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Lean production in construction

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Abstract

In manufacturing, great gains in performance have been realized by a new production philosophy, which leads to "lean production". This new production philosophy is a generalization of such partial approaches as JIT, TQM, time-based competition, and concurrent engineering. In construction, lean production is little known. The concepts, principles and methods of lean production are reviewed, and their applicability in construction is analyzed. The implications of lean production to construction practice and research are considered.

1. INTRODUCTION

The chronic problems of construction are well-known: low productivity, poor safety, inferior working conditions, and insufficient quality. A number of solutions or visions have been offered to relieve these problems in construction. Industrialization (i.e. prefabrication and modularization) has for a long time been viewed as one direction of progress. Currently, computer integrated construction is seen as an important way to reduce fragmentation in construction, which is considered to be a major cause of existing problems. The vision of robotized and automated construction, closely associated with computer integrated construction, is another solution promoted by researchers.

Manufacturing has been a reference point and a source of innovations in construction for many decades. For example, the idea of industrialization comes directly from manufacturing. Computer integration and automation also have their origin in manufacturing, where their implementation is well ahead compared to construction.

Currently, there is another development trend in manufacturing, the impact of which appears to be much greater than that of information and automation technology. This trend, which is based on a new production philosophy, rather than on new technology, stresses the importance of basic theories and principles related to production processes (Shingo 1988, Schonberger 1990, Plossl 1991). However, because it has been developed by practitioners in a process of trial and error, the nature of this approach as a philosophy escaped the attention of both professional and academic circles until the end of 1980's.

In construction, there has been rather little interest in this new production philosophy. The goal of this paper is to assess whether or not the new production philosophy has implications for construction. The paper is based on a more detailed study (Koskela 1992a).

2. LEAN PRODUCTION

2.1 Origins of lean production and the new production philosophy

Since the end of 1970's, a confusingly long array of new approaches to production management has emerged: JIT, TQM, time based competition, value based management, process redesign, lean production, world class manufacturing, concurrent engineering.

After closer analysis, it transpires that the above mentioned management approaches have a common core, but view this from more or less different angles. This common core is made up by a conceptualization of production or operations in general; the angle is determined by the design and control principles emphasized by any particular approach. For instance JIT stresses the elimination of wait times whereas TQM aims at the elimination of errors and related rework but both apply this angle to a flow of work, material or information.

Thus, a new production philosophy is emerging through generalization of these partial approaches, as has been suggested recently by various authors (Schonberger, 1990; and Plossl, 1991). The new production philosophy, regardless of what term is used to name it (world class manufacturing, lean production), is the emerging mainstream approach practised, at least partially, by major manufacturing companies in America, Europe and Japan. The new philosophy has already had a profound impact in such industries as car manufacturing and electronics. The application of the approach has also diffused to fields like customized production, services, administration and product development.

The conception of the new production philosophy evolved through three stages : It was viewed as a tool (like kanban and quality circles), as a manufacturing method (like JIT) and as a general management philosophy (referred to, for example, as world class manufacturing or lean production). The conceptual and theoretical aspects of the new production philosophy are least understood. However, without conceptual and theoretical understanding the application of methods is bound to remain inefficient and haphazard.

In Figure 1, an attempt for a consolidation of the new production philosophy is presented. The various levels are analyzed in the following.

2.2 Conceptual framework

The core of the new production philosophy is in the observation that there are two aspects in all production systems: conversions and flows. While all activities expend cost and consume time, only conversion activities add value to the material or piece of information being transformed into a product. Thus, the improvement of non value adding flow activities (inspection, waiting, moving), through which the conversion activities are bound together, should primarily be focused on reducing or eliminating them, whereas conversion activities should be made more efficient. In design, control and improvement of production systems, both aspects have to be considered. Traditional managerial principles have considered only conversions, or all activities have been treated as though they were value-adding conversions.

Due to these traditional managerial principles, flow processes have not been controlled or improved in an orderly fashion. We have been preoccupied with conversion activities. This has led to complex, uncertain and confused flow processes, expansion of non value-adding activities, and reduction of output value.

Material and information flows are thus the basic unit of analysis in the new production philosophy. Flows are characterized by time, cost and value.

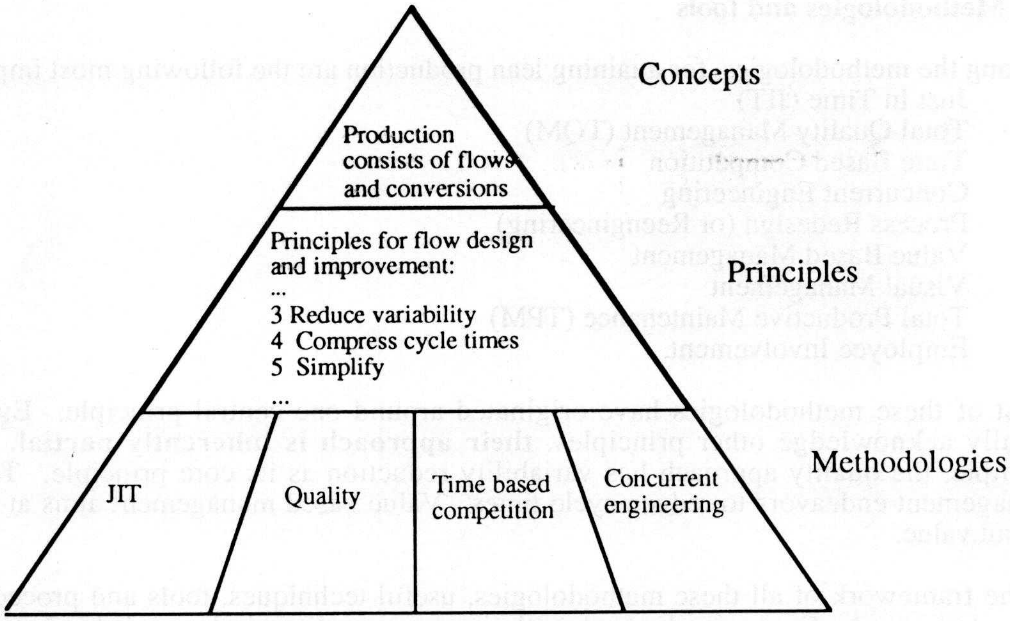

Figure 1. Different levels of the new production philosophy

2.3 Principles

In various subfields of the new production philosophy, a number of heuristic principles for flow process design, control and improvement have evolved. There is ample evidence that through these principles, the efficiency of flow processes in production activities can be considerably and rapidly improved. The principles may be summarised as follows (Koskela 1992a):

1. Reduce the share of non value-adding activities (also called **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.
11. Benchmark.

In general, the principles apply both to the total flow process and to its subprocesses. In addition, the principles implicitly define flow process problems, such as complexity, intransparency or segmented control.

Experience shows that these principles are universal: they apply both to purely physical production and to informational production, like design. Also, they seem to apply both to mass production and one-of-a-kind production.

2.4 Methodologies and tools

Among the methodologies for attaining lean production are the following most important:
- Just In Time (JIT)
- Total Quality Management (TQM)
- Time Based Competition
- Concurrent Engineering
- Process Redesign (or Reengineering)
- Value Based Management
- Visual Management
- Total Productive Maintenance (TPM)
- Employee Involvement.

Most of these methodologies have originated around one central principle. Even if they usually acknowledge other principles, **their approach is inherently partial.** Thus, for example, the quality approach has variability reduction as its core principle. Time based management endeavors to reduce cycle times. Value based management aims at increasing output value.

In the framework of all these methodologies, useful techniques, tools and procedures have been developed. For example, such techniques as quality circles and the 7 quality tools (fishbone diagram, Pareto-diagram etc.) are used in TQM.

2.5 Comparison between conventional production and lean production

What is the conventional production philosophy being now replaced by the new philosophy? It is the paradigm of industrial mass production, which evolved in the beginning of this century. The most important differences between the conventional and the new philosophy are summarized in Table 1.

Table 1. The conventional and the new production philosophy.

	Conventional Production Philosophy	*New Production Philosophy*
Conceptualization of production	Production consists of conversions (activities); all activities are value-adding	Production consists of conversions and flows; there are value-adding and non-value-adding activities
Focus of control	Cost of activities	Cost, time and value of flows
Focus of improvement	Increase of efficiency by implementing new technology	Elimination or suppression of non-value adding activities, increase of efficiency of value adding activities through continuous improvement and new technology

The results of the implementation of the conventional and the new production philosophy are schematically illustrated in Figure 2.

Conventional production is improved by implementing new technology, primarily in value adding activities, to some extent also in non-value adding activities (like automated storages, transfer lines and computerized control systems). However, with time, the cost share of non-value adding activities, which are not explicitly controlled, tends to grow: production becomes more complex and prone to disturbances.

In lean production, non value-adding activities are explicitly attended. Through measurements and the application of the principles for flow control and improvement, it is possible to initially reduce the costs of non value-adding activities considerably. Value adding activities are first improved through internal continuous improvement and finetuning of existing machinery. Only after these improvement potentials are realized, major investments in new technology are considered. The implementation of new technology is easier in lean production, because less investments are needed and the production is better controlled. Thus, after the initial phase, increase of efficiency of value adding activities should also be more rapid in lean production than in conventional production.

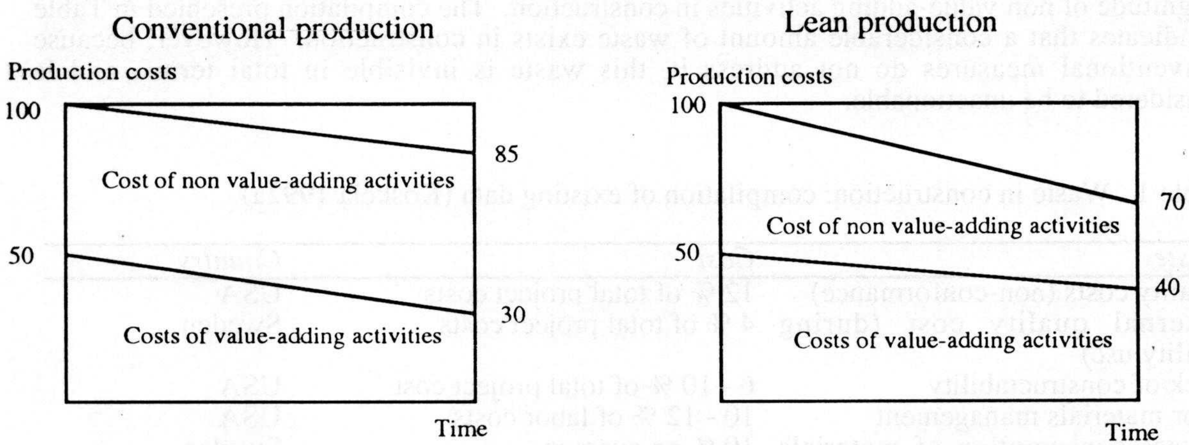

Figure 2. Conventional and lean production: focus of development efforts

3. LEAN PRODUCTION IN CONSTRUCTION

3.1 Preliminary implementation

In the construction industry, the overall diffusion of the new philosophy seems to be rather limited and its applications incomplete. Quality assurance and TQC have been adopted by a growing number of organizations in construction, first in construction material and component manufacturing, and later in design and construction. The new approach, in its JIT-oriented form, has been used by component manufacturers, for example in window fabrication and prefabricated housing.

Why has the diffusion of the new production philosophy been so slow in construction? The most important barriers to the implementation of these ideas in construction seem to be the following:

- Cases and concepts commonly presented to teach about and diffuse the new approach have often been specific to certain types of manufacturing, and thus not easy to internalize and generalize from the point of view of construction.
- Relative lack of international competition in construction.
- Lagging response by academic institutions.

However, it seems that these barriers are of a temporary nature. On the other hand, the slow diffusion is not explained by an inadequacy of the new philosophy with respect to construction. This is justified by following analyses of waste and peculiarities in construction.

3.2 Waste in construction

To what degree do the problems associated with the conventional production view, as observed in manufacturing, also exist in construction? If the flow aspects in construction have been historically neglected, it logically follows that current construction would demonstrate a significant amount of waste (non value-adding activities). Thus, it is appropriate to check whether the existing information supports this hypothesis.

There has never been any systematic attempt to observe all wastes in a construction process. However, partial studies from various countries can be used to indicate the order of magnitude of non value-adding activities in construction. The compilation presented in Table 1 indicates that a considerable amount of waste exists in construction. However, because conventional measures do not address it, this waste is invisible in total terms, and is considered to be unactionable.

Table 1. Waste in construction: compilation of existing data (Koskela 1992a).

Waste	*Cost*	*Country*
Quality costs (non-conformance)	12 % of total project costs	USA
External quality cost (during facility use)	4 % of total project costs	Sweden
Lack of constructability	6 - 10 % of total project cost	USA
Poor materials management	10 - 12 % of labor costs	USA
Excess consumption of materials on site	10 % on average	Sweden
Working time used for non-value adding activities on site	Appr. 2/3 of total time	USA
Lack of safety	6 % of total project costs	USA

3.3 Problems of construction are caused by neglect of flows

Analysis (Koskela 1992a) shows that, as in manufacturing, the conceptual basis of construction engineering and management is conversion or activity oriented. The construction process is seen as a set of activities, each of which is controlled and improved as such. Conventional managerial methods, like the sequential method of project realization or the CPM network method, deteriorate flows by violating the principles of flow process design and improvement. They concentrate on conversion activities. The resultant problems in construction tend to compound and self-perpetuate. In project control, fire-fighting current or looming crises consumes management resources and attention so totally that there is little room for planning, let alone improvement activities. As a consequence, there is considerable waste in construction.

3.4 New conceptualization of construction

Following the lead of manufacturing, the next task is to reconceptualize construction as flows. The starting point for improving construction is to change the way of thinking, rather than seeking separate solutions to the various problems at hand.

Thus, it is suggested that the information and material flows as well as work flows of design and construction be identified and measured, first in terms of their internal waste (non value-adding activities), duration and output value. For improving these flows, it is a prerequisite that new managerial methods, conducive to flow improvement, are developed and introduced.

Such methods have already been developed to varying degrees. Not unexpectedly, they try to implement those flow design and improvement principles which are violated by the respective conventional method. However, lacking a sound theory, these efforts have remained insufficient.

Generally, taking flows as the unit of analysis in construction leads to profound changes of concepts and emphasis.

3.5 Construction peculiarities

Construction peculiarities refer especially to following features: one-of-a-kind nature of projects, site production, and temporary multiorganization. Because of its peculiarities, the construction industry is often seen in a class of its own, different from manufacturing. These peculiarities are often presented as reasons when well-established and useful procedures from manufacturing are not implemented in construction.

Indeed, these peculiarities may prevent the attainment of flows as efficient as those in stationary manufacturing. However, the general principles for flow design and improvement apply for construction flows in spite of these peculiarities: **construction flows can be improved**. Consider, for example, the one-of-a-kind nature of construction projects. The same peculiarity is shared by many - if not most - product development projects in manufacturing. However, it has been possible to shorten the development time and to improve the output quality in such projects by implementing principles of the philosophy.

On the other hand, these construction peculiarities can be overcome. Initiatives in several countries, like "Sequential Procedure" in France, "Open Building System" in the Netherlands and "New Construction Mode" in Finland try to avoid or alleviate related problems:

- one-of-a-kind features are reduced through standardization, modular coordination and widened role of contractors and suppliers
- difficulties of site production are alleviated through increased prefabrication, temporal decoupling and through specialized or multi-functional teams
- the number of temporary linkages between organizations is reduced through encouragement of longer term strategic alliances.

However, the **elimination of construction peculiarities is not any solution itself**: it just brings construction to the same level as manufacturing. Unfortunately, a large amount of waste also exists in manufacturing before process improvement efforts begin. Thus, only a starting point for effective process improvement is provided.

Thus it is concluded that the construction peculiarities do not diminish the significance of the new philosophy for this industry.

4. IMPLICATIONS

The implications of the new production philosophy for construction will be far-reaching and broad, as they are in manufacturing. The renewal of manufacturing has been realized in a feverish burst of conceptual and practical development. This might also happen in construction.

4.1 Implications for academic research

Current academic research and teaching in construction engineering and management is founded on an obsolete conceptual and intellectual basis. It is urgent that academic research and education address the challenges posed by the new philosophy. The first task is to explain the new philosophy in the context of construction. Formalization of the scientific foundations of construction management and engineering should be a long term goal for research.

4.2 Implications for major development efforts in construction

Current development efforts like industrialized construction, computer integrated construction and construction automation have focused primarily on the efficiency of value-adding and to some extent also non value-adding activities. They have to be redefined in order to acknowledge the needs for flow improvement. For example, the following guidelines for construction automation can be derived from the principles presented above (Koskela 1992b):

- automation should be primarily focused on value-adding activities
- construction process improvement should precede automation
- continuous improvement should be present in all stages of development and implementation of automation.

4.3 Implications for the industry

Every organization in construction already can initially apply the generic principles, techniques and tools of the new production philosophy: defect rates can be reduced, cycle times compressed, and accident rates decreased. Examples of pioneering companies show that substantial, sometimes dramatic improvements are realizable in a few years after the shift to the new philosophy. Given the presently low degree of penetration, there are ample opportunities for early adopters to gain competitive benefits.

However, for continued progress, new construction specific managerial methods and techniques are needed; presumably they will emerge from pratical work, as occurred in manufacturing.

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