built upon the fundamentals of JIT and TQC, many other useful techniques have evolved. These techniques, together with JIT and TQC have formed the theoretical basis upon which Toyota developed the lean production theory (also referred to as new production philosophy, Toyota production system, JIT/TQC, and world class manufacturing). The term “lean” was coined by the research team working on international car production to contrast it with mass form of production, and also to reflect the waste reduction nature of the Toyota production system [Howell 1999]. Lean production has a dual view of production that is; it is consisted of conversion activities as well as flow activities. While both types of activities expend costs and consume time, just the conversion activities add values to the product. Thus, “reduction of cost through elimination of waste” was the most important principle in lean production philosophy [Toyota production system 2002].

The definition of waste includes any non value-adding activities, that is anything other than the minimum amount of equipment, materials, parts, and working time, which are absolutely essential to production. This principle was the core around which many principles were developed. In the following, ten of the most fundamental principles are introduced.

### 3.2 Principles of Lean Process Design

The following principles, introduced in [Koskela 1992], had originated mainly in manufacturing. They are the basis upon which lean techniques are built. It is important to notice that these principles are introduced at a high level of abstraction, which enables adopting them by other production systems.

1. **Reduce the share of non value-adding activities.**
   - This is an essential principle in lean production. Experience shows that usually only 3% to 20% of steps add value [Ciampa 1991] (cited in [Koskela 1992]). Thus, pinpointing the non value-adding activities and eliminating them, or reduce their share, will efficiently increase productivity.

2. **Increase output value through systematic consideration of customer requirements.**
   - The most interesting aspect of this principle is the definition of customer. Customer is defined to be the next activities, as well as the owner (for whom the product is produced). In this manner, the construction phase is a customer for the design phase. The design phase must recognize the requirements of construction phase, and try to fulfill them.

3. **Reduce variability.**
   - Variability in production is the main source of uncertainty. The direct impacts of variability recognized from practice are increasing waste, increasing activities cycle time and reducing the plan reliability. It was firmly stated that “variability is the universal enemy” [Koskela 1992]. Well measuring the variability causes and analyzing its roots will help in reducing waste, and increasing productivity.

4. **Reduce cycle time.**
   - The cycle time of a process consists, depending on flow principles, of: Cycle Time = Processing time + inspection time + wait time + moving time.

5. **Thus, to reduce the process cycle time, the share of the non value-adding activities, in the cycle time must be reduced, by either eliminating these activities, or combining them. Achieving this purpose can be facilitated by reducing variability, reducing work-in-progress, reducing batch sizes, and increasing work flow reliability. Reducing cycle time is consistent with the main tendency of lean production towards waste reduction.**

6. **Simplify by minimizing the number of steps and parts.**
   - In addition to increasing non value-adding activities, unnecessary flow of material or information will complicate the production process, reduce its reliability and increase the variability. Many procedures have been proposed to achieve simplification. Examples are: consolidating activities and thus shortening the flow, standardizing parts materials and tools, decoupling linkage between activities, and minimizing the amount of control information needed.

7. **Increase output flexibility.**
   - This principle seems to be at a lower degree of abstraction, that is, relatively closer to manufacturing. Nevertheless, a thorough understanding of its impacts may result in useful gains to construction design process, for example.

8. **Increase process transparency.**
   - To make a process transparent means “the main flow of...
operations from start to finish is visible and comprehensible to all employees” [Stalk & Hout 1989] (cited in [Koskela 1992]). The incentive for this principle is one of the most important doctrines in lean production conceptualization, which demands “to make full use of the workers’ capabilities” [Toyota production system 2002]. Transparency will make workers effectively interact with their work and even make them more creative. Transparency of work flow is an important principle because lean production stresses, highly, the concept of decentralizing decision making. Further illustration of transparency importance, as well as interesting examples can be found in [Santos et. al. 1998].

9. **Focus control on the complete process.** Instead of controlling individual activities, control actions must be taken with regard to the complete production process situation.

10. **Build continuous improvement into the process.** The attempt to improve work productivity and eliminate waste must be a continuous job of production management. Every participant in the production process must be given the opportunity to contribute in this effort. Solving production complications must be the prior target of the continuous improvement.

11. **Benchmarking.** Benchmarking is a method for improvement that involves continuous, systematic evaluation of work procedures, productivities, production costs, etc that are recognized as representing best practices [Marosszeky & Karim 1997]. Benchmarking can be applied on three levels: organizational level, project level, and processes level. It proved to be a useful principle that enhances productivity, and reduces production costs. Though considered benchmarks, industrial giants such as IBM are also adopting benchmarking as a continuous improvement tool.

3.3 **Can Lean Production Principles be Adopted by Construction?**

One of the main deficiencies of conventional planning and controlling techniques is that they were developed in environments that differ in many aspects and characteristics from construction environment. Thus, some of the main problems that face construction planning and controlling were not handled. Accordingly, can lean production be applied in construction industry? Can any benefits be gained from this application?

Two evidences confirm the applicability of lean concepts in construction despite their manufacturing origins. First there is an essential difference between borrowing conventional planning techniques such as CPM, PERT or GERT and implementing lean production concepts. In the first case, a complete technique was extracted as is from manufacturing, and then attempts were made to fit it to construction environment. Variables and problems that the borrowed techniques were originally developed to deal with, are different from those of construction projects, thus, no surprise that the borrowed techniques could not deal efficiently with many of the construction problems.

In the second case, the intention is not to borrow a technique or a planning tool, but rather to adopt fundamental principles and concepts that illustrate how to manage the flow and the interaction between production elements. These principles help in pinpointing the source of problems and the potentials of further progress. They set guidelines to ultimate practice of the production process, disregarding the type of production. In brief, a production philosophy is to be adopted not just a tool or a technique.

To make lean production theory fit to construction environment, and even cause radical changes in construction industry, the transformation of principles and concepts must be at a high level of abstraction. That is, the characteristics of manufacturing must not be slipped with the transformation of concepts, and subsequently, cause divergence between practice and theory. That is because transformation of methods and techniques will not result in great benefits to construction industry. This idea is best illustrated in Fig. 2.

Second, although construction differs in many of its characteristics from manufacturing yet, both fields have suffered from the impacts of the misleading mass production theory, and similar problems have been encountered. The following description of manufacturing problems can also fit to construction problems [Plossl 1991] (cited in [Koskela 1992]):

“The consensus of practically all people in manufacturing, until very recently, was that the problems experienced daily were inevitable and that it was necessary to learn to live with them. The real heroes were those individuals who could solve problems shortly after they arose, regardless of how they solved them”.

The previous recognition encouraged western manufacturing sector to adopt the new production theory developed originally at Japan. The successful implementation of this theory in manufacturing sector motivated construction practitioners to follow the steps of manufacturing. Lean construction then emerged!

Furthermore, the growing acceptance of lean construction-by-construction companies, and the brilliant benefits resulting from implementing lean concepts consist a third, practical evidence. A research study about the implementation of lean concepts in some USA construction companies indicates the following results [Garnett et. al. 1998]:
Office construction times reduced by 25 % within 18 months.
Schematic design reduced from 11 weeks to 2 weeks.
Turnover increases of 15- 20 %.
Productivity increases.
Satisfied clients looking to place repeat orders.
Project costs reduced.

Koskela clearly sums up the needs to implement lean construction by the following sentence: “what is needed is a production theory and related tools that fully integrate the transformation and flow concepts” [Koskela 1999]. In the following subheading some useful lean concepts and techniques, built upon the fundamental principles, are introduced.

4. SOME INNOVATIVE LEAN PRODUCTION TECHNIQUES

The continuous research studies on lean production, as well as the successful practical applications of it, led to the development of new concepts and techniques, mainly in manufacturing field. In the following, some of these important concepts and techniques are introduced, and the applicability of them to construction is explored.

4.1 Identifying and Mapping the Value Stream

Enhancing the value of a product is one of the most concerns of lean production. A fundamental lean principle is to add value to the product along its life cycle, mainly by eliminating all forms of waste. To get this concept into practice the value stream, the way the value will be realized, must be identified. Identifying value stream establishes when and how decisions are to be made [Dulaimi and Tanamas 2001]. A value stream map is a heuristic tool in this way. It is consisted of process flow charts that are especially devoted to identify what action releases work to the next operation, considering the customer requirements (next customer(s), as well as the final customer). Mapping the value stream enable identifying best planning policies regarding material management and resources flow. First a project level map must be prepared. This map is decomposed to further detailed maps. At this level of details, potential causes of waste can be identified, and better utilization of resources can be achieved. Subsequent tracking of value stream maps has two benefits: helping in standardizing construction practices and indicating potentials of reengineering an operation.

4.2 Stopping the Line versus Moving the Line

One of the important mass production practices, which is used to maximize production size and thereby minimize costs, is keeping the assembly line working without stopping it, as much as possible. Though it seems productive, this practice has wicked impacts on the production process. In car manufacturing, for example, the practice has led to extensive intermediate inventories, or what engineer Ohno described as “the waste of overproduction” [Howell 1999]. Furthermore, defects that happened in cars while being processed along the line were lift as they passed down the line. The result was the existence of completed cars with embedded defects, and thus, the need for more rework activities, in other words, more non adding-value activities.

The opposite lean production practice is stopping the line. Workers who received defected car (or product) from upstream were allowed to stop the assembly line so as to repair the defects. Though it seems for the first glance reducing productivity, stopping the line improves productivity by reducing output variability, reducing rework activities and increasing work flow reliability. But how stopping the line makes any sense in construction? At first, is there an assembly line in a construction project?

The way of assembling a product may differ, according to the nature of the industry. In most industries, the product moves through the assembly line to cross workstations, which add to it parts, or manipulate something in it. But in some fields of manufacturing the product is too large to move through the assembly line. Thus, workstations, themselves, move through the product, adding parts or doing works that add value to the product. Ship building is an example of such type of manufacturing. The work of crews in a construction site can be likened to the movement of workstations in ship building. The product (the building) remains fixed while the crews across it so as to process something that add value to, and approach the product to the final, desired shape. Now, talking about an assembly line in construction makes a sense, but how to stop that line? What are the benefits of such a stoppage?

Figure 2. Possible directions in transforming lean production concepts from manufacturing to construction [Koskela & Vrijhoef 2000]

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It was suggested that planning at the assignment level is the place to stop the assembly line in construction [Ballard & Howell 1998]. That is, when it is needed, the line can be stopped by delaying or changing the assignment of crews to their activities. Such stoppage reduces the output variability, and thereby, reduces uncertainty and makes work flow more reliable. Also coordination between various work crews and participants will be much facilitated.

4.3 Pull versus Push

As mentioned previously, keeping machines working as much as possible is one of the important mass production strategies. This practice means that assembly line will continuously push products to stores. The result is large amount of inventories, which Ohno considered to be source of additional costs, and restricting the turnover. Thus he developed a new strategy for production and inventory control. This strategy shares with “stopping the line” strategy the same decentralization tendency. It is a simple card information system that controls the production quantities (also referred to using the Japanese term “Kanban”). Kinds and quantities of units are drawn by any station, exactly as needed, from the previous station, starting from the downstream station, which is in contact with the customer. Therefore, the customer is said to pull the products from the assembly line. Each subprocess, in turn, is said to pull the product from its predecessor(s). Ohno hit his target... there were no inventories!

Conventional planning techniques employ push strategy in scheduling the project activities. Each activity in the project must start, as much as possible, at its earliest start. It is pushed to start without considering the possibility of starting its successors when it terminates. Thus, time gaps between activities may appear, which will affect work continuity, and resources utilization, especially in projects of repetitive nature. On the contrary, pull strategy can offer novel solutions for such problems. Activities will pull their predecessors to start; thus, resources will not enter idle states plentiful times or for long periods, but rather, flow in a continuous manner. Work flow will be smoother, and more reliable. Variability will diminish, and planning will be more accurate.

4.4 Continuous Improvement versus Innovation

Conventional production theory considered innovation as the path for changes and improvements. Innovation is seen as a breakthrough improvement in conversion processes, resulting from developing new materials or equipment. Sometimes, incremental improvement is also considered a form of innovation [Koskela 1992]. Lean production introduced another path for development, which is the continuous improvement. Continuous Improvement is concerned firstly with incremental improvement of flow processes.

Continuous improvement is at the core of all theories related to quality management, and is commonly associated with Plan-Do-Check-Act cycle (also referred to as Deming Wheel) [Santos 1999]. For powerful continuous improvement practice, the PDCA cycle is repeated over and over as illustrated in Fig. 3.

Continuous improvement efforts are directed to eliminate waste and add value to the product. Implementations of such a concept in construction project may result in improving work procedures and coordination mechanisms along the project life cycle.

5. CONSTRUCTION PLANNING AND LEAN PRODUCTION

Conventional planning techniques view production as conversion activities. They are activity-oriented tools, which focus primarily on describing activities’ characterizations. Therefore, the progress of work on site is defined in terms of “when”; when does the activity begin, when does it end, when does it become critical, when does the project end, ...etc. On the contrary, the site manager is interested in defining the work in terms of “how”. The needed planning technique must illustrate to the site manger how he accomplishes his work, how he makes the optimum use of the resources, how he manages materials flow and handling, how activities share common resources, ...etc. Conventional planning techniques set to the site manager objectives that he must achieve, but they do not provide him with any indications about the methods of achieving these objectives [Halpin & Woodhead 1976]. They may be useful at the top management level since they give a general view of the project and its milestones. But they can not be considered useful tools for managing the complex and dynamic environment at construction site because they ignore the day-to-day problems of the site manager related to methods and resources commitment.

Focusing on activities prevents conventional planning techniques from offering the required level of details needed by the site manager. To develop an effective and practical work plan, the site manager needs details related to work flow and resources, resources characteristics, site environment, work conditions, and any other factor that can affect the construction
process. This level of details will help him in determining the proper quantities and sequencing of labor and equipment within the context of a selected field construction technology.

Viewing production as flow enables lean construction to offer the needed level of details. The basic planning unit will not be a big conversion activity (e.g. brickwork for the first floor) but rather a smaller flow or conversion activity (e.g. mix mortar, supply mortar, lay bricks... etc). The construction operations will be viewed as a combination of flow and conversion activities. This view enables incorporating comprehensive details about the project elements and conditions into the plan. In fact working at that level of details is an attempt to transform the real world characteristics, and behavior into systematic data. This process is known as “Modeling”.

Modeling of construction works is one of the most fruitful gains of implementing lean construction. The planner can now assign, accurately, resources to activities. The interaction between resources can be examined to determine poor utilization of resources. Departures from expected productivities can be traced to specific flow activities. Therefore, the source of inefficiency can be pinpointed, and the inherent causes of uncertainty can be explained. Moreover, the net effects of various policies on the project cost and duration can be evaluated. Any combination and sequencing of resources that can achieve the work are examined to determine which is the most economical and practical, so as to adopt it.

The previous idea can be summarized in the following few sentences. Conventional planning techniques view the project as a network of conversion activities. Thus, a simple modeling tool, such as CPM, was able to model it. Lean construction has a different view of the project (the production process). The project is considered to be a network of flow and conversion activities. Accordingly, a high level of details will exist in the project network, and thereby, a powerful modeling tool is needed to model the lean project network. Using such a powerful modeling tool can facilitate the effective implementation of the new production principles and concepts.

6. MODELING THE LEAN PROJECT

6.1 Finding the Suitable Modeling Type

Reviewing the modeling types, so as to choose the one that fulfill the requirements of lean construction, is beyond the scope of this paper. Nevertheless, the authors will briefly mention these modeling types and determine which of them can be powerfully used in modeling the lean construction project.

Models are classified into the following types:

**Physical models:** which take the physical shape of the objects they represent, but with different sizes (mostly smaller).

**Symbolic models:** which express the characteristics of the objects or the systems they represent by symbols (e.g. graphical representations).

**Mathematical models:** convert the reality into mathematical equations, which relate between the variables representing the system characteristics.

**Simulation models:** in simulation modeling, the modeler produces a computer replication of reality, by means of logical and quantitative relationships.

Among these types, simulation modeling is the most powerful one that satisfies the requirements of modeling lean construction projects. It requires the minimum simplification assumptions, and thus, the simulation model can incorporate the intensive amount of project details resulted from considering flow activities. Another unique advantage is accessing the state of the model at runtime, and changing the system variables. Accordingly, the modeler can catch the causes of inefficiency in his plan, even prior to the work commencement.

6.2 Employing Simulation Modeling in Lean Construction

The advantages of simulation modeling, and the potential uses of it in modeling lean construction projects, were the subject of many researches.

Al-Najjar proposes the use of simulation as the modeling tool for lean construction, just as the CPM was the modeling tool for the conventional project management [2002]. Accordingly, he reviewed many of the existing simulation systems, exploring the advantages and shortcomings of each. He chose STROBOSCOPE [Martinez 1996] as the most powerful simulation system that can fulfill the requirements of modeling lean construction projects. Based on the lean construction notions, he then developed simulation models for nine construction operations. The developed models prove both, the ability of simulation to model construction projects from a lean perspective, and the practical solutions which lean production principles provide the construction planning with, when the project is modeled using simulation. Extensive details can be found in [Al-Najjar 2002].

Tommelein developed simulation models for two construction operations [1997]. She tried to illustrate how modeling concepts used in simulation can also be used to describe lean construction concepts such as push vs. pull, and flow and conversion activities. She concluded that implementing simulation using lean concepts will help in redesigning construction processes to make it more efficient.
Another research tried to evaluate the use of lean principles by modeling the erection of structural steel frame [Al-Sudairi et. al. 1999]. Dramatic improvement in project performance and extraordinary efficiency in the erection operation, were reported when lean principles are applied simultaneously.

In addition to the above-mentioned, Further researches had discussed the use of simulation in applying lean principles and techniques. However, much more efforts still have to be done. Although many simulation systems proved to be effectively used in modeling lean construction operations, yet this is not always done with ease, especially when more and more lean principles and concepts are to be incorporated into the model. Therefore, a new, more flexible and effective, simulation system must be developed. The design of the needed simulation system must consider the incorporation of lean principles and techniques, such as preparing value stream maps. Moreover, project level concepts have to be considered.

7. RESEARCH EFFORTS IN LEAN CONSTRUCTION

The train of thoughts, presented in this paper, imposed on the authors giving more attention to the researches discussing the use of simulation in modeling lean construction. However, this portion of the research efforts in lean construction consists just a minor part of it. In fact, since the emergence of lean construction by the innovative report of Koskela [1992], research efforts in this domain were directed to establish new scientific foundations for construction management and engineering, along with complete sets of tools and techniques. These efforts extended to reach disciplines that have attracted little attention, if any, in construction management researches (e.g. design management).

The annual conference held by the International Group for Lean Construction (IGLC) can be a good indication for the fervor of these research efforts. More than 300 technical papers were introduced in the eleven rounds of the conference. The main disciplines, which were discussed, are:

- Theory of production
- Work structuring and buffer management
- Lean design
- Site applications of tools and techniques
- Production planning and control
- Logistics and supply-chain management
- Assembly and prefabrication
- Organizational learning and action research
- Safety and environment
- Strategy and performance measurements
- Product development
- Information technology
- Case studies in lean construction implementation

Gains from these research efforts are tangible. A new tool for planning, programming, and following up at the operational level was developed, which is the “Last Planner” [Ballard & Howell 1994a, 1994b]. The Last Planner, which implements several lean Construction techniques, has been used in several construction projects, causing the realization of substantial improvements in productivity and performance [Junior et. al. 1998]. A computer implementation of the Last planner was also developed to facilitate the generation of quality work assignments, and detailed production scheduling [Choo et al. 1998].

Researches are continuing now at the “Lean Construction Institute” (LCI) to incorporate the main lean principles, tools, and practices into one comprehensive methodology, which is the “Lean Project Delivery System” (LPDS). The LPDS is being developed as a philosophy, a set of interdependent functions, rules for decision making, procedures for execution of functions, and as implementation aids and tools [Ballard 2000].

8. CONCLUSIONS

The current construction management techniques are built upon the conventional production theory, which views production as a conversion process. This paper has investigated the impacts of this theoretical basis on the construction planning process. It was concluded that the conventional production theory has counterproductive effects on construction planning. Viewing the construction project as a conversion process consisted of sub conversion processes, and neglecting other flow processes reduces the plans practicability. Network techniques, such as CPM and PERT, are built upon the theoretical basis of conversion model, and thus, inherit its problems. They were not able to deal efficiently with site problems related to the production process. The neglecting of flow processes makes these techniques poor tools for planning resource sharing and utilization.

On the other hand, it was concluded that lean production theory, originally developed in Japan, can be the sound theoretical basis upon which solutions for complicated and dynamic site problems can be developed. This theory views production as being consisted of both flow and conversion processes. Thus, practical work plans, which consider the need for resources sharing and work continuity, can be developed because the resources flows are no longer neglected.

However, implementing lean production principles in construction planning needs the fulfillment of two requirements. First, Lean production principles and concepts must be transformed from other production domains, such as manufacturing, at a high level of abstraction, to make it suitable for construction environment. Second, a powerful modeling tool other

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than the simple network techniques is needed. The needed modeling tool must be highly flexible, and has the ability to incorporate a high level of details in the project model. For the second requirement, simulation is suggested as the appropriate modeling tool that can satisfy the requirements of modeling lean construction projects. Nevertheless, more research efforts still have to be done, to improve the capabilities of simulation systems.

9. REFERENCES


10. ABBREVIATIONS

JIT: Just-In-Time.

TQC: Total Quality Control.