Lean Construction and IT principles, tools and applications in a South American Precast Concrete Industry

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ABSTRACT: During the precast concrete structures production process a challenging task is integration of the supply chain and the various departments within company. It is necessary to handle uncertainties related to the assembling process at construction site. The distance to the construction location, topography, weather conditions and other factors affect the level of these uncertainties. The challenge is to produce with reduced waste, high quality and on a synchronized fashion where every resource gets on exact time and quantity required by the production process. In order to achieve that situation the flow of design and engineering information plays a key role in order to enable a lean flow of materials. The present research investigated this issue on the largest factory of pre-fabricated components in the South of Brazil where the required information and the IT aspects that enable a lean material flow were studied. The emphasis was to look on process transparency and information flow among the design office, the factory and construction site. The paper presents key issues for improving integration of the automation islands in the whole process from design to component manufacturing and construction, like a web collaborative environment as a solution to enhance information flow transparency.

1 INTRODUCTION

A significant change has occurred in the last two decades concerning the importance of the production function within the construction organization. The production function used to be relegated to a second plan in many companies when compared to other organization functions such as planning, finance or marketing. It is now playing a far more pro-active role within construction companies. Taking this into account, the paper begins with a small review about production and its business role looking for a construction industry viewpoint. In the sequence it deals with 'lean thinking' concepts and implications for IT application. With these concepts in mind, a precast concrete plant case study developed in the South of Brazil is described. The analysis of the prefabricated elements production was made with respect to behavior, sequence, waiting, transportation, inspecting and controlling in order to understand the actual information flows and problems. Finally, based on this research tools and techniques of lean production and IT were proposed to collaborate in the search for problem solutions.

2 NEED FOR INTEGRATION

Galbraith (1986) argued that organizations are "packages of mosaics" in which all the pieces must fit together. In line with this, coherence of decision-making between production and other organizational functions, specifically concerning the business process, is a fundamental requirement for achieving a company's strategic objectives. Internal fights within a company, to satisfy fragmented objectives, are counterproductive and only lead to sub-optimization and waste of resources.

Production managers risk being affected by "cognitive nearsightedness" if they do not get involved in strategic planning. Short-term decisions may sacrifice a long-term strategic advantage. Bowman & Asch (1987) define "cognitive nearsightedness" as the tendency to pay more attention to physically observable, quantitative and immediate factors, at the expense of intangible dimensions of a problem that are remote in time and space. In other words, production managers may place too much emphasis on direct operational decisions and give little attention to their implications on the business strategy.

In this context, the production function may opt for one of the following strategic postures with respect to business needs (Hayes & Wheelwright 1984; Schroeder & al. 1986; Adler & al. 1992):

- *Internally neutral*: production that is simply reactive to the internal business demands. The function has few links with the rest of the business and makes a minimal contribution to increase the company's competitiveness;
- *Externally neutral*: production that is able to meet the standards imposed by the major competitors. It responds to problems encountered in the rest of the business, but never establishes its own long term strategy;
- *Internally supportive*: production that is tailored to the specific business strategy. In this case, the production function generates many new ideas and has a long term strategy, but it may not be well tuned to other functions needs or expectations;
- *Externally supportive*: production that aims to be as good as any other competitor in the world. In this case production supports both the current business priorities, and other organizational functions, thus, creating new opportunities for increased competitiveness.

Unfortunately, production is often found playing only an internally neutral role in many organizations. Production's usual response to competitive pressure has been a simple directive to "cut costs" which, in turn, results in the decision to reduce capital investment, minimize research and development, cut back preventive maintenance and to lay off workers (Wisner & Fawcett 1991). In some instances, production managers try to transfer and adopt the same "best practices" of other successful production systems. However, Mills & al. (1995) argue that "*the implementation of the best practices alone is unlikely to develop the production function ability to create and understand its own strategy*".

According to Skinner (1969), one of the main barriers for moving the production towards a more strategic role is the lack of a leadership that understands and accepts the idea of developing strategic thinking in the production function.

Hill (1992) adds some other reasons for the poor participation of production at the business strategic debate:

- The production manager's view of themselves: strategic implications of the production decisions are not fully understood even by the production managers themselves;
- The company view of the production manager's role: business strategic decisions are formulated assuming the production manager has few strategic contributions to give;
- Production managers are late into the corporate debate: very often production managers have their first contact with the content of the strategic decisions only after they have already been defined;
- The "can't say no" syndrome to orders: a result from the fear of losing face or being accused of incompetence in relation to other functions within the company;
- Lack of language: production managers rarely understand the language and practice at the corporate level because of their operational background (the lack of strategic management in the curriculum of undergraduate courses is also often a serious gap in higher education in this field);
- Functional goals and measures: the link between production goals and actions in the business performance is not always clearly made.

Hammer & Champy (1994) credit to Henry Ford this fragmentation approach to management where the business processes are broken up in tasks and services. A monumental effort is necessary to reconstitute the fragmented work, particularly on large companies. Davenport (1992) presents the theory of process management against these called functional structures. The idea is simple and looks for results in a linear way based on a continuous flow of actions through an enterprise structure without barriers. The result is an integrated process, transparent and without loss of visibility in the main focus (Gianesi & Correa 1994).

3 FLOW CONCEPT

This research used as a main theoretical framework the principles presented by Shingo (1989) and Koskela (1992) regarding lean thinking. "Flow" was key concept from lean thinking investigated in this research. According to the 'flow model', production is a flow constituted of processing, waiting, inspecting and transporting activities (Gilbreth 1911, Koskela 1992). Within this model, processing activities are the only ones that can add value to the customer and, therefore, waiting, inspecting and transporting are considered non-value-adding activities and should be eliminated from the main process flow.

Based on this model, a production system could be further described as a network of process flows and operations flows, lying along intersecting axes. A process flow is the designation for the flow of materials (or information) and represents the pathway in which raw material is transformed into semi-processed components and then into a finished product (Shingo 1989). In car production, the 'process flow' can be further divided into the flow of components to the workstations, and then flow of the car body through the assembly line. In industries such as construction, an additional process flow may occur with the movement of material within and across workstations (Birrel 1980, Koskela 1999).

An operations flow is the designation for the flow of humans or machines that carry on the work over each stage of the process flow. Operations are very diverse and dynamic in terms of content and position in time and space. Thus, in order to facilitate the analysis of production systems, operations can be further classified as (Shingo 1989):

- Set-up operations: preparation of the workstation before and after the principal operations (e.g. installing a scaffolding);
- Principal operations: actions which actually accomplish the essential operation (e.g. launching concrete on the formwork) and, also, those actions that help to achieve the essential operation (e.g. loading and unloading material);
- External operations: activities indirectly related to the principal operation, or common to a number of different operations (e.g. lubricating);
- Personal allowance: activities that serve the needs of the worker in terms of fatigue and biological needs (e.g. rest, drinking water).

4 PRACTICAL IMPLICATIONS AND APPLICATION IN CONSTRUCTION

The strategy to improve performance in the flow model sharply contrasts with the conversion model where the focus is on the replacement of human labor with new technology (Koskela 1997). In the flow model the aim of production managers and workers alike is different and aims to eliminate the inherent non-value adding activities (inspecting, waiting and transporting) and improve the efficiency of value adding activities (processing) (Koskela 1992).

The aim of the flow model is, therefore, to obtain "lean production systems", with little or no waste of resources. Therefore, identifying and eliminating sources of waste is a constant preoccupation on the minds of people using this paradigm in their every day activities. According to Imai (1997) and Shingo (1989), sources of waste are classified according to seven main categories:

- Overproduction: this type of waste results from "getting ahead" with respect to production schedules. Here the required number of products is disregarded in favour of efficient utilization of the production capacity;
- Inventory: final products, semi-finished products, or parts kept in storage do not add any value. Even worse, they normally add cost to the production system by occupying space and financial resources and, also, by requiring additional equipment, facilities and manpower;
- Repair/rejects: rejects interrupt production and, in general, require expensive rework. Moreover, they may end up discarded or damaging other equipment or generating extra paperwork when dealing with customer complaints;
- Motion: any motion not related to adding value is unproductive;
- Transport: although sometimes this activity seems to be an essential part of production, moving materials or products adds no value at all;
- Processing: this waste happens when the use of inadequate technology or poor design results in inefficient processing activities. Sometimes this waste may appear as a consequence of a failure to synchronize processes, where workers achieve performance levels beyond or below the requirements of downstream processes;
- Waiting: this waste occurs when the hands of a worker are idle such as when there are imbalances in schedule, lack of parts, machine downtime or when the worker is simply monitoring a machine performing a value-adding job.

This classification could extend further with the inclusion of vandalism, theft and other sources of waste. Koskela (1999) proposes the inclusion of a type of waste that occurs frequently in construction when production operates under 'sub-optimal conditions'. Congestion of a workstation in small places, work out-of-sequence and excessive stops in the flow are examples of these conditions that lead to production having sub-optimal performance (Ballard & Howell 1998, Koskela 1999). Formoso & al. (1999) adds that on building sites it is possible to find waste due to 'substitution'. This waste happens when, for instance, there is a monetary loss caused by the substitution of a material by a more expensive one or when the execution of a simple task uses over qualified workers.

Another important aspect of the flow model is the importance of the differentiation between 'process and operations flow', particularly for those searching for improvements in production systems. 'Process flows' (material/information) should always receive top priority in improvement activities within production systems. For example, and conventionally, most people simply think that improving transport efficiency refers to the adoption of forklifts or installing conveyors, etc. However, within the process/operation model, improving transport can also mean reducing or even eliminating the transport altogether. It is only after this broader analysis has been carried out in the entire 'process' that improvements should be devoted to the actual operation of "transport" (Shingo 1988, Edward & Peppard, 1994).

In the case of 'operations flow', the objective of managers/workers involved in the analysis of production should be to reduce the amount of set-up, external and personal operations involved or interfering in the principal operations. At the same time, the analysts should attempt to increase the efficiency of the principal operations. Activities such as adjustments, rest or lubrication, for instance, should be moved out of the main process flow in order to allow a smoother and faster process cycle time.

There are many techniques available to analyse and improve production systems using the flow model as the conceptual base. They allow the analyst to understand actual behavior, sequence, proportion and variability of inspecting, waiting, processing and transporting activities. Many of them were invented in the early days of Scientific Management School, such as time-lapse video recording, work sampling and flow charts.

From an Information Technology (IT) point-of-view the flow concept has profound implications. Henderson & Venkatraman (1993) point that one of the difficulties for the companies in getting profits with the implantation of IT relies in the lack of ability to co-ordinate and to line up the business strategies with the IT strategies. Various authors like Laudon & Laudon (2003) agree with it confirming that the most difficult part of an information system project is to efficiently understand the actual problem that should be considered. From a lean production point of view the problem that IT could tackle is straightforward: it could contribute on the reduction of all waiting, transporting and inspecting/controlling activities that interfere on the material/information flow.

5 RESEARCH METHODOLOGY

The chosen research method was the case study supported by bibliographic review. The case study was carried through structured direct observations within the precast plant and interviews with objective of knowing and understanding the actual process and operations flow.

Based on the principles of the lean production, the research team made detailed comments on the transformation processes from raw materials to finished products. A detailed description of all operations to accomplish the processing activities was obtained at the end of the data collection, following traditional approaches used to obtain standard processes. A photographic survey, video recording, document analysis was also carried out in addition to the direct observation and interviews.

A workshop between researchers and company representatives was set in order to increase internal validity of the data and analysis. The company representatives were the team leaders and the people actually in charge of the production system. This workshop adopted the "brainstorming" as a tool to instigate the participants to put their views on the problems and solutions related to information flows that support production.

5.1 Company characterization

Precast concrete is a significant contributor in many building types, including commercial, like shopping malls and supermarkets, and parking garages. Precast concrete plants usually serve limited geographic regions, restricted by the distance over which pieces can be economically transported. Although many companies operate more than one plant, the industry remains somewhat fragmented (Eastman & al. 2003).

The elements most commonly produced for the Brazilian building construction are double tees, hollow-core slab elements, inverted tee and ledger beams, spandrels, columns and façade panels. Like other countries, there is no standard for element dimensions. For example, each company produces double-tees with varied basic dimensions.

This study case is based on data and analysis related to the largest precast industrial plant in Brazil. The same company has another four plants in Brazil. The visited plant has a nominal capacity for 200 cubic meters per day of diverse products. The actual production is about 160 cubic meters. More than a half is of hollow-core slabs and about 60 cubic meters of beams and columns. The inverted tee beams has a non-uniform production and is less than 20% of the production.

The production system within the case study was divided in five main bodies: slabs, roof beams, foundation piles, columns, and beams. In each of these cells there was two main activities: to prepare steel armors and to launch the concrete for the elements. There was a "steel central office" and a "concrete central office" providing all information and resources related to steel and concrete to all production cells.

Each precast element remains in its place until the concrete achieved the required rigidity. This phase usually last around one day and, after that, the concrete elements were transported to a storage area. A subcontracted company transported the elements to the construction site and another team carried out the assembling process.

The main departments involved in this process were: "general management"; "personnel"; "finance" and "accounting"; "purchasing" and "marketing"; "technical/engineering"; "supply management"; and "production". The manufacturing leader in the precast industrial plant had direct communication with the board of directors. In fact, the researchers have identified only one hierarchical level between the director board/management and the manufacturing plant. Taking into account these organizational aspects of the production function, the present research investigated the required information and IT applications that could help this company to enable a lean material flow, with emphasis on the increase of process transparency.

6 MAIN IDENTIFIED INFORMATION FLOWS

The analysis of data collected on the factory and during the workshop with company representatives allows the identification of ten major production problems that could receive a positive input from IT support:

– variation in the production productivity;
– reduced commitment from employees in relation to business goals;
– no effective communication between teams (factory x designers x construction site);
– losses due to design integration (hydraulic, structure, etc) and lack of standardization;
– losses with storage due to delays on the cutting process of precast element like roof beams and, also, delays on the concrete launch;
– process unbalancing particularly on the concrete launch;
– cure of the concrete as a key bottleneck in the production process;
– excessive time spend on activities such as formwork cleaning, demould and stretching of steel cables;
– losses due to overproduction (production without confirmed client orders with the solely intent of keeping production personnel "busy");
– deficient layout planning: excessive transportation distances and lack of transparency.

One of the main problems pointed in brainstorming was the lack of commitment of the employees regarding the production goals established by the company. This can be attributed to the lack of clarity in the communication which could be observed between the members of a department and between different departments. It can be understood as "noise" during the communication processes, i.e., interferences that make difficult to have clarity in the information reception. Another relevant aspect is the lack of feedback culture between the receiver and the sender of a message or command. It was also identified a deficient communication between the company and its customers and between professionals involved in the architectural design and the assembling team. Such communication problems resulted in poor design standardization and sub-optimized design solutions (Fig. 1).

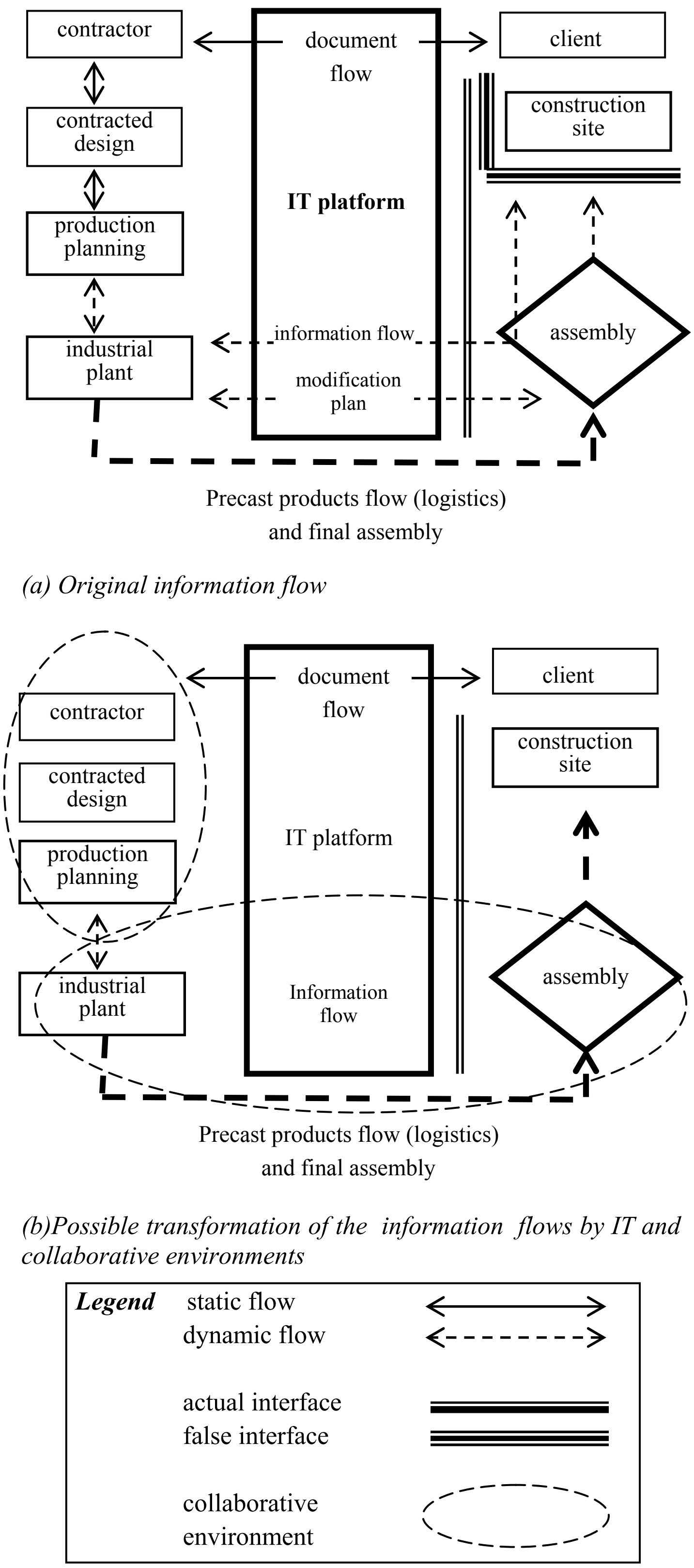

Figure 1. Information flow: original and modified flow

The research observations disclosed that there are lacks of synchronism between the actual flow of the construction site execution and the production flow in the precast industry floor plant. This significantly increased the time wait in the assembly of components and in the allocation of people and machines.

Production flexibility, both in terms of volume as product mix, was a major issue to change this scenario. Such flexibility implies in the implementation of devices for increase the speed of setup operations. Therefore, information availability was a key aspect to enable higher flexibility of the workstations.

The first part of Figure 1 shows the reported situation with the disconnected, fragmented and naive sequential use of the information technologies without a real information system characterization. In the second diagram of Figure 1 it is presented a solution approach with the information flow reorganization through web collaborative environment that permits the data sharing for the product characterization and customization: owner demands, manufacturability and constructability, costs and history of the firm. The data sharing provides stronger team commitment and better management decision support. In the case, the suggestion was for a convenient adoption of two different collaborative environments: one for the product design process and one for the product manufacturing.

7 INFORMATION TECHNOLOGY CONTRIBUTIONS TO SOLVE CASE STUDY PRODUCTION PROBLEMS

Current Information Technology solutions are capable of providing solutions to the problems presented above. As described earlier, the process should be tackle first (flow of information/material). Once it has been exhausted there is a number of IT solutions that could be installed like mobile phones, faxes, webcams, desktops, notebooks, handheld computers, and radios and contribute to actually reduce waste in this case study. However, because this company operates in a large geographical area the researchers concluded that it was necessary the use of systems based on local area networks, world-wide area networks (Internet), satellites, magnetic waves and others.

Table 1 summarizes some of the main information problems and proposed tools and techniques of lean production and IT identified.

Currently, it is possible to use different technologies generated under the Internet and the World-Wide-Web development like e-mail, web sites, document servers, chat, business-to-business (B2B) applications and peer-to-peer (P2P) systems (Issato & Formoso 2004). In this scenario, the solution devised to tackle the problems identified in production was to establish the communication between the involved ones by means of an extranet.

Table 1. Information problems, lean production and IT applications.

Information Problem	*Lean Production Principle*	*Lean Production Tool*	*IT Application*
Excessive storage of slabs and piles	Pulled production	Just in time Kanban system	To promote more agile communication with construction sites Extranet and webcams in the construction sites
Excessive timeloss to prepare formwork, demould, etc.	Flexible production	Celular manufact. Quick setup Multi-task workers	Time accounting, dairy schedule and tasks control, production reports, discuss variations
Lack of project standardization and production program without previous plan	Leveled production	Quick setup Small lots Production synchronization	Establish standard procedures; forecast variations; promote feedback culture; promote online meetings; adopt collaborative engineering practices
Lack of commitment with company goals; weak communication with team leaders	Adequate use of human resources	Multi-task workers Kaizen Training	Establish communication channels between departments; small team meetings with self-leadership
Lack of information about solved problems and other fails	Visual management	"Andons" Light panels Call-lights systems	Promote transparency through information panels with goals; more participation of workers in problem-solving routines; videoconferenc. and web cameras
Layout problems: excessive movements for people and transportation; frequent/repeated bottlenecks	Continuous flow of production – Process intervention	Layout in harmony with process Waste elimination	Online communication in the bottlenecks; search for team 'spirit' and results sharing; give visibility and transparency to whole process

According Pakstas (1999), extranet is based on the Internet infrastructure (servers, e-mail clients and web browsers). Extranet is defined as a business-oriented technology that consists of a private network that involves various organizations that may act in a cooperative way. An extranet needs a server that could be a local hardware or a virtual server. Through this server the information will be controlled and storaged in real time as efficient IT system.

The use of extranets as the communication and exchange of information method can bring good results in this case. However, according to Nascimento & Santos (2002), it must be considered some barriers, that can make difficult the implantation of the system:

- professional staff with little IT training;
- resistance to the change of some involved personnel;
- lack of physical structure and technical staff;
- lack of standardization in the communication as a complex process;
- lack of training adjusted to the system in use;
- necessity of high-speed (broadband) connection to the Internet (availability, cost).

8 CONCLUSION

Each segment of the market demands specific systems that take care of its necessities. Companies such as the one investigated in this research need to establish an IT strategic plan for the development of these systems. In this plan it should be defined which hardware, software and ways of transmission to use. The company needs to define the managerial guidelines for the IT professional who will develop the IT plan: Which is the amount of capital to invest in IT? Which are the necessities that the system will have to take care of? Which are the speed of transmission of information? And so on.

First, it is necessary to define the different departments or external customers that will exchange information. After this definition, with the available amount of capital for IT investments, the IT staff will define hardware, software and transmission (communication) alternatives to use. In the case study, the communication must happen between the customer, the commercial department, the technical/engineering department, the floor production plant and the assembly team. And, the commercial department needs an open channel with all the integrants because it is responsible for the follow-up of the schedules and the relationship with the customer.

In this case study it was verified that it is crucial to have accurate information and at the right moment so that the system of pulled production reaches its full effectiveness. All lack or accuracy of information immediately generates unnecessary supplies that only increase the cost. The production teams with lack of information start to produce more than necessary, looking to safe margins. In this context IT assumes a strategic position in the production flexibility. IT acts directly in the external environment of the company verifying consumption trends and surveying purchasing speed, as well as the products that present bigger acceptance.

In order to achieve full transparency the production system must implement IT solutions along with all visual management practices like visual controls.

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