



CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

**APPLICATION OF
THE NEW PRODUCTION PHILOSOPHY
TO CONSTRUCTION**

By

Lauri Koskela

CIFE Technical Report #72

September, 1992

STANFORD UNIVERSITY

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Summary: TECHNICAL REPORT #72

Title: Application of the New Production Philosophy to Construction

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Date: August, 1992

Funding: The study has been realized during the stay of the author as a Visiting Scholar at CIFE. Funded by Technical Research Centre of Finland, the Federation of the Finnish Building Industry and the Wihuri Foundation.

1. **Abstract:** The background and development of the new production philosophy are presented. The conceptual basis of the traditional and the new production philosophies, as applied in manufacturing, are examined. The traditional conceptual basis of construction is criticized, and an initial new interpretation of construction is given based on the new philosophy. Finally, the challenges of implementing the new production philosophy in construction are considered.
2. **Subject:** The term “new production philosophy” refers to an evolving set of methodologies, techniques and tools, the genesis of which was in the Japanese JIT and TQC efforts in car manufacturing. Several alternative names are presently used to refer to this philosophy: lean production, JIT/TQC, world class manufacturing, time based competition. In manufacturing, great gains in performance have been realized by this new production philosophy. With the exception of quality methodologies, this new philosophy is little known in construction.
3. **Objectives/Benefits:** The goal of this report is to assess whether or not the new production philosophy has implications for construction.
4. **Methodology:** The study consisted mainly of a literature review and a conceptual analysis and synthesis. In the last stage of the study, four engineering or construction companies were visited to ascertain the present level of implementation of the new philosophy.
5. **Results:** Construction should adopt the new production philosophy. In manufacturing, the new production philosophy improves competitiveness by identifying and eliminating waste (non value-adding) activities. Traditionally, construction is viewed and modeled only as a series of conversion (value-adding) activities. For example, waste activities such as waiting, storing inventory, moving material, and inspection are not generally modeled by Critical Path Models (CPM) or other control tools. Construction has traditionally tried to improve competitiveness by making conversions incrementally more efficient. But judging from the manufacturing experience, construction could realize dramatic improvements simply by identifying and eliminating non conversion (non value-adding) activities. In other words, actual construction should be viewed as flow processes (consisting of both waste and conversion activities), not just conversion processes. As demonstrated previously by the manufacturing industry's experience, adoption of the new production philosophy

will be a fundamental paradigm shift for the construction industry. The implications of this for design is that the process of construction must be developed in conjunction with the design itself.

An initial set of design and improvement principles for flow processes is presented that can serve as an implementation guideline.

Major development efforts in construction, like industrialization, computer integrated construction and construction automation have to be redefined to acknowledge the need to balance flow improvement and conversion improvement.

The conceptual foundation of construction management and engineering, being based on the concept of conversion only, is obsolete. Formalization of the scientific foundations of construction management and engineering should be a primary long term task for research.

6. **Research status:** This exploratory study raises a series of research questions. Some of them are currently addressed in other ongoing CIFE projects. For example, the relation between process improvement and technical integration is assessed in the study on integration's impact on plant quality. Other questions will be addressed in future CIFE projects.

The author will continue this line of research at the Technical Research Centre of Finland, focusing on problems of implementation.

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EXECUTIVE SUMMARY

1. In manufacturing, great gains in performance have been realized by a new production philosophy. In construction, this new philosophy is little known.
2. The conventional thinking views production as conversion processes. The new philosophy views production as consisting of both conversions and flows. Only conversions add value. This has fundamental implications for design, control and improvement of production processes.
3. The improvement of flow activities should primarily be focused on reducing or eliminating them, whereas conversion activities have to be made more efficient. An initial set of design and improvement principles for flow processes has evolved.
4. In construction, conceptualization of production is based on the conversion process model, as formerly in manufacturing.
5. According to the new view, a construction project consists of three basic flows (design process, material process and work process) and supporting flows. For most participating organizations, these processes repeat from project to project with moderate variations.
6. Traditional managerial concepts, based on the conversion conceptualization, have ignored and often deteriorated flows in construction.
7. As a consequence of traditional managerial concepts, construction is characterized by a high share of non value-adding activities and resultant low productivity.
8. The peculiarities of construction (one-of-a-kind projects, site production, temporary organization) often prevent the attainment of flows as efficient as those in stationary manufacturing. However, the general principles for flow design, control and improvement apply: construction flows can be improved, in spite of these peculiarities.
9. Due to deficient conceptualization, such development efforts as industrialization and computer integrated construction have often been misdirected. The resultant neglect of process improvement has become a barrier for progress.
10. The concept of process improvement provides a framework, which can - and should - be immediately applied in all construction industry organizations.
11. Measures, which directly pinpoint improvement potential (waste or value) and facilitate targeting and monitoring of improvement, are crucial for implementation of process improvement.
12. The conceptual basis of construction management and engineering is obsolete. Formalization of the scientific foundations of construction management and engineering should be a primary long term task for research.

ACKNOWLEDGEMENTS

This research was made possible through grants from the Technical Research Centre of Finland, the Federation of the Finnish Building Industry and the Wihuri Foundation. The Center for Integrated Facility Engineering (CIFE) at Stanford University provided for office facilities, advice and a stimulating environment. Special thanks are due to the Director of CIFE, Professor Paul Teicholz and the advisor for this study, Professor Bob Tatum. The language of the report was checked by Kelly Jean Fergusson.

I also wish to thank the persons in the companies I visited, who gave generously of their time, and who willingly shared their experiences in process improvement: Bechtel, Brown & Root, Hensel & Phelps, The M.W. Kellogg Company.

The ideas of the report, in their various stages, were commented upon by several faculty members and students in the Department of Civil Engineering and the Center for Integrated Facility Engineering at Stanford University. Valuable feedback was also given by construction faculty members of UC Berkeley.

1 Introduction

The problems of construction are well-known. Construction productivity lags that of manufacturing. Occupational safety is notoriously worse than in other industries. Due to inferior working conditions, there are work force shortages in many countries' construction sector. The quality of construction is considered to be insufficient.

A number of solutions or visions have been offered to relieve the chronic 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.

Now, 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. 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 report is to assess whether or not the new production philosophy has implications for construction.

The study on which this report is based consisted mainly of a literature review and a conceptual analysis and synthesis. In the last stage of the study, four companies were visited to ascertain the present level of implementation of the new approach. Findings from companies are presented as anecdotal evidence in support of argumentation.

The structure of the report is as follows. In Chapter 2, the background and development of the new production philosophy are presented. In Chapter 3, the conceptual basis of the traditional and the new production philosophies, as applied in manufacturing, are examined. Chapter 4 analyzes and critiques the traditional conceptual basis of construction. An interpretation of construction based on the new philosophy is given in Chapter 5. Next, the implementation of the new production philosophy in construction is considered in Chapter 6. Finally, Chapter 7 contains a short summary of the report.

2 New production philosophy: origin, development, and main ideas

2.1 Origins and diffusion

The ideas of the new production philosophy first originated in Japan in the 1950's. The most prominent application was the Toyota production system. The basic idea in the Toyota production system is the elimination of inventories and other waste through small lot production, reduced set-up times, semiautonomous machines, co-operation with suppliers, and other techniques (Monden 1983, Ohno 1988, Shingo 1984, Shingo 1988).

Simultaneously, quality issues were attended to by Japanese industry under the guidance of American consultants like Deming, Juran and Feigenbaum. Quality philosophy evolved from a statistical method of quality assurance to a wider approach, including quality circles and other tools for company-wide development.

These ideas were developed and refined by industrial engineers in a long process of trial and error; establishment of theoretical background and wider presentation of the approach was not seen as necessary. Consequently, up to the beginning of the 1980's, information and understanding of the new approach in the West was limited. However, the ideas diffused to Europe and America starting in about 1975, especially in the automobile industry.

During the 1980's, a wave of books were published which analyzed and explained the approach in more detail (Deming 1982, Schonberger 1982, Schonberger 1986, Hayes & al. 1988, O'Grady 1988, Garvin 1988, Berang r 1987, Edosomwan 1990).

In the beginning of the 1990's, the new production philosophy, which is known by several different names (world class manufacturing, lean production, new production system) is the emerging mainstream approach. It is practiced, at least partially, by major manufacturing companies in America and Europe. The new approach has also diffused to new fields, like customized production (Ashton & Cook 1989), services, administration (Harrington 1991), and product development.

In the meantime, the new production philosophy has been undergoing further development, primarily in Japan. New approaches and tools have been established to augment the philosophy, such as Quality Function Deployment (QFD) (Akao 1990), Taguchi-method, design for manufacture, etc.

In Japan, the spearhead organization for the new approach is the New Production System (NPS) Research Association, formed in 1982 for refining and implementing the new production system in member companies (Shinohara 1988).

2.2 Main ideas and techniques

2.2.1 Overview

Several factors make it difficult to present a coherent overview of the ideas and techniques of the new production philosophy. The field is young¹ and in constant evolution. New

¹ The first scholarly paper in English was published in 1977 (Golhar & Stamm 1991).

concepts emerge and the content of old concepts change. The same concept is used to refer to a phenomenon on several levels of abstraction. It is not clear where to place the boundaries between related concepts.

We have chosen to base this overview on two historically important “root” terms, Just In Time (JIT) and Total Quality Control (TQC), which are outlined briefly below. Next we present related newer concepts, which are primarily outgrowths of JIT and TQC. These outgrowths show that the field of application of the original ideas has extended far beyond the production sphere.

2.2.2 Just In Time (JIT)

The starting point of the new production philosophy was in industrial engineering oriented developments initiated by Ohno and Shingo at Toyota car factories in the 1950’s. The driving idea in the approach was reduction or elimination of inventories (work in progress). This, in turn, led to other techniques that were forced responses to coping with less inventory: lot size reduction, layout reconfiguration, supplier co-operation, and set-up time reduction. The pull type production control method, where production is initiated by actual demand rather than by plans based on forecasts, was introduced.

The concept of waste is one cornerstone of JIT. The following wastes were recognized by Shingo (1984): overproduction, waiting, transporting, too much machining (overprocessing), inventories, moving, making defective parts and products. Elimination of waste through continuous improvement of operations, equipment and processes is another cornerstone of JIT².

2.2.3 Total Quality Control (TQC)

The starting point of the quality movement was the inspection of raw materials and products using statistical methods. The quality movement in Japan has evolved from mere inspection of products to total quality control. The term total refers to three extensions (Shingo 1988): (1) expanding quality control from production to all departments, (2) expanding quality control from workers to management, and (3) expanding the notion of quality to cover all operations in the company.

The quality methodologies have developed in correspondence with the evolution of the concept of quality. The focus has changed from an inspection orientation (sampling theory), through process control (statistical process control and the seven tools³), to continuous process improvement (the new seven tools⁴), and presently to designing quality into the product and process (Quality Function Deployment).

There has always been friction between the JIT camp and the quality camp. Representatives of the JIT camp tend to stress process improvement (Harmon 1992) and error checking at the source (Shingo 1986) rather than statistical control and quality programs.

² For a short discussion of JIT, see (Walleigh 1986). For opposing views, see (Zipkin 1991).

³ Pareto-diagram, cause-and-effect diagram, histogram, control chart, scatter diagram, graph and checksheet.

⁴ Relations diagram, affinity diagram, tree diagram, matrix diagram, matrix data-analysis diagram, process decision program chart, arrow diagram.

2.2.4 Related concepts

Many new concepts have surfaced from JIT and TQC efforts. These have been rapidly elaborated and extended, starting a life of their own. Several of these concepts are described below.

Total Productive Maintenance (TPM)

Total productive maintenance refers to autonomous maintenance of production machinery by small groups of multi-skilled operators (Nakajima 1988). TPM strives to maximize production output by maintaining ideal operating conditions. Nakajima states that without TPM, the Toyota production system could not function.

Employee involvement

There are several reasons for employee involvement (for a good, concise discussion, see Walton 1985). Rapid response to problems requires empowerment of workers. Continuous improvement is heavily dependent on day-to-day observation and motivation of the work force, hence the idea of quality circles (Lillrank & Kano 1989). In order to avoid waste associated with division of labor, multi-skilled and/or self-directed teams have been established for product/project/customer based production.

Continuous improvement

Continuous improvement, associated with JIT and TQC, has emerged as a theme in itself especially after the book by Imai (1986). A key idea is to maintain and improve the working standards through small, gradual improvements. The inherent wastes (as characterized in section 2.2.2) in the process are natural targets for continuous improvement. The term “learning organization” refers partly to the capability of maintaining continuous improvement (Senge 1990).

Benchmarking

Benchmarking refers to comparing one’s current performance against the world leader in any particular area (Camp 1989, Compton 1992). In essence, it means finding and implementing the best practices in the world. Benchmarking is essentially a goal-setting procedure, which tries to break down complacency and NIH-attitudes (not invented here). It focuses on business processes, rather than the technologies used in them. The procedure of benchmarking was formalized in the 1980’s based on work done at Xerox (Camp 1989). Japanese companies informally applied benchmarking earlier.

Time based competition

The book by Stalk and Hout (1990) popularized this term. Time based competition refers to compressing time throughout the organization for competitive benefit. Essentially, this is a generalization of the JIT philosophy, well-known to the JIT pioneers. Ohno states that shortening lead time creates benefits such as a decrease in the work not related to processing, a decrease in the inventory, and ease of problem identification (Robinson 1991). Time based competition has become popular, especially in administrative and information work where the JIT concepts sound unfamiliar.

Concurrent engineering

Concurrent (or simultaneous) engineering deals primarily with the product design phase. As far as is known, it did not originate directly from JIT or TQC, even though it is based on similar ideas. The term refers to an improved design process characterized by rigorous upfront requirements analysis, incorporating the constraints of subsequent phases into the conceptual phase, and tightening of change control towards the end of the design process. In comparison to the traditional sequential design process, iteration cycles are transferred to the initial phases through teamwork. Compression of the design time, increase of the number of iterations, and reduction of the number of change orders are three major objectives of concurrent engineering.

Various tools for concurrent engineering have been developed, such as the principles and systems used in Design for Assembly and Design for Manufacturability.

Value based strategy (or management)

Value based strategy refers to “conceptualized and clearly articulated value as the basis for competing” (Carothers & Adams 1991). Firms driven by value based strategies are customer-oriented, in contrast to competitor-oriented firms. Continuous improvement to increase customer value is one essential characteristic of value based management.

Visual management

Visual management is an orientation towards visual control in production, quality and workplace organization (Greif 1991). The goal is to render the standard to be applied and a deviation from it immediately recognizable by anybody. This is one of the original JIT ideas, which has been systematically applied only recently in the West .

Re-engineering

This term refers to the radical reconfiguration of processes and tasks, especially with respect to implementation of information technology (for example Hammer 1990, Davenport & Short 1990, Rockart & Short 1989). According to Hammer, recognizing and breaking away from outdated rules and fundamental assumptions is the key issue in re-engineering.

Lean production, world class manufacturing

Rather than defining a specific set of methods, these terms are loosely used to refer to an intensive use of the ideas of the new production philosophy.

2.3 Conceptual evolution

The conception of the new production philosophy has evolved through three stages (Plenert 1990). It has been understood primarily as

- a set of tools (like kanban and quality circles)
- a manufacturing method (like JIT)
- a general management philosophy (referred to as lean production, world class manufacturing, JIT/TQC, time based competition, etc.).

This progression is due to the characteristics of the new approach as an engineering-based innovation in contrast to a science-based innovation. The practical application of the new

philosophy began and was diffused without any scientific, formalized basis: factory visits, case descriptions and consultants have been the means of technology transfer.

The conception of the new production philosophy as a general management philosophy was first promoted by Deming (1982), Schonberger (1990), the NPS Research Association (Shinohara 1988) and Plossl (1991). Each has formulated a set of implementation principles.

A number of definitions of the new production philosophy are exhibited in Table 1. Even a superficial analysis shows that they differ widely. The theoretical and conceptual understanding of the new production approach is still limited. In spite of initial efforts to raise the abstraction level of the definition (as evident with Plossl, Table 1), there is as yet no unified, coherent and consistent theory. Rather, the new approach could be characterized as a research frontier - an extremely fruitful one.

2.4 Benefits

The benefits of the new production philosophy in terms of productivity, quality and other indicators have been tangible enough in practice to ensure a rapid diffusion of the new principles. However, the benefits have received surprisingly little study by scholars.

In a statistical study covering 400 manufacturing plants, mostly in the U.S. and Europe, it was found that of all the possible techniques for improving productivity, only those related to the new philosophy (termed JIT) are demonstrably effective (Schmenner 1988).

One of the best researched industries is car manufacturing (Womack & al. 1990). Lean car production is characterized as using less of everything compared with mass production: half the human effort in the factory, half the manufacturing space, half the investments in tools, half the engineering hours to develop a new product in half the time.

The same order of magnitude of benefits in other industries is substantiated by other authors. For example, improvement results from applying lean production in a wide variety of plants are reported by Schonberger (1986) and Harmon and Peterson (1990). Japanese companies have typically doubled factory productivity rates over a 5 year period while implementing the new principles (Stalk & Hout 1989). A reduction of manufacturing space by 50 % is a typical target (Harmon and Peterson 1990).

The competitive benefits created by means of the new approach seem to be remarkably sustainable. Toyota, the first adopter, has had a consistent lead in stock turnover and productivity as compared to its Japanese competitors (Lieberman 1990).

Table 1. Definitions of the new production philosophy.

Goals of the Toyota production system according to Monden (1983):

The Toyota production system completely eliminates unnecessary elements in production for the purpose of cost reduction. The basic idea is to produce the kind of units needed, at the time needed, and in quantities needed. The system has three subgoals:

1. Quantity control, which enables the system to adapt to daily and monthly fluctuations in terms of quantities and variety.
2. Quality assurance, which assures that each process will supply only good units to subsequent processes.
3. Respect for humanity, which must be cultivated while the system utilizes the human resource to attain its cost objectives.

The basic philosophy of the new production system according to the NPS Research Association (Shinohara 1988):

1. To seek a production technology that uses a minimum amount of equipment and labor to produce defect-free goods in the shortest possible time with the least amount of unfinished goods left over, and
2. To regard as waste any element that does not contribute to meeting the quality, price, or delivery deadline required by the customer, and to strive to eliminate all waste through concerted efforts by the administration, R&D, production, distribution, management, and all other departments of the company.

The organizational features of a lean plant according to Womack & al. (1990):

It transfers the maximum number of tasks and responsibilities to those workers actually adding value to the product on line, and it has in place a system for detecting defects that quickly traces every problem, once discovered, to its ultimate cause.

First law of manufacturing according to Plossl (1991):

In manufacturing operations, all benefits will be directly proportional to the speed of flow of materials and information.

Corollary 1: This law applies to every type of manufacturing business.

Corollary 2: The tightness of control of manufacturing activities will vary inversely with their cycle times.

Corollary 3: Any planning and control system will be more effective with fewer problems causing slower rates of materials and information.

Corollary 4: Solving one problem which slows down or interrupts material or information flow will cost less and be more effective than efforts to cope with the problem's effects.

3 New production philosophy: conceptual basis

A basic tenet of this report is that lack of theoretical understanding has greatly hampered the diffusion of the new production philosophy to industries which do not have many similarities with car production. An explicit, preferably formalized theoretical basis is necessary for transfer of the new philosophy to new settings and for effective education.

In the following, we first define a production philosophy and then proceed to analyze the traditional production philosophy. After observing certain flaws in the traditional conceptual basis, the essential elements of the new production philosophy are presented. A number of design and improvement principles, implicit in the various practical approaches of the new production philosophy, are examined. Finally, other important implications of the new philosophy are considered.

3.1 What is a production philosophy?

The answer to the above question is not self-evident. As Bloch argues, this lack of definition may be associated with the fact that there is presently no science of manufacturing (Heim & Compton, p. 16). Rather, production has been seen as the task of applying existing technology in a systematic way.

A study (Heim & Compton 1992) by the Committee on Foundations of Manufacturing¹ is a noteworthy effort to define production philosophy, which the Committee calls “foundations of manufacturing”:

“The foundations for a field of knowledge provide the basic principles, or theories, for that field. Foundations consist of fundamental truths, rules, laws, doctrines, or motivating forces on which other, more specific operating principles can be based. While the foundations need not always be quantitative, they must provide guidance in decision making and operations. They must be action oriented, and their application should be expected to lead to improved performance.”

Another interesting characterization is provided by Umble and Srikanth (1990), who require a manufacturing philosophy to contain the following elements:

- Definition of the common goal in terms that are understandable and meaningful to everyone in the organization.
- Development of the causal relationships between individual actions and the common global goal.
- Guidelines for managing the various actions so as to achieve the greatest benefit.

The discussion on paradigm shifts, initiated by Kuhn, is also valid for production philosophies. Paradigms, according to Kuhn (Smith & al. 1991):

- direct the ways problems are posed and solved
- indicate given assumptions
- indicate values, such as priorities and choice of problems and goals
- indicate exemplars which display the thinking.

Although originally used to refer to scientific activity, the term paradigm is now used in other contexts as well. In manufacturing, people have beliefs about good practice and models of the production process guiding their decisions and actions. However, due to the

¹ Assembled in 1989 by the National Academy of Engineering of the United States.

lack of an explicit production philosophy, such individual paradigms have often evolved from beliefs or rules of thumb that derive from personal experience (Heim & Compton 1992). They are often situation dependent and impossible to generalize or to apply in a new situation.

Paradigms are often implicit. They are adopted by a process of socialization into a craft or an organization, forming “practitioner’s knowledge”. This often makes it difficult to discuss the paradigm, or to argue for the need of a more detailed and accurate paradigm. However, the lack of an adequate paradigm can be recognized. A direct association of a solution to a problem often seems to indicate that the paradigm is too shallow; the many complexities of the situation are not perceived. Often paradigms are considered so self-evident that they hardly get mentioned. For example, textbooks in industrial engineering or construction engineering rarely begin with the foundations of the subject, but proceed to the treatment of individual techniques after introductory remarks.

However, there are several problems associated with implicit paradigms. Such paradigms are not generalizable or testable; their domain of feasibility is not known so applying them to new situations is problematic; their transfer and teaching is difficult. Thus, it is natural that the progress of a field often leads to increasing explicitness and formalization of the paradigm or philosophy.

Thus, in trying to understand the new philosophy, there is the dual task of uncovering the core in both the old and the new philosophies.

3.2 Conceptual basis of the conventional production philosophy

3.2.1 The conversion model

The conceptual model dominating the conventional view of production is the conversion model and its associated notions of organization and management. Up until recently these models have been self-evident, often implicit, and beyond criticism.

Production as a **conversion process** may be defined as follows:

1. A production process is a conversion of an input to an output.

Several disciplines (economics and industrial engineering, for example) have used this idea as a basis for understanding production. The model, illustrated in Figure 1, allows for convenient measurements, such as those of productivity, e.g. the ratio of output to the input (or a particular part of it) in a given time period. Thus, even if we do not have the conversion process in mind, our concepts and measurements often implicitly reflect this model.

However, for practical application to complex production situations, more features are needed. Though rarely stated explicitly, the following statements seem to be used in conjunction with the conversion model:

2. The conversion process can be divided into subprocesses, which also are conversion processes.
3. The cost of the total process can be minimized by minimizing the cost of each subprocess.
4. The value of the output of a process is associated with costs (or value) of inputs to that process.

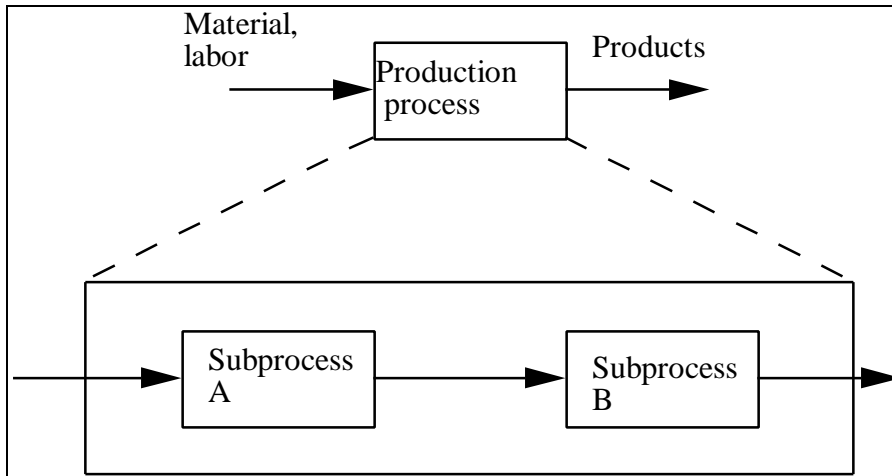


Figure 1. The conventional view of a production process as a conversion process that can be divided hierarchically into subprocesses.

Statements 2 and 3 are especially related to the theories of control in a hierarchical organization. Conventional accounting theory, which supports this mode of control, is based on the following assumptions (Umble & Srikanth 1990):

- total cost of the production process equals the sum of the costs of each operation
- the total cost of each operation (excluding material cost) is proportional to the cost of direct labor for that operation

This standard cost procedure is reversed when estimating the profitability of an equipment investment. If the labor cost of any operation can be reduced, the total cost will be reduced by both respective labor cost and the associated overhead cost. Thus the financial impact of any particular change on the whole production process can be determined. Attention can be focused on cost management in each operation, subprocess or department. In a hierarchical organization the costs of each organizational unit have thus to be minimized.

As suggested by statement 4, value is not very important in the traditional philosophy. Value of the output can be raised by using better material and more skilled specialists, the costs of which are higher. The following quote from an influential early accounting theoretician defines value: "...value of any commodity, service, or condition, utilized in production, passes over into the object or product for which the original item was expended and attaches to the result, giving it its value." (from Johnson & Kaplan 1987).

3.2.2 The conventional conceptual model is false

However, there are well-grounded theoretical arguments (Shingo 1988) and substantial empirical evidence from manufacturing which shows that the conversion process model, as applied to analyze and manage productive operations, is misleading or even false. The critique comes from two sources: JIT and TQC.

JIT critique

By focusing on conversions, the model abstracts away physical flows between conversions. These flows consist of moving, waiting and inspecting activities. In a way,

this is a correct idealization; from the customer point of view these activities are not needed since they do not add value to the end product. However, in practice, the model has been interpreted so that (1) these non value-adding activities can be left out of consideration or (2) all activities are conversion activities, and are therefore treated as value-adding.

These erroneous interpretations are present in conventional production control methods and performance improvement efforts. The principle of cost minimization of each subprocess leads to the need for buffers that allow high utilization rates. It also leads to a situation where the impact of a particular subprocess on efficiency of other subprocesses tends to be unconsidered. Performance improvement is focused on improving the efficiency of subprocesses, typically with new technology. This, in turn, leads to improvement of and investment in non value-adding activities, which would be better suppressed or eliminated.

By focusing only on control and improvement of conversion subprocesses, the conversion model not only neglects, but even deteriorates overall flow efficiency. Unfortunately, in the more complex production processes, a major part of total costs are caused by flow activities rather than conversions. In fact, leading authorities in production control attribute the fact that “manufacturing is out of control in most companies” directly to the neglect of flows (Plossl 1991). In addition, poor ability to control manufacturing makes improving conversion processes more difficult: “Major investments in new equipment are not the solution to a confused factory” (Hayes & al. 1988).

Quality critique

The critique from the quality point of view addresses the following two features²:

- the output of each conversion is usually variable, to such an extent that a share of the output does not fulfill the implicit or explicit specification for that conversion and has to be scrapped or reworked
- the specification for each conversion is imperfect; it only partially reflects the true requirements of the subsequent conversions and the final customer.

The conversion model does not include these features, thus suggesting that they are not pertinent problems of production processes.

The consequences of the absence of the first feature are clear in practice: “about a third of what we do consists of redoing work previously ‘done’”(Juran 1988).

The impact of the second conceptual failure is more subtle and concerns lost opportunities to fulfill customer requirements. In practice, the result is that improvement efforts are directed toward making conversions more efficient rather than making them more effective. Products which poorly fulfill customer requirements and expectations are then produced with great efficiency.

Note that although these problems are different than those analyzed from the JIT standpoint, they too ultimately impact physical flows. Quality deviations cause waste in themselves, but also through interruption of the physical flow. In a similar way, poorly defined requirements in internal customer-supplier relationships add to conversion time and costs and thus slow down the physical flow.

²These two items correspond to the common views on quality (Juran 1988):

- conformance to the specification or freedom from deficiencies
- product performance.

3.2.3 Why has the conventional model been adopted?

Why has the conversion model been used in the first place, when its drawbacks, at least in hindsight, are so evident? A clue to a possible answer is given by Johnson and Kaplan (1987). The conversion model was established in the 19th century, when plants and companies were centered around just one conversion. Towards the end of the century, the trend was to form hierarchically organized companies, controlling several conversion processes. The organizational models and the accounting practices were developed to conform to the new requirements. Production processes were simpler, flows shorter and organizations smaller, so the problems due to the conceptual basis remained negligible. Only later, as the conversion model has been applied to more complex production, have the problems surfaced clearly.

3.3 Conceptual basis of the new production philosophy

The new conceptual model is a synthesis and generalization of different models suggested in various fields, like the JIT movement (Shingo 1984) and the quality movement (Pall 1987). Thus the task is to develop a model covering all important features of production, especially those that are lacking in the conversion model. The new production model can be defined as follows:

Production is a flow of material and/or information from raw material to the end product (Figure 2). In this flow, the material is processed (converted), it is inspected, it is waiting or it is moving. These activities are inherently different. Processing represents the conversion aspect of production; inspecting, moving and waiting represent the flow aspect of production.

Flow processes can be characterized by time, cost and value. Value refers to the fulfillment of customer requirements. In most cases, only processing activities are value-adding activities. For material flows, processing activities are alterations of shape or substance, assembly and disassembly.

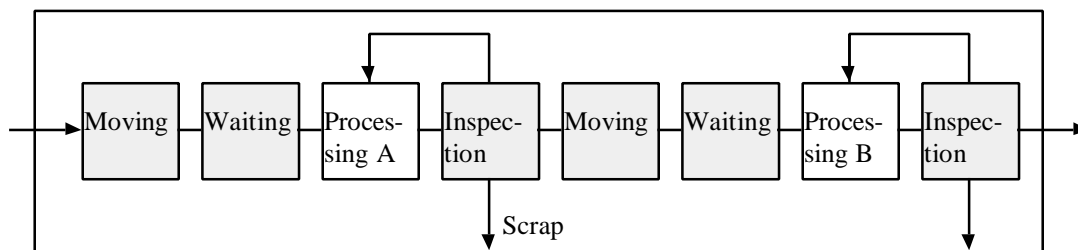


Figure 2. Production as a flow process: simplistic illustration. The shaded boxes represent non value-adding activities, in contrast to value-adding processing activities.

In essence, the new conceptualization³ implies a dual view of production: it consists of conversions and flows. The overall efficiency of production is attributable to both the efficiency (level of technology, skill, motivation, etc.) of the conversion activities

³ Note that there are several related definitions that only partially cover the important features considered here. For example the process definition of Pall (1987) - typical of the quality literature - does not cover the physical flow aspect. In the value chain of Porter (1990) all activities add value.

performed, as well as the amount and efficiency of the flow activities through which the conversion activities are bound together⁴.

While all activities expend cost and consume time, only conversion activities add value to the material or piece of information being transformed to a product. Thus, the improvement of flow activities should primarily be focused their reduction or elimination, whereas conversion activities have to be made more efficient. This core idea of the new production philosophy is illustrated in Figure 3.

But how should flow processes be designed, controlled and improved in practice? In various subfields of the new production philosophy, the following heuristic principles have evolved:

1. Reduce the share of non value-adding activities.
2. Increase output value through systematic consideration of customer requirements.
3. Reduce variability.
4. Reduce the cycle time.
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.

These principles are elaborated in the next section. 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.

Note that it is rarely possible to devise the best possible process by design only; usually the designed and implemented process provides a starting point for continuous improvement, based on measurements of actual process behavior.

⁴ In recent discussion on strategy, the former has been called core competence, the latter capability (Stalk & al. 1992).

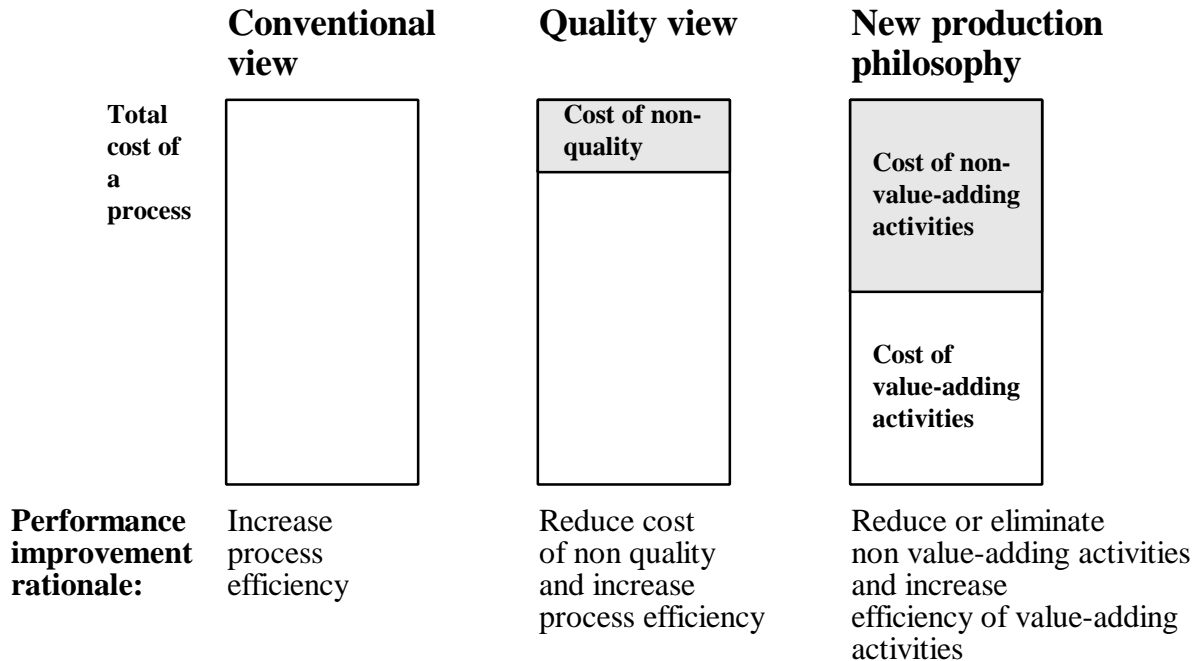


Figure 3. Performance improvement in conventional, quality and new production philosophy approaches. Note that the customary quality view addresses only a subset of all non value-adding activities.

3.4 Principles for flow process design and improvement

In the following, the eleven important principles for flow process design and improvement are examined.

Note, that most “buzzword approaches” to the new production philosophy 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.

Many principles are closely related, but not on the same abstraction level. Some are more fundamental, while others more application oriented.

It is also important to note that the understanding of these principles is of very recent origin. It is presumed that knowledge of these principles will rapidly grow and be systematized.

3.4.1 Reduce the share of non value-adding activities

Value-adding and non value-adding activities can be defined as follows:

Value-adding activity: Activity that converts material and/or information towards that which is required by the customer.

Non value-adding activity (also called waste): Activity that takes time, resources or space but does not add value.

Reducing the share of non value-adding activities is a fundamental guideline. Experience shows that non value-adding activities dominate most processes; usually only 3 to 20 % of steps add value (Ciampa 1991), and their share of the total cycle time is negligible, from 0.5 to 5 % (Stalk & Hout 1990). Why are there non value-adding activities in the first place? There seems to be three root causes: design, ignorance and the inherent nature of production.

Non value-adding activities exist by design in hierarchical organizations. Every time a task is divided into two subtasks executed by different specialists, non value-adding activities increase: inspecting, moving and waiting. In this way, traditional organizational design contributes to an expansion of non value-adding activities.

Ignorance is another source of non value-adding activities. Especially in the administrative sphere of production, many processes have not been designed in an orderly fashion, but instead just evolved in an *ad hoc* fashion to their present form. The volume of non value-adding activities is not measured, so there is no drive to curb them.

It is in the nature of production that non value-adding activities exist: work-in-process has to be moved from one conversion to the next, defects emerge, accidents happen.

With respect to all three causes for non value-adding activities, it is possible to eliminate or reduce the amount of these activities. However, this principle cannot be used simplistically. Some non value-adding activities produce value for internal customers, like planning, accounting and accident prevention. Such activities should not be suppressed without considering whether more non value-adding activities would result in other parts of the process. However, accidents and defects, for example, have no value to anybody and should be eliminated without any hesitation.

Most of the principles presented below address suppression of non value-adding activities. However, it is possible to directly attack the most visible waste just by flowcharting the process, then pinpointing and measuring non value-adding activities⁵.

3.4.2 Increase output value through systematic consideration of customer requirements

This is another fundamental principle. Value is generated through fulfilling customer requirements, not as an inherent merit of conversion. For each activity there are two types of customers, the next activities and the final customer.

Because this sounds self-evident, we again have to ask why customer requirements have not been considered.

The organizational and control principles of the conventional production philosophy have tended to diminish the role of customer requirements. In many processes, customers have never been identified nor their requirements clarified. The dominant control principle has been to minimize costs in each stage; this has not allowed for optimization of cross-functional flows in the organization.

The practical approach to this principle is to carry out a systematic flow design, where customers are defined for each stage, and their requirements analyzed. Other principles,

⁵ A detailed methodology for administrative processes is presented, for example, by Harrington (1991).

especially enhanced transparency and continuous improvement, also contribute to this principle.

3.4.3 Reduce variability

Production processes are variable. There are differences in any two items, even though they are the same product, and the resources needed to produce them (time, raw material, labor) vary.

There are two reasons for reducing process variability. First, from the customer point of view a uniform product is better. Taguchi proposes that any deviation from a target value in the product causes a loss, which is a quadratic function of the deviation, to the user and wider society (Bendell & al. 1989). Thus, reduction of variability should go beyond mere conformance to given specifications.

Secondly, variability, especially of activity duration, increases the volume of non value-adding activities. It may easily be shown through queue theory that variability increases the cycle time (Krupka 1992, Hopp & al. 1990). Indeed, there are no instances where more variability is good (Hopp & al. 1990).

Thus, reduction of variability within processes must be considered an intrinsic goal (Sullivan 1984). Schonberger (1986) states strongly: “Variability is the universal enemy.” Alternative expressions for this principle are: reduce uncertainty, increase predictability.

The practical approach to decreasing variability is made up of the well-known procedures of statistical control theory. Essentially, they deal with measuring variability, then finding and eliminating its root causes. Standardization of activities by implementing standard procedures is often the means to reduce variability in both conversion and flow processes. Another method is to install fool-proofing devices (“poka-yoke”) into the process (Shingo 1986).

3.4.4 Reduce the cycle time

Time is a natural metric for flow processes. Time is a more useful and universal metric than cost and quality because it can be used to drive improvements in both (Krupka 1992).

A production flow can be characterized by the cycle time, which refers to the time required for a particular piece of material to traverse the flow⁶. The cycle time can be represented as follows:

Cycle time = Processing time + inspection time + wait time + move time

The basic improvement rationale in the new production philosophy is to compress the cycle time, which forces the reduction of inspection, move and wait time. The progression of cycle time reduction through successive process improvement is depicted in Figure 4.

In addition to the forced elimination of wastes, compression of the total cycle time gives the following benefits (Schmenner 1988, Hopp & al. 1990):

- faster delivery to the customer
- reduced need to make forecasts about future demand

⁶ There often are several flows which unite or diverge in the total production process. However, it is generally possible to recognize the main flow and side flows, which have to be assessed separately.

- decrease of disruption of the production process due to change orders
- easier management because there are fewer customer orders to keep track of.

The principle of cycle time compression also has other interesting implications. From the perspective of control, it is important that the cycles of deviation detection and correction are speedy. In design and planning, there are many open-ended tasks that benefit from an iterative search for successively better (if not optimal) solutions. The shorter the cycle time, the more cycles are affordable.

From the point of view of improvement, the cycle time from becoming conscious of a problem or an opportunity to the implementation of a solution is crucial. In traditional organizations, this cycle time is sometimes infinite due to lack communication where no message is passed, or a long channel of communication where the message gets distorted.

Every layer in an organizational hierarchy adds to the cycle time of error correction and problem solving. This simple fact provides the new production philosophy's motivation to decrease organizational layers, thereby empowering the persons working directly within the flow.

Practical approaches to cycle time reduction include the following (for example, Hopp & al. 1990, Plossl 1991, Stalk & Hout 1990)):

- eliminating work-in-progress (this original JIT goal reduces the waiting time and thus the cycle time)
- reducing batch sizes
- changing plant layout so that moving distances are minimized
- keeping things moving; smoothing and synchronizing the flows
- reducing variability
- changing activities from sequential order to parallel order
- isolating the main value-adding sequence from support work
- in general, solving the control problems and constraints preventing a speedy flow.

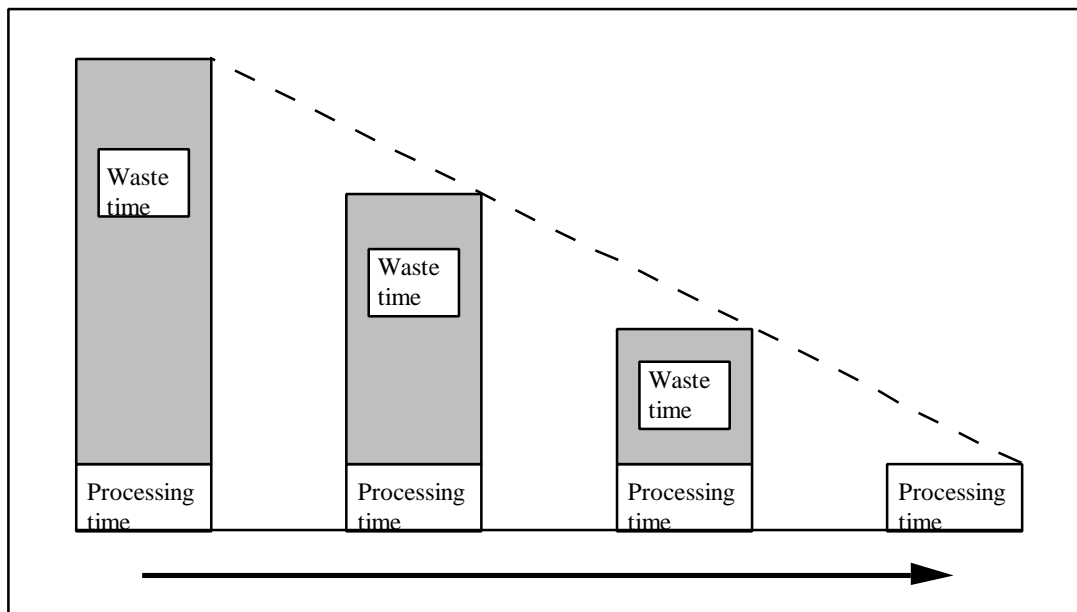


Figure 4. Cycle time can be progressively compressed through elimination of non value-adding activities and variability reduction (Berliner & Brimson 1988).

3.4.5 Simplify by minimizing the number of steps and parts

Other things being equal, the very complexity of a product or process increases the costs beyond the sum of the costs of individual parts or steps. Conventional accounting shows the price differential of two materials, but not the additional costs created in the whole production system by using two instead of one (Child & al. 1991). Another fundamental problem of complexity is reliability: complex systems are inherently less reliable than simple systems. Also, the human ability to deal with complexity is bounded and easily exceeded.

Simplification can be understood as

- reducing of the number of components in a product
- reducing of the number of steps in a material or information flow

Simplification can be realized, on the one hand, by eliminating non value-adding activities from the production process, and on the other hand by reconfiguring value-adding parts or steps.

Organizational changes can also bring about simplification. Vertical and horizontal division of labor always brings about non value-adding activities, which can be eliminated through self-contained units (multi-skilled, autonomous teams).

Practical approaches to simplification include:

- shortening the flows by consolidating activities
- reducing the part count of products through design changes or prefabricated parts
- standardizing parts, materials, tools, etc.
- decoupling linkages
- minimizing the amount of control information needed.

3.4.6 Increase output flexibility

At first glance, increase of output flexibility seems to be contradictory to simplification. However, many companies have succeeded in realizing both goals simultaneously (Stalk & Hout 1990). Some of the key elements are modularized product design in connection with an aggressive use of the other principles, especially cycle time compression and transparency.

Practical approaches to increased flexibility include (Stalk & Hout 1990, Child & al. 1991):

- minimizing lot sizes to closely match demand
- reducing the difficulty of setups and changeovers
- customizing as late in the process as possible
- training a multi-skilled workforce.

3.4.7 Increase process transparency

Lack of process transparency increases the propensity to err, reduces the visibility of errors, and diminishes motivation for improvement. Thus, it is an objective to make the production process transparent and observable for facilitation of control and improvement: “to make the main flow of operations from start to finish visible and comprehensible to all employees” (Stalk & Hout 1989). This can be achieved by making the process directly observable through organizational or physical means, measurements, and public display of information.

In a theoretical sense, transparency means a separation of the network of information and the hierarchical structure of order giving (Greif 1991), which in the classical organization theory are identical. The goal is thus to substitute self-control for formal control and related information gathering.

Practical approaches for enhanced transparency include the following:

- establishing basic housekeeping to eliminate clutter: the method of 5-S⁷
- making the process directly observable through appropriate layout and signage
- rendering invisible attributes of the process visible through measurements
- embodying process information in work areas, tools, containers, materials and information systems
- utilizing visual controls to enable any person to immediately recognize standards and deviations from them
- reducing the interdependence of production units (focused factories).

3.4.8 Focus control on the complete process

There are two causes of segmented flow control: the flow traverses different units in a hierarchical organization or crosses through an organizational border. In both cases, there is a risk of suboptimization.

There are at least two prerequisites for focusing control on complete processes. First, the complete process has to be measured.

Secondly, there must be a controlling authority for the complete process. Several alternatives are currently used. In hierarchical organizations, process owners for cross-functional processes are appointed, with responsibility for the efficiency and effectiveness of that process (Rummler & Brache 1990). A more radical solution is to let self-directed teams control their processes (Stewart 1992).

For inter-organizational flows, long term co-operation with suppliers and team building have been introduced with the goal of deriving mutual benefits from an optimized total flow.

3.4.9 Build continuous improvement into the process

The effort to reduce waste and to increase value is an internal, incremental, and iterative activity, that can and must be carried out continuously. There are several necessary methods for institutionalizing continuous improvement:

- Measuring and monitoring improvement.
- Setting stretch targets (e.g. for inventory elimination or cycle time reduction), by means of which problems are unearthed and their solutions are stimulated.
- Giving responsibility for improvement to all employees; a steady improvement from every organizational unit should be required and rewarded.
- Using standard procedures as hypotheses of best practice, to be constantly challenged by better ways.
- Linking improvement to control: improvement should be aimed at the current control constraints and problems of the process. The goal is to eliminate the root of problems rather than to cope with their effects.

⁷ The method of 5-S takes its name from the initials of five Japanese words referring to organization, orderliness, cleanliness, personal cleanliness and discipline (Imai 1986). The method is used for creating a basic workplace organization.

Continuous improvement is analyzed in more detail in section 3.5.

3.4.10 Balance flow improvement with conversion improvement

In the improvement of productive activities, both conversions and flows have to be addressed. But how should these two alternatives be balanced?

For any production process, the flow and conversion aspects each have a different potential for improvement. As a rule,

- the higher the complexity of the production process, the higher the impact of flow improvement
- the more wastes inherent in the production process, the more profitable is flow improvement in comparison to conversion improvement.

However, in a situation where flows have been neglected for decades, the potential for flow improvement is usually higher than conversion improvement. On the other hand, flow improvement can be started with smaller investments, but usually requires a longer time than a conversion improvement.

The crucial issue is that flow improvement and conversion improvement are intimately interconnected:

- better flows require less conversion capacity and thus less equipment investment
- more controlled flows make implementation of new conversion technology easier
- new conversion technology may provide smaller variability, and thus flow benefits.

Therefore one is tempted to agree with Ohno, who argues that “improvement adheres to a certain order” (Ohno 1988). It is often worthwhile to aggressively pursue flow process improvement before major investments in new conversion technology: “Perfect existing processes to their full potential before designing new ones” (Blaxill & Hout 1991). Later, technology investments may be aimed at flow improvement or redesign.

3.4.11 Benchmark

Unlike technology for conversions, the best flow processes are not marketed to us; we have to find the world class processes ourselves.

Often benchmarking is a useful stimulus to achieve breakthrough improvement through radical reconfiguration of processes. It helps to overcome the NIH-syndrome and the power of ingrained routines. By means of it, fundamental logical flaws in the processes may be unearthed⁸.

The basic steps of benchmarking include the following (Camp 1989):

- knowing the process; assessing the strengths and weaknesses of subprocesses
- knowing the industry leaders or competitors; finding, understanding and comparing the best practices
- incorporating the best; copying, modifying or incorporating the best practices in your own subprocesses

⁸ Through benchmarking, Ford Company observed that Mazda’s accounts payable department was run by 5 persons, in comparison to Ford’s over 500 employees (Hammer 1990). Ford’s accounts payable function was then radically “re-engineered” by simplifying the procedures and by implementing “invoice-less processing”. It was realized that the objective of the department, “payment upon invoice” was not appropriate any more, and a new goal “paying upon delivery” was adopted.

- gaining superiority by combining existing strengths and the best external practices.

A detailed methodology for benchmarking is presented by Camp (1989).

3.5 Continuous improvement vs. innovation

Many of the principles discussed above are realized in the framework of continuous improvement. Because the concept is relatively new, it is useful to analyze and compare it with innovation, which has been the primary framework of analysis until now.

The Western view on technological advancement has seen product and process⁹ innovation as the prime movers of change. Characteristic to both product and process innovation is that the innovative features are embodied in a product or in production equipment. Most often, innovation is stimulated by external technological development or market demand. Innovation is often seen as a breakthrough leap, though incremental refinement is also accepted as a form of innovation. In many disciplines, like economics and industrial engineering, the residual technological progress that remains unexplained by innovation has been called learning.

Imai (1986) argues that this conceptual framework of innovation has prevented the understanding of the significance of continuous improvement, characterized by incremental steps, wide internal involvement and organization-embodied innovation (Table 2).

Table 2. Comparison of innovation and continuous improvement (modified from Imai (1986)).

	<i>Innovation</i>	<i>Continuous improvement</i>
Focus	Efficiency of conversions	Efficiency of flow processes
Goal	Leaps in efficiency	Small steps, details, finetuning
Involvement	Company and outside specialists, champions	Everybody in the company
Time frame	Intermittent and non-incremental	Continuous and incremental
Technology relied upon	Outside technological breakthroughs, new inventions, new theories	Internal know-how, best practice
Incentive	New superior technology or need for capacity extension	Overcome constraints in variability reduction or cycle time compression
Practical requirements	Requires large investment, but little effort to maintain it	Requires little investment, but great effort to maintain it
Mode of action	Scrap and rebuild	Maintenance and improvement
Transferability	Transferable: embodied in individual equipment and related operating skill	Primarily idiosyncratic: embodied in system of equipments, skills, procedures and organization
Effort orientation	Technology	People

To some extent continuous improvement parallels the traditional view on innovation: they both incorporate incremental product and conversion process improvement. However, continuous improvement is more geared towards development of the flow process than

⁹ In innovation literature, the term “process innovation” refers to conversion process innovation rather than to flow process innovation.

conversions (Figure 5). On the other hand, in some cases an innovation may enhance the efficiency of the flow process.

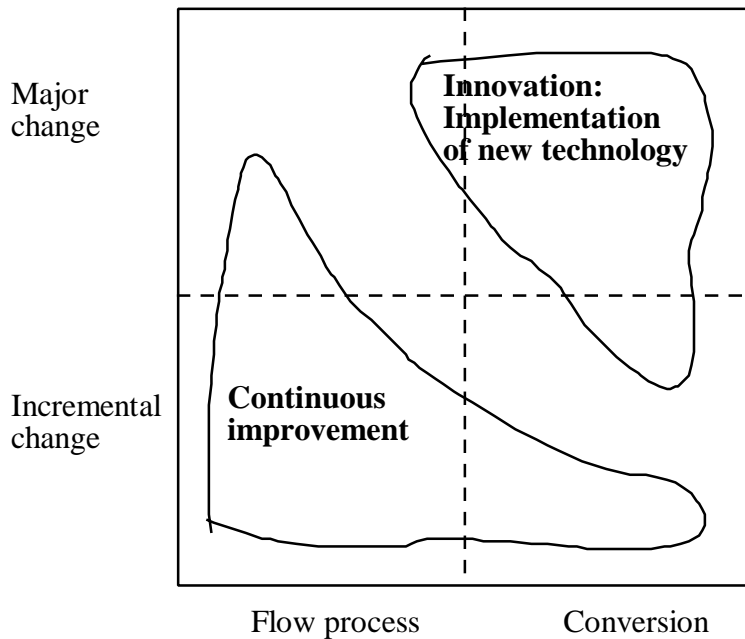


Figure 5. Continuous improvement and innovation: focus and aimed change.

The focus of continuous improvement is typically:

- eliminating bottlenecks (elaborated in the theory of constraints (Umble & Srikanth 1990))
- variability reduction
- cycle time reduction
- elimination of non value-adding steps from the flow
- ongoing consideration of customer requirements for each activity.
- finetuning different parts of the process for better synchronization
- maintenance for better reliability
- incremental development of equipment (procured from outside or self-fabricated).

In practice, innovation-oriented performance improvement is seen as an ongoing series of decisions as to whether the probable gain from each proposed improvement activity, independently considered, will exceed the expenditure to implement it (Hall & al. 1991). Only clear-cut investments in new machinery capable of showing productivity gains tend to overcome this hurdle of justification. Organizationally, performance improvement is strictly separated from control and does not address problems of control. Thus, performance improvement activities remain unfocused and limited in their scope.

As argued earlier, the interaction between continuous improvement and innovation has to be acknowledged. Poor flow efficiency is a barrier to innovation, because the benefits of an innovation become invisible in the confused environment. Implementation is difficult when there are many intervening disturbances (Hayes & al. 1988, Chew & al. 1991). This is related to the argument that there is a preferred sequence of improvement and innovation (Ohno 1982). Only after exhausting incremental innovation potential are major changes suggested.

Thus, the new production philosophy provides a vision and focus for improvement and innovation. It stresses improvement directed at the present constraints in the production flow.

3.6. Measurements in continuous improvement

Measures are extremely important in the pursuit of lean production. Measures provide access to continuous improvement by pinpointing improvement potential and monitoring progress achieved.

The traditional measures that most often focus on costs, productivity or utilization rates, have been criticized from several points of view. Their major problems include the following:

- they do not give impetus for continuous improvement
- they do not attempt to understand the sources of indirect costs and thus misdirect attention; for example, the principle of allocating overhead cost in proportion to direct labor focuses the cost reduction attention solely to direct labor (Johnson & Kaplan 1987)
- they lead to local optima instead of the global optimum (Umble & Srikanth 1990)
- they measure after the fact
- there is a tendency to collect too much data, especially in the framework of computerized systems (Plossl 1991).

In lean production, measurements should support the application of the new principles. Thus, there are a number of requirements for measurements:

- Waste reduction. The measurement system should be able to measure waste inherent in the process.
- Adding value. The measurement system should be able to measure value added by each step in the process.
- Variability reduction. Measurement of variability and defects is necessary.
- Cycle time. Cycle time for the main process and the various side and subprocesses has to be measured.
- Simplification. Measures for complexity/simplicity have to be developed and applied.
- Transparency. Measurements should be close to each activity so that the people performing each activity receive direct, immediate and relevant feedback (Harrington 1991). Invisible features of the process have to be made visible by measurements. Both global and local measures should be provided for each activity.
- Focus on complete process. Both the process and the product should be measured. Measurements should focus on causes rather than results, e.g. costs (Schonberger 1990).
- Continuous improvement. The measurement system should be able to measure the status and rate of process improvement (Hayes & al. 1988). Measures should be capable of pinpointing the potential for improvement. Measures should foster improvement rather than just monitor it (Maskell 1991). Trends are more important than absolute values.

Some of the new principles are also applicable to measurement itself:

- Simplification. Measurement should not require much additional effort. There should not be too many different measures. After all, measurement does not directly add value to the product.

- Measures should be transparent and understandable. Aggregates are better than details, physical measures better than financial, and visual feedback is more useful than systems data (Plossl 1991).

Non financial, physical measurements that directly reflect the status of improvement activities are emphasized (Plossl 1991, Maskell 1991). While costs are based on a number of physical factors, it is impossible to influence these through cost control; however, it is possible the other way around, to influence cost through manipulating physical factors.

Time as a suitable global measuring dimension is suggested by Stalk and Hout (1990) and other authors. Related measures include

- cycle time (per major subprocess)
- inventory turnover
- value-added time as percent of total elapsed time
- decision cycle time
- lead time (from order to delivery)
- schedule performance (meeting daily schedule).

Some authors argue for the need to tailor measurements closely to the requirements of the situation. Measurements should vary between locations even within one firm, and they should change over time (Maskell 1991). For example, quality costs may be a good measure in initial phases as a motivation, but for continuous, operational use it might be too laborious.

3.7 Implementation of the new philosophy

Even if there are numerous examples of successful implementation of the new philosophy, there also are examples of failures and false starts. After all, the majority of companies has not yet launched full scale efforts for adopting these ideas.

There are emotional and conceptual barriers for implementation. Ashton & al. (1990) argue that many managers derive their perceived knowledge from their position in the organization and they fear that their actual lack of knowledge would be exposed. Conceptual barriers are related to the difficulty of abandoning the conventional assumptions concerning organizing, controlling, etc.

Experience shows that there are four key factors that have to be balanced in implementing the new philosophy (the framework is based on Ashton & al. (1990), Schaffer & Thomson (1992), and Plossl (1991)):

1. Management commitment

Leadership is needed to realize a fundamental shift of philosophy, with the goal of improving every activity in the organization. Without an active initiative from the management, change will stop at all natural barriers. Management must understand and internalize the new philosophy. The change will be realized only through people; it cannot be delegated to staff specialists, like in the case of investment into new technology.

Management must create an environment which is conducive to change. As Deming (1982) says, there must be constancy of purpose.

2. *Focus on measurable and actionable improvement*

The focus should be on actionable and measurable improvement, rather than just on developing capabilities. Of course, defining various flow processes and focusing on their bottlenecks to speed up and smooth out material and information flows means just that. Short term successes then reinforce motivation for further improvement.

Originally in JIT, the overarching goal was to reduce or eliminate inventories. However, reduction of inventories uncovered other problems, which had to be solved as a forced response. Cycle time, space and variability have also been used as drivers, because they too are increased by underlying problems. Especially cycle time provides an excellent, easy to understand driver, which can be improved continually.

3. *Involvement*

Employee involvement happens naturally, when organizational hierarchies are dismantled, and the new organization is formed with self-directed teams, responsible for control and improvement of their process (Stewart 1992). But also even if the hierarchy remains intact, involvement can be stimulated through problem solving teams.

However, Shingo (1988) and Imai (1986) stress that management and staff specialists have a dominant role in targeting and realizing the improvement. Employee involvement is thus necessary, but not sufficient for realizing the full potential of continuous improvement.

4. *Learning*

Implementation requires a substantial amount of learning. First, learning should be directed at principles, tools and techniques of process improvement. In the next phase, the focus turns to empirical learning from manipulating the processes. For this reason, formal reviews of progress and experiences are useful. One form of learning consists of pilot projects for testing new ideas on a limited scale. A third source of learning is made up by external information, which can be tapped through benchmarking.

Lack of balance among these four factors leads usually to a dead end. For example:

- lack of management's commitment and changed priorities will be rapidly visible and demotivate other parties
- primary emphasis on learning and involvement, without simultaneous attack on real, urgent problems, does not lead to bottom line results (Schaffer & Thomson 1992).

3.8 Conclusions

The traditional and the new production philosophies are summarized in Table 3.

The core of the new production philosophy is in the observation that there are two kinds of phenomena in all production systems: conversions and flows. In the 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. This has led to complex, uncertain and confused flow processes, expansion of non value-adding activities, and reduction of output value.

Eleven principles for flow process design and improvement have evolved. There is ample evidence that through these principles, the efficiency of flow processes can be considerably and rapidly improved.

Table 3. The traditional and new production philosophies.

<p style="text-align: center;">The traditional production philosophy</p> <p>Production activities are:</p> <ul style="list-style-type: none">- conceived as sets of operations or functions, which are- controlled, operation-by-operation, for least costs, and- improved periodically with respect to productivity by implementing new technology. <p style="text-align: center;">The new production philosophy</p> <p>Production activities are:</p> <ul style="list-style-type: none">- conceived as material and information flow processes, which are- controlled for minimal variability and cycle time, and- improved continuously with respect to waste and value, and periodically with respect to efficiency by implementing new technology.
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4 Construction as activity

To what degree do the problems associated with the conventional production view, as observed in manufacturing, also exist in construction? This is the basic question we address in this chapter. To answer it, we first analyze the traditional conceptual basis of construction, and then discuss the problems caused by these traditional concepts. Available information on wastes in construction is summarized, and the detrimental impact of the traditional concepts on development efforts in construction is presented.

4.1 The traditional conceptualization of construction

Construction is a very old industry. Its culture and many of its methods have their roots in periods before explicit scientific analysis. However, especially after the Second World War, there have been several different initiatives to understand construction and its problems and to develop corresponding solutions and improvement methods. We can recognize strategic initiatives like industrialization, computer integrated construction, and total quality management. We also see operational and tactical techniques such as project planning and control tools, organizational methods, project success factors, and productivity improvement methods. What conceptualizations have been used in these efforts by practicing builders and researchers?

By far the most general concept seems to be the understanding of construction as a set of activities aimed at a certain output, i.e. conversions. This activity view of construction is shared both by the old traditions of construction and the newer methods.

The traditional method of cost estimation is at the heart of this activity view. The building (or other structure) is divided into its constituent elements, and for each element, the costs of needed materials and labor (conversion of input to output) are estimated. In later stages, contracts which specify a part of the building as the output, and a remuneration as input, are established. This is exactly according to the conversion model: it is assumed that the total production process consists of a set of subprocesses which convert an input to an output, and which can be realized and analyzed in isolation from each other¹. Also in network based project planning (CPM networks), a relative newcomer in the historical perspective of construction, the activities needed for producing the various elements of the building are the basic unit of analysis.

This activity view is the basis for several managerial concepts in construction that are also seen in manufacturing. A sequential mode of project realization, hierarchical organization, and neglect of quality issues are such concepts.

That construction has been based on the conversion model is further supported by cases where unexpected interaction between activities is observed. The great influence of design on construction and operating costs was first pointed out and analyzed as recently as 1976 (Paulson 1976). Friedrich et al. (1987) strongly criticize the customary notion that large projects can be measured using yardsticks viewed as simple summations of individual yardsticks taken discipline by discipline, system by system, or component by component.

¹ Even the newest theory formation is based on this. Bennett presents in his recent book (1991) a general theory of construction project management. His basic unit of analysis is days-work: "The whole point and purpose of construction project management is to create conditions that enable the teams who make up project organizations to carry out days-work efficiently."

Thus, the overall effects of revisions, repairs, and rework on large projects can be very significant, even when the individual effects of specific functions and disciplines appear small and within “normal” acceptable practices.

Beyond this conversion model, what theories or frameworks have been used in construction? As odd as it might seem, there are hardly any other theoretical or conceptual frameworks in general use. As elaborated below, this conclusion is suggested by textbook content, research content, and discussions by other construction researchers.

Even a rapid glance at the contents of textbooks on construction management shows that they usually begin with a descriptive account of a construction project (Clough & Sears 1991, Barrie & Paulson 1986) and then proceed to specific techniques of management and control. No major conceptual or theoretical analysis of construction is provided at the outset.

The research into construction project success factors endeavors to find the factors that are important for achieving outstanding project results. Because of its integrative nature, we could justifiably anticipate that the existing conceptual frameworks and theories are synthesized in that research. However, studies undertaken (Ashley & al. 1987, Jaselskis & Ashley 1991) are purely empirical, with little theoretical emphasis.

This lack of construction related theories has not gone unobserved by researchers. The lack of sufficient conceptual framework for construction project organizational design has been discussed by Sanvido (1988). Laufer and Tucker (1987) suggest an overall re-examination of the philosophy of project management.

This lack of a unified conceptual and theoretical framework has been persistent in spite of the growing realization of the flaws of the activity model.

We do need to acknowledge that there have been some flow oriented approaches in construction. Especially in heavy civil engineering practice as well as research, flows of material and equipment have been the framework of analysis. In addition, discrete event simulation of site activities has addressed flow characteristics (Halpin 1976, Bernold 1989). However, these are exceptions in the otherwise activity-oriented mind set of construction.

4.2 Flow problems caused by conventional managerial concepts

Criticisms of the conventional managerial concepts may be structured into three groups: sequential method of project realization, lack of quality considerations and segmented control. From manufacturing, there is overwhelming evidence of the counterproductive effects of these managerial principles. In addition to these generic managerial concepts, CPM (critical path method) network methods are a fourth specific problem source in construction. **These managerial principles violate principles of flow process design and improvement, and thus lead to non-optimal flows and an expansion of non value-adding activities.**

The flaws of these methods have been observed to varying degrees and alternatives have been sought. However, lacking a sound theory, these efforts have remained insufficient.

4.2.1 Sequential method of design and engineering

In sequential design and engineering, the total task is divided into temporally sequential tasks, which are given to different specialists for execution. This has been the conventional method of organizing product development in manufacturing. In construction, the traditional approach to project execution (for example, Barrie & Paulson 1984) is similar. Here, the client first selects an architect, who prepares overall designs and specifications. Designs for structural and mechanical disciplines are then prepared. Construction is the responsibility of a general contractor under contract to the client.

The problems of the traditional, sequential approach to construction have been widely discussed in recent years. However, what has not been generally realized is that this procedure leads to several generic flow process problems (based on Dupagne 1991):

- there are few or no iterations in the design process (long cycle times)
- constraints of subsequent phases are not taken into account in the design phase (poor consideration of requirements of next internal customers)
- unnecessary constraints for subsequent phases are set in the design phase (poor consideration of requirements of next internal customers)
- little feedback for specialists (poor process transparency, segmented project control)
- lack of leadership and responsibility for the total project (segmented project control).

Consequentially, the sequential procedure leads to

- suboptimal solutions
- poor constructability and operability
- large number of change orders (and thus rework in design and construction)
- lack of innovation and improvement.

4.2.2 Traditional approaches to quality

In conventional managerial approaches,

- no special effort is made to eliminate defects, errors, omissions, etc. and to reduce their impact, or
- it is thought that a fixed optimal level of quality exists.

It is now generally accepted that without special consideration, the cost of poor quality in average business operations is considerable. Figures in the range of 20 - 50 % are mentioned. This has also been substantiated in construction, as discussed in Section 4.3, below. Because processes in construction frequently have only one run, making continuous improvement is difficult, and the impacts of quality problems are accentuated.

Processes with quality problems are characterized by

- excessive variability
- poor deviation detection (long cycle time from detection to correction)
- insufficient consideration of customer requirements.

4.2.3 Segmented control

In the conventional approach, parts of a flow process are controlled rather than the whole. More often than not, the reason for this is the hierarchical organization.

Control in a hierarchical organization focuses on an organizational unit or a task, the costs of which are to be minimized. This leads to maximization of utilization rates and to large batches. This mode of control is characterized by both accumulation of work-in-process

between units or operations and disruptions due to material or information shortages. The situation is further aggravated by specialization which leads to an increase in the number of units or tasks.

A typical construction example may be found in materials management (Oglesby & al. 1989). Responsibility for different tasks related to the preparation of a material flow is often divided among several persons. Purchasing of materials is often handled by a special department, which aims at minimizing the total purchase and transportation costs for each material. The resultant material flow is therefore not likely to be optimal from the point of view of site operations.

The disadvantages caused by this are:

- space and attention required for materials and work-in-progress (WIP), deterioration of WIP through natural elements, loss due to misplacement, theft, etc.
- error correction is too slow
- multiple handling.

Improvements that require co-operation from several units are very difficult to make under these circumstances.

4.2.4 Network planning

Network planning requires the division of flows into specific activities, which are then organized into a sequence providing for the (apparently) shortest duration.

Let us consider an activity in a CPM network. An activity is usually a part of the overall work flow of a team or it is a complete work flow in itself. It is usually fed by a material flow.

When an activity is a part of a wider work flow, it is strongly affected by the previous activity. The work team has to move from the previous location, and if the activities are the same, learning benefits are gained and the set-up time reduced. The cost of supervision and control also depends on the continuity of the work flow. CPM networks do not generally model these issues.

When an activity is a complete work flow (say, installation of an elevator), the network method just determines the starting time, but does not plan the flow itself.

Thus, traditional network planning fails to support the planning of work flows of teams or material flows and may lead to suboptimal flows. Neither work flows of teams nor material flows are planned in a consistent way (Birrell 1980, 1986). Stated briefly, disruptive disconnects in these flows are bound to result.

4.2.5 Neglect of flow control and improvement

One could say that the picture given above is too selective and negative; the flow aspects are certainly taken into account by seasoned practitioners.

To some extent, this is true. Take work flow control as an example. Birrell (1980) reports that in practice project planning is done by considering the spatial work flow of teams, rather than by CPM network analysis.

However, there is an overwhelming amount of contrary evidence. Whatever flow in construction we analyze, a tradition of neglect and mismanagement is found:

- Project planning: Owners start lump sum projects with absurd uncertainties (Laufer 1991). The detrimental impact of changes is not realized: “the true impact of changes is not well understood and seldom fully recognized in terms of cost and schedule adjustments” (Hester & al. 1991). Work hours for changes are underestimated by as much as 40 to 50 percent.
- Construction planning: “Today, it is the unusual contractor who does formal preplanning” (Oglesby, Parker & Howell 1989). On the contrary, construction planning should ensure smooth information, material and work flows.
- Materials management: This is found to be generally neglected (Oglesby, Parker & Howell 1989). “...many small- and medium sized contractors do not readily accept the notion that their profitability can be substantially improved through better material management” (Thomas, Sanvido, Sanders 1990). “...few materials-management systems are presently being effectively utilized by the industry” (Bernold & Treseler 1991).
- Work flows: Successful application of methodical work improvement, based on Taylor’s scientific work study, was first reported in 1911 (Drewin 1982). However, the authors of a leading volume in productivity improvement state in 1989 that “adoptions [of techniques for improving productivity have] seldom occurred (Oglesby, Parker, Howell 1989).

This state of affairs has not emerged by chance, but rather as a result of a mind set which has not observed and analyzed the flow aspects of construction properly.

4.2.6 Compound effects

The problems described above tend to compound, aggravate and self-perpetuate. They cause a situation where the flow processes in construction are unnecessarily fragmented, complex, intransparent and variable. This has consequences for the behavior and mind set of all parties in construction. In project control, “firefighting” ongoing or looming crises consumes management resources and attention so totally, that there is little room for planning, let alone improvement activities : “Managers are too occupied with the complexities involved in getting the work done to think about, much less to carry out, organized programs [for productivity improvement]” (Oglesby & al. 1989).

In fact, the whole construction culture is characterized by this short term, action oriented behavior: “Firefighters get the laurels” (Ballard 1989). Rewards for improvement based on proactive and systematic action are not clear.

Developments in construction technology and market demands, like the increasing variety of materials and components, and requirements for shorter project duration, tend further to aggravate the inherent problems in construction processes.

4.3 Waste and value loss 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, loss of value, and non value-adding activities. Thus, it is appropriate to check whether the existing information supports this hypothesis.

As far as it is known, 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. However, the figures presented tend to be conservative, because the motivation to estimate and share them is greatest in leading companies, which may be near the best practice. Furthermore, even an energetic effort to observe all quality problems does not reach all of them. A wide variation due to local conditions, project types, construction methods etc. may also be anticipated.

Quality costs are perhaps the best researched area. In numerous studies from different countries, the cost of poor quality (non conformance), as measured on site, has turned out to be 10 - 20 % of total project costs (Cnudde 1991). In a very detailed Swedish study on a design-construct project, the costs of quality failures for a construction company were found to be 6 % (Hammarlund & Josephson 1991). In an American study of several industrial projects, deviation costs averaged 12.4 % of the total installed project cost; however, "this value is only the tip of the iceberg" (Burati & al. 1992).

The causes of these quality problems are attributed to

- design 78 % (Burati & al. 1992), 23 % (Hammarlund & Josephson 1991) and 46 % in a Belgian study (Cnudde 1991)
- construction 17 %, 55 % and 22 %, respectively
- material supply 20 % and 15 % (in the last two cited studies).

The loss of value (understood as exceptional maintenance) to owners during facility use has also been studied in several countries. In Sweden and Germany these external quality costs are estimated to be 3 % of the value of annual construction production (Hammarlund & Josephson 1991). When the average costs for exceptional maintenance are traced back to the time of the actual construction, the loss of value is found to be 4 % of the production cost, in the case of Sweden. 51 % of these costs are associated with design problems, 36 % with construction problems and 9 % with use problems. As for the other aspect of loss of value, failure to attain the best possible performance, we have little data.

Thus, quality problems are considerable in all phases of construction. Especially, design is often the source of quality problems: sometimes it seems that the wastes and losses caused by design are larger than the cost of design itself. Even if there is a lack of data on the internal waste in design, it can be inferred that a substantial share of design time is consumed by redoing or waiting for information and instructions.

Constructability is the capability of a design to be constructed (The Construction Management Committee 1991). Constructability of a design depends on the consideration of construction constraints and possibilities. Projects where constructability has been specifically addressed have reported 6 - 10 % savings of construction costs (Constructability 1986).

In a Business Roundtable study, materials management was found to be generally neglected (referred by Oglesby & al. (1989)). It has been estimated that 10 - 12 % savings in labor costs could be produced by materials-management systems (Bell & Stukhart 1986). Further, a reduction of the bulk material surplus from 5 - 10 % to 1 - 3 % would result. Savings of 10 % in materials costs are reported from vendor cooperation in streamlining the material flow (Asplund 1991). According to a Swedish study, excess consumption of materials on site (scrap, wastage and surplus) is on average 10 %, varying in the range of 5 - 30 % for different materials (Bättre materialhandling på bygget 1990).

As for work flow processes, the average share of working time used in value-adding activities is estimated to be 36 % (Oglesby & al. 1989) or 31.9 % (Levy 1990) in the United States. There are similar figures from other countries (for example, National Contractors Group 1990).

Another waste factor is lack of safety. In the United States, safety-related costs are estimated to be 6 percent of total project costs (Levitt & Samelson 1988).

Thus, there is strong empirical evidence showing that a considerable amount of waste and loss of value exists in construction². A large part of this waste has been hidden, and it has not been perceived as actionable.

4.4 Detrimental impact on development efforts

The many problems of construction have led to various development efforts. However, deficient conceptualization may lead to suboptimal or counterproductive conclusions and actions. Industrialization and computer integrated construction are examples of efforts that initially have been based on the traditional conceptualization, but the neglect of flow processes seems to have become a barrier for progress.

4.4.1 Industrialization

The traditional goals of industrialization of construction (Warszawski 1990) match well with the goals of process improvement: industrialized construction simplifies site processes and provides benefits of repetition. However, the total process of construction tends to become more complex and vulnerable due to using two production locations (factory and site) and increased co-ordination needs.

In industrialization, process improvement has not been taken as a goal in itself. This has been detrimental because industrialized construction requires considerably better controlled processes than on-site construction. For example, requirements for dimensional accuracy as well as co-operation within the design and planning processes are more important in industrialized construction.

Thus, it seems to be a plausible hypothesis that poorly controlled design, prefabrication, and site processes have often consumed the theoretical benefits to be gained from industrialization.

4.4.2 Computer integrated construction

In recent years, computer integration has become a major development target in construction. The basic idea in the pursuit of computer integrated construction (CIC) is to facilitate communication of data, knowledge and design solutions between project participants. Related development efforts have focused primarily on technical issues: the data structure of the constructed product and, to a lesser extent, of the production process.

²Of course, this is not surprising in view of the widely held opinions on construction. Schonberger (1990) comments that construction does not fit the usual categories of industries:

“One industry, construction, is so fouled up as to be in a class by itself. Delay, lack of coordination, and mishaps (especially return trips from the site to get something forgotten) are normal, everyday events for the average company.”

The original basis of CIC is activity-oriented. After observing a task poorly carried out, namely data communication, it is suggested that this task be computerized³. However, here we again confront the myopic view of improving tasks or activities in isolation from the flow.

In fact, there is increasing empiric evidence that flow process problems, like excessive fragmentation and segmentation, effectively hamper the implementation of integration technology (Liker & al. 1992, Anon. 1991). Thus, a neglect of process improvement is a barrier to technical integration⁴.

4.5 Conclusions

The situation in construction may be characterized as follows:

- the conceptual basis of construction engineering and management is conversion oriented (though the term activity is most commonly used)
- the managerial methods deteriorate flows by violating principles of flow process design and improvement
- as a consequence, there is considerable waste in construction
- waste is invisible in total terms, and it is considered to be inactionable
- improvement efforts have been hampered by their neglect of flow aspects.

However, this is the very situation faced by manufacturing. The following characterization by Plossl (1991) could as well describe construction:

“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.”

Thus, 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 isolated solutions to the various problems at hand.

³ For more detailed treatment, see Dupagne (1991).

⁴ Recently, these issues have been increasingly addressed in the framework of organizational integration.

5 Construction as flow

Construction should be viewed as composed of flow processes. In the following, a view of the construction project based on flows and their associated wastes and values is given. Measuring flows in construction is then commented upon.

The most acute flow problems of construction are caused either by traditional design, production and organization concepts, or the peculiarities of construction. Thus, these issues necessitate special consideration. After examining solutions to the problems caused by the traditional managerial principles, the impact of construction peculiarities on process control and improvement is analyzed.

Taking flows as the unit of analysis in construction leads to deep changes of concepts and emphasis. This initial interpretation will only scratch the surface.

5.1 Flow processes in construction

There are two main processes in a construction project:

- *Design process*: is a stagewise refinement of specifications¹ where vague needs and wishes are transformed into requirements, then via a varying number of steps, to detailed designs. Simultaneously, this is a process of problem detection and solving. It can be further divided into individual subprocesses and supporting processes.
- *Construction process*: is composed of two different types of flows:
 - Material process consisting of the flows of material to the site, including processing and assembling on site.
 - Work processes of construction teams. The temporal and spatial flows of construction teams on site are often closely associated with the material processes.

Other processes, which control or support the main processes, include:

- Project management process by the owner.
- Design management process by the engineering or design project manager.
- Construction management process, where the detailed design is transformed into a construction/fabrication plan and into day-to-day coordination and control of processes on site or in a factory.

The processes may be characterized by their cost, duration and the value for the customer. The value consists of two components: product performance and freedom from defects (conformance to specification). Value has to be evaluated from the perspective of the next customer and the final customer. Cost and duration depend on the efficiency of value-adding activities and the amount of non value-adding activities.

Let us consider, in a simplified manner, design and construction from the point of view of value and cost. Time (duration) could be analyzed in a similar manner to cost. Let us assume that efficiency of value-adding activities is the same in organizations considered².

¹ For more detailed discussion, see (Juran 1988, Webster 1991).

² This is not a too rigorous assumption; especially in site construction, where equipment renting is common, all competitors have access to the same assortment of technology.

The cost of design is made up of costs of value-adding activities and waste. The waste in the design process is formed by

- rework (due to design errors detected during design)
- non value-adding activities in information and work flows

The design process has two customers: the construction process and the client. The value for the client is determined by

- how well the implicit and explicit requirements have been converted into a design solution
- the level of optimization achieved
- the impact of design errors that are discovered during start-up and use.

The value of the design for the construction process is determined by

- the degree to which requirements and constraints of the construction process have been taken into account
- the impact of design errors that are detected during construction

The inherent waste in construction is created by

- rework due to design or construction errors
- non value-adding activities in the material and work flows, such as waiting, moving, inspecting, duplicated activities, and accidents

The construction process has as its customer the client. The value of the construction to the client is determined by

- the degree of freedom of defects discovered during start-up and use.

The primary focus in design is thus on minimizing value loss, whereas in construction it is on minimizing waste. It has to be stressed that both wastes and value losses are real and considerable, as described above.

Due to the one-of-a-kind project character of construction, it is necessary to have two time frames for analysis: a project time frame and a longer time frame. From the viewpoint of a particular one-of-a-kind project, the goal is to attain the level of cost and value of the best existing practice (Figure 6). For the project, flows from different companies are combined, often only for one run. Consequently it is important to assure the process capability of companies to be selected for the project.

From the longer term point of view, the organizations in construction have to improve the processes continuously in order to meet and beat the best practice. However, even the best practice has an ample reserve of improvement potential, and the efficiency of the best practice is - or at least should be - continuously moving (Figure 7).

The above discussion, with its emphasis on process improvement, down plays the potential of innovation to improve conversion processes. However, innovation is often closely related to process improvement: new equipment may ensure less variability, new material may make a simplified process possible.

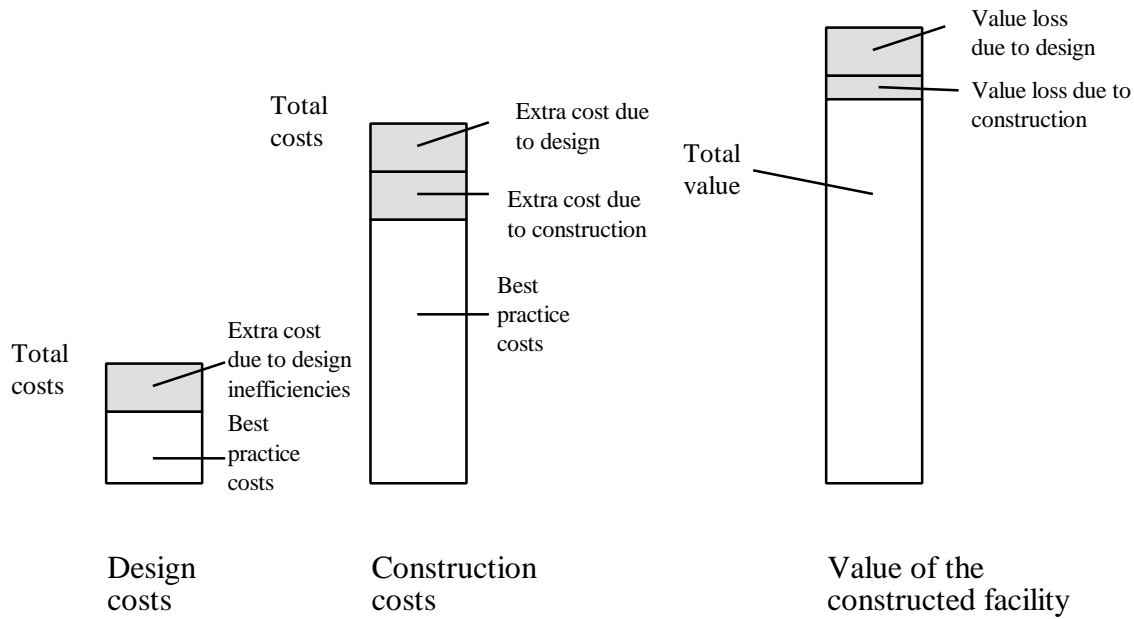


Figure 6. The decision situation from the point of view of the client. Note that design and construction duration can be analyzed similarly to costs.

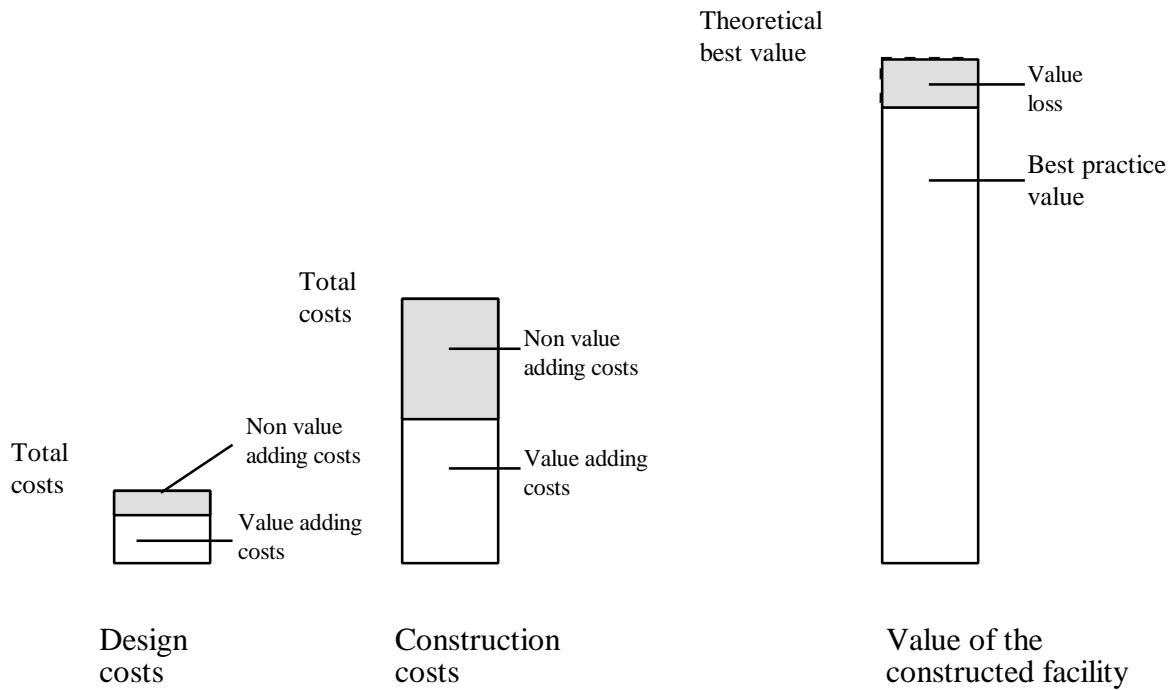


Figure 7. The process improvement potential for the best practice organizations. Again, time should be analyzed in a parallel fashion to costs.

Compare this analysis with the conventional discussion on the diminishing degree of influence of decisions on project cost during the progress of the project (for example, Barrie & Paulson 1984). It is acknowledged in this analysis that

- time and value, in addition to costs, are influenced by decisions in the project,

- influencing costs, time and value within the project is equivalent to manipulating flow characteristics,
- cost, time and value are also dependent on the long term efforts of participating organizations for continuous improvement.

5.2 Measures for construction

It is evident that the conventional measures of construction, which most often focus on cost or productivity, fail to make waste visible and to stimulate continuous improvement, as argued in Section 3.6. New measures are needed. Clearly, this theme is an open invitation to research and development³.

Three of the visited companies were in the process of developing or already using new measures and measurements systems in connection to continuous improvement efforts⁴.

The following discussion is confined to illustrating new measures and to commenting on difficulties in establishing suitable measures for comparisons and benchmarking.

Measurement data are needed for two purposes: for driving internal improvement in the organization, and for targeting and comparison across projects and organizations. For organizations permanently participating in construction, both sets of measures are important. For a one-time owner, the latter type of performance data is of interest.

In the following, construction related measures are illustrated, based on the requirements presented in section 3.6:

- Waste: Such issues as number of defects, rework, number of design errors and omissions, number of change orders, safety costs, excess consumption of materials and the percentage of non value-adding time of the total cycle time for a particular work or material flow may be addressed.
- Value: The value of the output to the internal or external customer often has to be evaluated subjectively. For example, an aggregate measure for quality of industrial plants, based on subjective views, has been developed in a current study at CIFE (Fergusson & Teicholz 1992).
- Cycle time: The cycle times of main processes and subprocesses are powerful measures⁵.
- Variability: Any deviations from the target can be addressed, like in schedule performance (percent of activities executed as planned).

There are three special problems encountered in developing measures for construction:

- Uniqueness of projects, related lack of repetition, and environmental uncertainty, which—at first sight—might make it difficult to compare between projects or organizations.
- Difficulty of data collection on site.
- Varying definitions and procedures for data collection.

When measurements are used internally, these problems can be overcome. Most organizations carry out roughly comparable projects, and data collection methods can be standardized inside the organizations. Also, it might be possible to measure uniqueness,

³ Construction Industry Institute's Quality Performance Task Force is currently in the process of analyzing and evaluating measures used in design and construction.

⁴ This format is used to present anecdotal evidence from the companies visited by the author.

⁵ For discussion on time based competition in construction, see (Puyana-Camargo 1992).

complexity and uncertainty and to link efficiency and effectiveness targets to the degree of difficulty met.

As for measurement data used for comparison and targeting, the problems stated above are more severe. However, they may be solved by focusing on rates of improvement rather than on absolute values. This has other benefits as well:

- Differences in definition and data collection are to a great extent filtered away.
- Differences in project complexity, uncertainty, etc. between various companies are heavily reflected in the absolute values; however, it is reasonable that a logarithmic measure, like halving time, is comparable.
- Overall rate of improvement is the single most important measure in the long term.
- Halving time or percent change per year are simple and easy to understand.

As observed in benchmarking practice, information on rates of improvement, to be operational, should be accompanied by information about means for triggering that improvement .

In spite of all difficulties in finding commensurate data, an important measure for comparison and targeting is surely the world class level, that is, the absolute value of achievement of the best companies in the world. However, for targeting, it is useful to know the time it will take to reach this level, which is reflected in the rate of improvement, discussed above.

The industry average (or median) level of a performance measure is interesting, but potentially counterproductive. It tends to produce complacency in those companies better than average. For those companies worse than average, the target implicitly pinpointed by this benchmark is the average.

5.3 Overcoming flow problems caused by conventional managerial concepts

As stated in the previous chapter, the traditional managerial concepts have not only ignored but actively deteriorated flows of construction. Thus, it is of prime importance to introduce alternative methods conducive to flow improvement. 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 managerial method in question.

It should be noted that the introduction of these alternative methods is only the start of process improvement. Other improvement actions will build on that foundation.

5.3.1 Alternatives to sequential mode of project realization

In manufacturing, the problems caused by the sequential method of product development have been addressed by the notion of concurrent engineering. To some extent, corresponding solutions have been developed and introduced in construction.

In general, the solutions have aimed at reduced cycle time, better consideration of the next stages, and complete processes as the focus of control. These are exactly the principles that are violated in the sequential method.

The term concurrent (or simultaneous) engineering (Barkan 1991) has been coined to refer to an improved design process, characterized by a rigorous upfront requirements analysis, incorporating the constraints of subsequent phases into the conceptual phase, and

tightening change control towards the end of the design process. In comparison to the traditional sequential design process, iteration cycles are transferred to the earlier phases through cross-functional teamwork. Also overlapping of phases is used; however, intense information exchange is required. Compression of the design time, increase of the number of iterations and reduction of the number of change orders are three major objectives of concurrent engineering.

In construction, various partial solutions have been implemented for remedying the evident problems of the traditional approach. Most solutions concern organizational rethinking. For example, in design-build contracts, the contractor gains more influence in design solutions. In solutions involving construction management, an additional party is recruited for taking care of the flows.

Performance specification refers to a structured design procedure, where the requirements are made explicit, so that firms can offer their own technical solutions corresponding to the required performances (Louwe & van Eck 1992). The technical part of the design is thus transferred to parties which earlier were responsible only for execution. In conventional building design practice, functional performances often are not handled very explicitly, but rather iteratively during the stagewise development of the design solution and by soliciting client reactions to it. Performance specification endeavors to advance both the optimality of a particular project and the rate of innovation in general by involved parties. Concurrent engineering is facilitated by this structured approach.

Another area having been developed as a reaction to the traditional approach is systematization of constructability knowledge (The Construction Management Committee 1991).

5.3.2 Improving quality

At the risk of oversimplification, there are three recommendations presented in the extensive body of quality literature to the quality problem:

- design and improve processes to have low variability
- establish means for rapid detection and correction of any defect or deviation
- improve the mechanism by which specifications are defined for each conversion activity.

These correspond to the flow design and improvement principles concerning variability, cycle time and customer requirements. Various quality goals reflecting these recommendations have been increasingly accepted and implemented in construction during the last five years. Because this area is rather well understood, it is not discussed in more detail.

5.3.3 Non-segmented control

The basic solution is, of course, to focus control on complete flow processes. Usually this means that flows are the basis for organization, rather than specialties or functions as in the hierarchical organization. For example, a component manufacturer should be responsible for the whole material chain, including the installation on site. This will facilitate the application of other solutions developed in the JIT-approach to material flows, like smaller batch size and continuous flow, which contribute to cycle time reduction.

However, solutions which overcome the problems of segmented control in construction are still scarce and tentative. Experimentation, development and research are needed.

5.3.4 From network planning to flow planning

In both work planning and materials management, the emphasis should change to complete flow processes rather than discrete activities. Birrell (1980) has described a heuristic method for flow oriented work planning. Recently, there have been attempts to integrate flow planning with network methods (Huang, Ibbs & Yamazaki 1992, Osawa 1990).

This field will provide fruitful opportunities for research and development, especially with respect to computerized tools to accomplish flow planning.

5.4 Overcoming flow problems caused by the peculiarities of construction

5.4.1 Construction peculiarities

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 - or excuses - when well-established and useful procedures from manufacturing are not implemented in construction.

Construction peculiarities refer especially to following features (Tatum & Nam 1988, Warszawski 1990):

- One-of-a-kind nature of projects
- Site production
- Temporary multiorganization
- Regulatory intervention

Other construction attributes, such as durability and costliness, are not considered relevant in this context. Also construction may be characterized as complex and uncertain. These two features, which are shared by many other industries, are treated as resultant process features rather than as primary peculiarities.

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**. But certainly it is a core issue to understand these peculiarities and to be able to avoid or alleviate their detrimental effects.

In the following, the process control and improvement problems caused by the peculiarities are analyzed. Solutions, both well-known and those suggested by the new production philosophy, are presented.

5.4.2 One of a kind product

Characterization

The one-of-a-kind nature of each building or facility is caused by differing needs and priorities of the client, by differing sites and surroundings, and by differing views of designers on the best design solutions (Warszawski 1990). This one-of-a-kind nature, which varies along a continuum, covers most often the overall form of the building or facility. The materials, components and skills needed are usually the same or similar. From the point of view of contractors and design offices, there is continuity and repetition:

roughly similar projects and tasks recur⁶. Thus, it has to be stressed that the problems associated with one-of-kindness affect only certain processes in any project.

Usually there is significant input into the design process by the client, who is often a one-time participant in the process and thus does not have the benefit of learning from prior project cycles.

Problems of process control and improvement

There are several major problems of process control and improvement related to one-of-a-kind production.

No complete feedback cycles are possible because the product is costly: what would be a prototype to be debugged and developed further in manufacturing, is the end product in construction.

The input by a lay client tends to be incoherent and unorganized, often activated by exposure to detailed design solutions. Such corrections of omissions in later phases of the project disrupts the otherwise smooth flow of activities.

The general problem in the production of one-of-a-kind buildings is that the configuration of the flows has to be specifically designed. There are activities in the flow that are difficult to control because of novelty. In one-of-a-kind tasks, figuring out the respective goals and constraints is error-prone and time-consuming; the benefits of learning and continuous improvement are not at hand. Also, the coordination of the project is hampered by duration uncertainty and unknown characteristics of one-of-a-kind activities.

From the point of view of process improvement, measuring is a concern: one-of-a-kind projects are not viewed as comparable, and incremental progress from project to project has been difficult to perceive.

To sum up, the following principles for flow design and improvement are difficult to realize: reduction of variability, continuous improvement, enhancement of transparency, compression of (learning) cycle time. The solutions presented below attempt to implement these principles.

Solutions

The first, and most basic approach to the one-of-a-kind nature of construction is to eliminate those unique solutions in a project not absolutely necessary due to client or site idiosyncrasies or artistic expression of the designer. In this way, proven standard work flows and associated components, skills, etc. can be used. Closed or open industrialized building systems provide solutions to be considered (Warszawski 1990). Recently, construction companies have begun to offer concept buildings (office buildings, schools, day nurseries, etc.), which are pre-engineered solutions that can be adapted to different needs.

The lack of repetition and thus feedback cycles can be remedied by creating artificial feedback cycles (Chew 1991 & al. 1991): simulation in its various forms, physical models,

⁶ It is often argued that construction projects are unique, and especially different from manufacturing in this aspect. However, claims of uniqueness of particular plants abound in manufacturing as well (Plossl 1991, Chew & al. 1990). It seems that there is a psychological urge to see one's own system as unique.

or learning from corresponding earlier projects. Accomplishing novel tasks on site can be facilitated by planning and training with mock-up models. Interestingly, it is a practice in Japan to publish solutions used in unique projects in scholarly journals.

The management of the client requirement formulation process is another need. Systematic investigation of requirements and client involvement in conceptual design produce upfront a requirements list, which facilitates progress in subsequent phases.

With regard to site activities, the problems of one-of-a-kind tasks can be remedied with high quality documents and clear instructions. Costly activities of sufficient duration warrant careful methods study and improvement. Continuous planning⁷ will prevent non value-added time from inflating on site.

In general, the problems of one-of-a-kind nature are compounded by the two next problems: production on site and temporary organization⁸.

5.4.3 Site production

Characterization

Construction production is typically carried out at the final site of the constructed product, often inside the evolving product

Problems of process control and improvement

There are four major process control and improvement problems with respect to site production:

- Variability problems: There is usually little protection against elements or intrusion, rendering operations prone to interruptions. Permanent safety fixtures cannot be used in the evolving environment. Local material and labor input often has to be used, potentially adding to uncertainty. Other areas of uncertainty include site geology and additional environmental factors.
- Complexity problems: The spatial flow of work stations (teams) has to be coordinated (in contrast to a factory, where only material flow through work stations is planned).
- Transparency problem: The working environment is continuously evolving, making layout planning laborious. Due to the evolving environment, visual controls are difficult to implement.
- Benchmarking problem: Site production is by nature decentralized production, with associated problems of transferring improvement⁹.

Solutions

The most basic solution to alleviate the site problems is to configure the material flows so that a minimum number of activities are carried out on site. The rationale of prefabrication, modularization and preassembly is partly based on this principle. Likewise, in more site

⁷ The observations of Laufer (1991) on coping with uncertainty in planning are relevant here.

⁸ The methods and concepts of schedule compression (Construction Industry Institute 1988) address all these problems.

⁹ In manufacturing, there are also great difficulties in transferring improvement from plant to plant within one company (Chew & al. 1990). The performance differences may as great as 2:1 (after controlling for other differences in age, technology, etc.) between the best and the worst plant.

oriented construction some activities such as inspection, storage, sorting etc., can be pushed upstream in the material flow.

The next solution is to arrange necessary protection by means of temporary enclosures, if feasible and cost-effective.

Site production sets high demands on planning because of its uncertainty, changing work environment and numerous coordination needs. Planning of material and work flows is time consuming, and in practice it is poorly executed. Research shows that more meticulous planning, than currently is usual, is beneficial¹⁰. The difficulty of spatially coordinating the work flow can be alleviated by establishing multi-skilled work groups, which coordinate through mutual adjustment.

In practice, site operations are rather poorly systematized; only a handful of companies have standard methods for various site operations (Oglesby & al. 1988). However, only through standard methods can the variability be decreased and the rapid diffusion of improvements be ensured.

The general JIT-technique of smaller batches may also be beneficial for reducing variability and inducing improvement on site. Indeed, there are several work planning methods in Japan which aim at this (Takada 1991). Typically, each floor is divided into multiple zones, and repeated cycle operations are allotted to various teams.

5.4.4 Temporary multiorganization

Characterization

A construction project organization is usually a temporary organization designed and assembled for the purpose of the particular project. It is made up by different companies and practices, which have not necessarily worked together before, and which are tied to the project by means of varying contractual arrangements. This is a multiorganization. Its temporary nature extends to the work force, which may be employed for a particular project, rather than permanently.

However, these characteristics are often not caused by objective conditions, but rather are a result of managerial policy aimed at sequential execution and shopping out the various parts of the building at apparently lowest cost.

Problems of process control and improvement

The problems for process control and improvement are related to the principles concerning continuous improvement, variability and complete processes as the focus of control. In practice there are problems of:

- communicating data, knowledge and design solutions across organizational borders
- stimulating and accumulating improvement in processes which cross organizational borders
- achieving goal congruity across the project organization
- stimulating and accumulating improvement inside an organization with a transient workforce.

¹⁰ See (Laufer & Tucker 1987, 1988) and (Shohat & Laufer 1991).

Solutions

The basic problem of communicating data, knowledge and design solutions over organizational borders can be addressed by

- procuring from a network of organizations with long term cooperation
- team building during the project
- clear definition (general or project wise) of roles of each participant and mutual interfaces (essentially a Project Quality Plan)
- decoupling of work packages (as in the French sequential procedure, to be explained in section 6.1.4).

Improvement across the conventional organizational borders can be stimulated by long term relationships or partnerships between

- contractor and subcontractor
- owner and engineering firm
- engineering firm and vendor.

Goal congruence may be enhanced with facility procurement solutions, like the construct and operate procurement method, becoming common for new electrical power generation plants in the U.S.

5.4.5 Intervention of regulatory authorities

Characterization

The design solution and many work phases in a construction project are subject to checking and approval by regulatory authorities.

Problems of process control and improvement

Authority intervention causes uncertainty and constraints to the process. Getting an approval for a design solution is often unpredictable. Checking by authorities during the construction process can cause delays. Codes may be barriers for innovation, if they rigidly require a procedure, rather than a performance.

These principles of (regulatory) cycle time, variability and continuous improvement need to be applied to these problems.

Solutions

Inspection activities should be included as part of the flow process of production, subject to improvement by application of the eleven principles. The approval process can usually be simplified and speeded (as realized for example, in Norway). Authority checking during execution can be substituted with self-checking by the executing firm, provided it has a necessary quality control system. The building codes can be converted to be performance based (as has already happened in the Netherlands) (Louwe & van Eck 1991).

5.4.6 Discussion

The problems associated with the peculiarities of construction are well-known in practice, and various countermeasures have been developed and implemented, as presented above and summarized in Table 4. These peculiarities tend to hamper control and improvement by violating principles of flow design and improvement, and increasing the share of non value-adding activities. However, by implementing structural solutions these peculiarities

can be avoided or at least minimized. Various operational solutions alleviate control problems and improvement problems respectively.

In any case, the general principles for flow design, control and improvement apply. Construction peculiarities cannot serve as an excuse for neglect of process improvement.

These solutions will be refined and novel solutions will surely emerge through practical improvement efforts.

Table 4. Overview on problems related to construction peculiarities and corresponding solutions. Process control refers to the management of a project, process improvement to the development efforts of the permanent organizations in construction (designing, manufacturing of materials and components, contracting).

Peculiarity	Process control problems	Process improvement problems	Structural solutions	Operational solutions for control	Operational solutions for improvement
One-of-a-kind	No prototype cycles Unsystematic client input Coordination of uncertain activities	One-of-a-kind processes do not repeat, thus long term improvement questionable	Minimize the one-of-a-kind content in the project	Upfront requirements analysis Set up artificial cycles Buffer uncertain tasks	Enhance flexibility of products and services to cover a wider variety of needs Accumulate feedback information from earlier projects
Site production	External uncertainties: weather etc. Internal uncertainties and complexities: flow inter-dependencies, changing layout, variability of productivity of manual work	Difficulty of transferring improvement across sites solely in procedures and skills	Minimize the activities on site in any material flow	Use enclosures etc. for eliminating external uncertainty Detailed and continuous planning Multi-skilled work teams	Enhance planning and risk analysis capability Systematized work procedures
Temporary organization	Internal uncertainties: exchange of information across organization borders (flow disconnects)	Difficulty of stimulating and accumulating improvement across organization borders	Minimize temporary organizational interfaces (interdependencies)	Team building during the project	Integrate flows through partnerships
Regulatory intervention	External uncertainty: approval delay			Compression of approval cycle Self-inspection	

5.5 Conclusions

The view of a construction project based on flow processes leads to theoretical understanding and to practical guidelines for improvement.

Theoretically, the causes for the chronic problems in construction are clarified by pinpointing the generic process problems from which they originate. The problems of construction fall into two different clusters of causes. The first is the application of traditional design, production and organization concepts, which in the course of time have become inefficient. Secondly, construction has peculiarities which have not been adequately handled. These issues necessitate special consideration in regard to avoiding or alleviating their detrimental impact on process control and improvement.

With respect to practical application, this approach provides for evaluation of existing flows (by means of measures like those presented above), identification of improvement potential, and guidance of operational improvement action. Thus, persistent problems may be identified and cured and processes generally improved in a long term effort by committed companies in the construction sector. These issues will be discussed in more depth in the following chapter.

6 Implementation of the new production philosophy in construction

6.1 Present status of implementation: experiences and barriers

6.1.1 Initial implementation limited by barriers

In the construction industry, interest in the new production philosophy has grown rather slowly. Three major thrusts of implementation can be discerned¹:

- The new approach, in its JIT-oriented form, has been used in manufacturing oriented parts of the construction industry, like in the production of windows, elevators and prefabricated housing.
- In mainstream construction, quality-based efforts have been launched by a growing number of organizations; this includes TQM but also such developments as partnering, team building, continuous improvement and constructability.
- In several countries, there are initiatives to change the project organization and procurement methods so that obstacles for process improvement will be eliminated.

All in all, however, the overall adoption of the new philosophy in construction is rather limited in scope and methods. What are the reasons for this reluctance?

The following barriers to the implementation of these ideas in construction can be observed:

- Cases and concepts presented to illustrate the new approach (for example batch size reduction, work-in-progress reduction, set-up time reduction, layout simplification) are usually from the realm of mechanical fabrication and assembly, so are often not easy to internalize and generalize from the point of view of other industries, as pointed out by Baudin (1990). It has not been clear whether the new approach is at all feasible in an activity so different from manufacturing.
- The idiosyncrasies of construction, like unique, one-of-a-kind products, site production, temporary project organizations and regulatory intervention necessitate an industry-specific interpretation of the general principles of the new production philosophy, which currently exist only in outline.
- International competition, which in car manufacturing is a major influencing factor, is relatively sparse in domestic construction of major industrialized countries.
- Lagging response by academic institutions: the new philosophy is not acknowledged in educational curricula or research programs. The nature of the new production philosophy as an engineering based, rather than as a science based endeavor is certainly a major cause for this.

However, all of these barriers are temporary; they may retard and frustrate the diffusion but not thwart it.

¹ One could argue that the Japanese construction industry is a fourth area, where many of the ideas of the new production philosophy have already been incrementally introduced. Bennett (1991) writes: "The Japanese building industry delivers reliable quality, on time, with a certainty not matched anywhere else in the world. This performance is the result of decades of steady development based on the principles of mass production: simplify, standardize and systematize." Unfortunately, current Japanese practice could not be examined in this study in detail.

6.1.2 Construction subprocesses of manufacturing character

Currently some construction subproducts are produced in processes that possess a manufacturing character. The assembly of such components with the building frame usually represents a minor share of the total costs. Windows, doors, elevators, prefabricated concrete components, and prefabricated houses, are examples of this kind of manufactured product. (However, ceramic tiles or bricks, for example, even if produced in factories, are not in this group because a considerable part of the cost of the end product accrues on site.)

There are several notable examples of successful implementation of the new production philosophy to this kind of process. Schonberger (1990) reports on a Japanese factory producing prefabricated houses with a customer lead time of forty days (from order to completion on site), and production time (first to last operation) of one day. A Finnish window manufacturer provides delivery and installation of windows on site with a 15 minute accuracy (Koskela 1991). An American industrial door manufacturer has gained a considerable competitive benefit from JIT production and short cycle times (Stalk & Hout 1990).

In regard to quality management, clear progress has been made in many countries. Many supplying firms have acquired quality certification according to the ISO standard.

The application of the new production philosophy is least problematic in this part of the construction industry: the methods and techniques developed in manufacturing can be applied directly. However, except for quality management techniques, only a minor fraction of the factories and plants delivering to construction sites have begun to implement the new philosophy. It may be anticipated that this transformation will proceed rapidly after having gained initial momentum. Thus, industrialized construction might gain competitive benefits sooner than site construction.

6.1.3 Mainstream construction

Only the quality oriented approaches have been applied to any considerable extent in the mainstream construction world. The quality issues have received increasing attention since the beginning of the 1980's, and construction specific interpretations of the general quality methodologies have been published (for example, Shimizu 1979 and 1984, Cornick 1991, Burati 1992, Leach 1991). On the basis of the practical experiences of pioneering companies², the methods may be further refined.

Three of the visited companies had recently launched formal TQM programs. The thrusts in those programs are:

- definition and standardization of work processes (especially cross-functional) and appointment of process owners, responsible for maintenance and improvement of the respective process
- establishment of teams for finding solutions to selected bottleneck problems
- development of a measurement system to support and monitor process improvement.

One company had explicitly adopted the goal of cycle time reduction, beyond the customary TQM emphasis on customer value and variability reduction.

While quality management has provided considerable direct benefits, it has also served as a starting point for process improvement. However, continued progress and widening of

² See the forthcoming CII report "Implementation Process for Improved Quality".

themes considered seems to be somewhat problematic. The basic problem is that quality management basically addresses only a partial (although important) set of wastes, namely defects and failures to consider customer requirements. The often somewhat rigid and dogmatic methodologies do not easily allow for a wider perspective. Another problem seems to be that quality management has often been introduced as a second management track, separate from the real management process. Sometimes the implementation of quality management is more related to marketing and image, say ISO certification or winning a national quality award, than to an urge for internal improvement.

Other process improvement principles are being used incidentally³. A French construction company has carried out a simplification campaign for streamlining administrative procedures. A British construction company has taken as its goal to be on-time, that is to reduce time variability in its processes. In a Swedish company, the reduction of cycle time for construction projects is being adopted as a goal.

However, the common problem of the majority of these efforts is that only a few process design and improvement principles are used. Thus, while quality management remains a useful and proven entry point to process improvement, there is a need to proceed to the application of all available principles of process design and improvement.

6.1.4 Industry wide initiatives

The traditional way of organizing construction has been found in many countries to hamper performance improvement and innovation. The idea of changing the organization in order to eliminate these obstacles has been the motivation of three initiatives aimed at industry wide changes in European countries:

- the sequential procedure in France
- the open building method in the Netherlands
- the new construction mode in Finland.

These methods have been developed primarily to advance innovation in construction, and they have not been based directly the new production philosophy. However, they have several implications regarding the new production philosophy. In the following, they are analyzed in more detail from that point of view.

The sequential procedure

The main idea of the sequential procedure⁴ is to plan the site work as successive realizations of autonomous sequences. A sequence is defined in terms of regrouping of tasks by functions of the building, not in terms of traditional techniques or crafts. During a sequence a firm can operate without interferences because it is the only organization on site. After each sequence, there is a quality inspection and turn over of the works. The due dates of sequences are strictly controlled.

The sequential procedure follows closely, even if implicitly, the ideas of the new production philosophy. In the following, an interpretation of the methods and purposes of the sequential procedure, as presented in (Gilbert 1991, Lenne 1990, Cazabat & al. 1988, Bobroff & Campagnac 1987), is made from the point of view of applicable process improvement principles:

³ Information in this paragraph is based on trade journals and oral communication.

⁴ Note that “sequential procedure” has quite a different meaning than the term “sequential method of project organization” discussed earlier.

- Waste reduction. The goal is to reduce non value-added time due to excessive specialization: however, other waste components are not as explicitly attacked.
- Variability reduction. With several strict due dates and quality control points during the project, defects and problems do not easily migrate downstream. Preplanning is facilitated through reduced external uncertainty.
- Cycle time compression. Sequence cycle time (site time of each sequence) is compressed by utilizing more prefabrication and preassembly (of course, the total cycle time may be longer than in conventional construction due to preparation and prefabrication)
- Simplification. By establishing strictly sequential work packages, activity interdependencies are reduced and organization and planning of construction is thus simplified.
- Flexibility. Development of multi-skilled personnel is encouraged.
- Transparency. In the framework of each sequence, transparent material and information flows are easier to arrange.
- Control of complete processes. The sequences roughly correspond to separate material flow processes in construction. Processes are thus isolated from reciprocal disturbances. Development and optimization of the whole span of a process is encouraged.
- Continuous improvement. Long-term relationships are formed between firms for a particular sequence, which facilitates continuous improvement and innovation.

The sequential procedure has been tried out in a rather large number of projects, and the method has been further refined. It seems that this method is being adopted to use by owners, contractors and subcontractors in France; however, we do not know of actual data.

The open building system

The open building system is an integrated set of rules and agreements concerning the organization of design and building. The following features are stressed (Louwe & van Eck 1992, van der Werf 1990, van Randen 1990):

- performance concept
- modular coordination
- separation of the “support” (structural) and “infill” (interior work) parts of buildings
- specialized and multi-functional teams of craftsmen.

Especially the following process design and improvement principles are emphasized:

- Flexibility of design solutions in spite of relying on pre-engineered and prefabricated components.
- Simplification through modular coordination and standardization of interfaces between different building components.
- Control of complete processes, while allowing decision power for all concerned parties.
- Continuous improvement through project-independent product development by supplying companies.

This concept, having been developed over a period of 25 years, is now being introduced by a number of contractors and suppliers in the Netherlands.

The new construction mode

The goal of this new building process is to remove the causes of the current inherent problems in construction (Lahdenperä & Pajakkala 1992). It combines performance based

design and final product (rather than input resource) oriented construction procurement . On the basis of performance requirements, supplier firms (or company groups) offer their pre-engineered (and often prefabricated) solutions for different subassemblies of the building.

A detailed procedure for implementing building projects by means of the new model has been prepared.

This model especially supports the following principles:

- Simplification: Through cutting off dependencies between subprojects, the effect of disturbances is diminished.
- Control of complete processes: Integration of design and construction is encouraged. Thus, learning through feedback is enhanced and product development is facilitated.
- Continuous improvement. Continuous collaboration is to be strengthened within firms and between firms.

This model has been developed toward the end of 1980's. The new building process has been the subject of heated discussion during the last two years or so in Finland. It is understood that it creates a lot of changes and it cannot be applied immediately as a whole. However, it has been applied to supplying subassemblies to buildings and also to a few whole buildings on an experimental basis.

Discussion

It is striking that these initiatives try to avoid or alleviate the problems caused by the peculiarities of construction:

- 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.

While there are initial encouraging indications that these kinds of industry wide initiatives can eliminate barriers and stimulate improvement efforts, it must be noted that the actual implementation of process improvement has to be carried out by the organizations themselves. Here we can again consider the analogy provided by manufacturing. Elimination of construction peculiarities just brings construction to the same starting point as manufacturing. Unfortunately, a large amount of waste also exists in manufacturing before process improvement efforts begin.

Thus, we argue that process improvement initiated by the construction organizations is the primary driving force that should be strongly promoted in industry wide programs. Changes in project organizational systems will then be empowered by this momentum.

This kind of industry wide initiative might be especially beneficial to trigger improvement in medium and small construction companies . On the other hand, good results in process improvement have been gained by organizations not influenced by such initiatives. Also, the ideas presented here cannot easily be applied to all types of construction. All in all, empirical investigations are needed for clarifying the significance of these new organizational models for process improvement and innovation.

6.2 Implementation of process improvement by engineering and construction organizations

The inherent recommendation of the new philosophy to construction practitioners is clear: the share of non value-adding activities in all processes has to be systematically and persistently decreased. Increasing the efficiency of value-adding activities has to be continued in parallel.

The basic improvement guideline is thus: get started, define processes, measure them, locate and prioritize improvement potential, implement improvement and monitor progress! Several proven step-to-step methodologies that are useful even if most are narrow and not construction oriented (Imai 1986, Robson 1991, Plossl 1991, Kobayashi 1990, Harrington 1991, Kaydos 1991, Rummler & Brache 1991, Camp 1989, Moran & al. 1991, forthcoming CII report "Implementation Process for Improved Quality"). Earlier, some general remarks on the implementation of process improvement were presented in section 3.8. In the following, some issues that are likely to be encountered by construction organizations are commented upon briefly.

Getting started is often the toughest problem. It might be wise to adopt a proven, even if narrow, methodology for getting started. Total quality management often seems to be a good first step. On the other hand, there are experts who suggest an approach more focused on just starting to solve immediate problems and on learning-by-doing, rather than following specific implementation methodologies (Schaffer 1988).

Process definition and measurement is crucial. Work processes must first be made transparent by charting them. Next, the inherent waste in processes must be made visible through suitable measures, and targets and **monitoring** should be focused on it. As discussed earlier, a significant issue is to find measures which are project-independent. Even if measurements are not as straightforward as in manufacturing, they are not an insurmountable problem.

With regard to **improvement potential**, relations with other organizations might often be observed as sources of problems. However, for obvious reasons it is better to start with solving internal problems.

It is important to select and systematically use appropriate **principles, techniques and tools**. In manufacturing, a considerable number of specific principles and techniques have been developed for process improvement. To a perhaps considerable extent, they are also usable in construction. For example, the ideas concerning basic industrial housekeeping are directly applicable. Presumably construction-specific methods and techniques will emerge from practical work, as occurred in manufacturing.

Owners may be in a critical position for advancing flow process based thinking. Even if owners formally buy the output of all processes in a project, it is the capability of these processes which produce the success of the project, or the unanticipated problems which directly or indirectly cause losses to the owner. Thus, it is in the best interest of the owner to evaluate bidders on the basis of their process capabilities as well as cost. Owners are often in a unique position for complete process control and driving project-wide improvement.

Implementation of the new philosophy may be started with different levels of ambition. It is a multidimensional change and learning process, which can be launched by picking up

just a few principles and techniques. If these are successfully institutionalized, adoption of further principles will be more easily accepted.

Given the relatively high share of waste in construction at present, it is evident that notable gains may be achieved in most organizations even by well directed initial efforts. Waiting for a consolidation of construction specific implementation methodology - which certainly will happen - is no excuse for sticking to the old routines.

6.3 Redefining major development efforts in construction

In many countries, major resources have been and are currently channeled to such development targets as industrialization, construction safety, computer integrated construction and construction automation. It is of prime importance that they are redefined in terms of the new conceptual basis.

6.3.1 Industrialization

Industrialization has been discussed in several contexts above. Here we summarize: Industrialization usually lengthens complete flow processes and makes them more complex than in conventional site construction (although flow processes on site are surely shortened and simplified). These processes must be improved in order to realize the potential that industrialization offers.

6.3.2 Safety

Safety is one of the chronic problems in construction. The new production philosophy can also contribute in this area.

Standardized, systematized and regularized production can be expected to lead to better safety as a side effect (Kobayashi 1990). There are several mechanisms for this:

- there is less material in the work area
- the workplace is orderly and clean
- the work flows are more systematized and transparent, so there is less confusion
- there are fewer disturbances (which, as it is known, are prone to cause accidents)
- there is less firefighting, and attention can thus be directed to careful planning and preparation of activities.

Viewed on the whole, a production process that progresses towards the goals of the new philosophy (less waste and variability) also improves its safety conditions. However, as far as is known, no statistical studies to verify this have yet been done.

This view is reflected in the policy of one company to evaluate vendors on basis of their safety rate (among other criteria): “Without safety, a production process cannot produce high quality products.”

Where the working environment is constantly changing, as it is in construction, safety is ultimately dependent on the avoidance of unsafe acts by workers (Nishigaki & al. 1992). In this respect, the principle: “Reduce the cycle time” should be applied. For example, the STOP-method (Safety Training Observation Program), developed by Dupont, aims at creating a procedure and atmosphere where all unsafe acts of workers, when observed by foremen, can be immediately noted and corrected. This rapid cycle of deviation detection and correction helps to realize a strict compliance to safety regulations in daily work.

One company visited by the author had achieved a dramatic improvement in safety through general improvement in engineering and planning processes, the implementation of STOP-method, and other safety measures. In a period of five years, the OSHA recordable accident rate was reduced by 94 %, and the lost time accident rate by 84 %.

Another company had also achieved a steady decrease in safety rates and costs mainly through systematic safety management and planning (including the STOP-method), and refined work planning methods.

Thus, it seems that major improvements of construction safety can be achieved through a three-pointed effort:

- improving engineering and construction planning processes to ensure safe, predictable work flow on site
- improving safety management and planning processes themselves to systematically consider hazards and their countermeasures
- instituting procedures which aim at minimizing unsafe acts.

Earlier approaches often viewed safety as a separate subject, which could be improved in isolation from other issues in construction. However, safety depends on the nature of material and work flows (and design and planning processes which support them), and must be continuously maintained and improved as an aspect of those processes.

6.3.3 Computer integrated construction

It was argued earlier that a neglect of process improvement has turned into a barrier to integration. As the previous analysis has shown, there are many different problems and corresponding solutions in construction. The concept of (technical) integration as general facilitation of information transfer by means of standardized data structures, to be implemented over a long time period, is unfocused and long term oriented in comparison to the immediate needs of the construction industry.

It has to be noted that technical integration provides only the infrastructure and potential for integration. Technical integration does not help much if the processes are otherwise not of high quality (errors, omissions, wait and inspection times, changes due to poor requirement analysis, long feedback cycles); probably it just adds to mess and complexity. This has been put succinctly with regard to CIM (Computer Integrated Manufacturing): “CIM acts as a magnifying glass. It makes the good system much better; it makes the poor system much worse” (Melnik & Narasimhan 1992).

This analysis suggests that computer integration should not be a primary goal, but rather a means among others for attaining process improvement goals. The need for process improvement is often urgent and should be initiated with the means readily available (simultaneous engineering, work process definition and improvement, team approach, vendor quality programs) whereas many solutions for computer integration seem to take a longer time period to mature.

On the other hand, computerized systems often provide unique and superior solutions for process improvement (e.g. systematizing and error-proofing activities); however, without a drive for process improvement, such applications have often diffused slowly. The following are examples of this kind of solution:

- The transparency of a process may be augmented by computer visualization and simulation.
- Knowledge-based systems may be used for systematizing and standardizing operations and as error-proofing devices.

- Knowledge-based systems may be used for providing simplification advice (constructability).

Integration is thus not an intrinsic goal, but should rather be motivated by specific improvement needs of the construction process. Neither is CIC a construction theory; it cannot substitute for the substantial theories of production processes.

Thus, we should clarify the roles of process improvement and information technology (IT): process improvement is the primary phenomenon, which can be supported by information technology. More specifically, information technology may benefit process improvement in two ways:

1. Information technology may be used for automating specific conversions and subflows, leading to variability reduction, shortened cycle times, added transparency and other benefits.
2. Information technology may allow for process redesign, leading to radical process simplification.

In both cases, IT solutions should be tightly intertwined with and preceded⁵ by organizational and other forms of process improvement⁶. Isolated process redesign through computerization, without a preceding culture of process improvement, is risky and difficult.

This fully conforms to the experiences gained in manufacturing in relation to CIM. The current guidelines heavily stress process improvement before automation (Table 5).

Table 5. Implementation steps for CIM systems (based on current practices of leading CIM users) (Melnyk & Narasimhan 1992).

1.	Focus: Manufacturing objectives derived from corporate objectives and strategy
2 a.	Simplification: Elimination of non value-adding activities or bottlenecks.
2 b.	Integration: Introduction and management of coordination and cooperation between activities and groups.
3.	Automation: Application of well-defined computer aided procedures to physical or information flows.

In the new approach, the integrated construction engineering process could be defined as follows: A process of well defined design subprocesses which cross over specialist functions and temporal phases in order to shorten iteration cycles and the whole design cycle and to move from local optima towards the global optimum.

⁵ Of course, this should not be taken categorically; in many tasks computers are used routinely, and process improvement and computerization can proceed in parallel.

⁶ This view is supported by a current CIFE study on the impact of integration on plant quality. The results, even if still subject to final evaluation, strongly indicate that organizational integration had a considerably larger positive impact on plant quality than technical integration in the projects studied.

Characteristic features of integrated construction engineering are the following (of course these are goals for process improvement in general):

- systematic, upfront requirements analysis
- explicit stagewise refinement of specifications
- maximizing the number of iterations
- assuring that no omissions and errors flow downstream
- minimizing non value-adding engineering activities.

6.3.4 Construction automation⁷

In contrast to computer integrated construction, where at least partial implementation has already occurred, construction automation is primarily a research and development theme in most countries. The primary question asked has been: To which construction tasks can robotics be applied? Answers to this question have been searched for in feasibility studies and construction robot prototypes.

How should we analyze construction automation from the point of view of the new production philosophy? Let us illuminate the relations between process improvement and automation in construction by means of the framework presented originally by Béranger (1987) in the context of manufacturing (Figure 8). Based on the principles for process design and improvement, the following statements will be elaborated and justified below:

- automation should be focused on value-adding activities (reduce non value-adding activities)
- process improvement should precede automation (balance flow improvement with conversion improvement)
- continuous improvement should be present in all stages (build continuous improvement into the process).

Automation should be primarily focused on value-adding activities

It is usually more effective to eliminate or reduce non value-adding activities than to automate them. If elimination is not possible, these activities should be automated with simple and inexpensive technology. However, it is usually not worthwhile to automate them with high technology, because a competitor might find the means to eliminate those activities. Thus, the automation efforts should be directed to value-adding activities.

Process improvement should precede automation

There are several specific arguments for focusing on process improvement before automation (Béranger 1987):

- simplified, streamlined and stable material and work flow contributes to the reliability of automated systems: automation hardware already has in itself a relatively high frequency of breakdowns;
- multi-skilled personnel are needed during the automation stage: the development of such personnel can be started during process improvement;
- process improvement and simplification decreases the difficulty and costs of automation and thus increases the profitability of automation; and
- process improvement can be started immediately with little cost, whereas automation can be a long, and expensive project.

⁷ The discussion is based on (Koskela 1992).

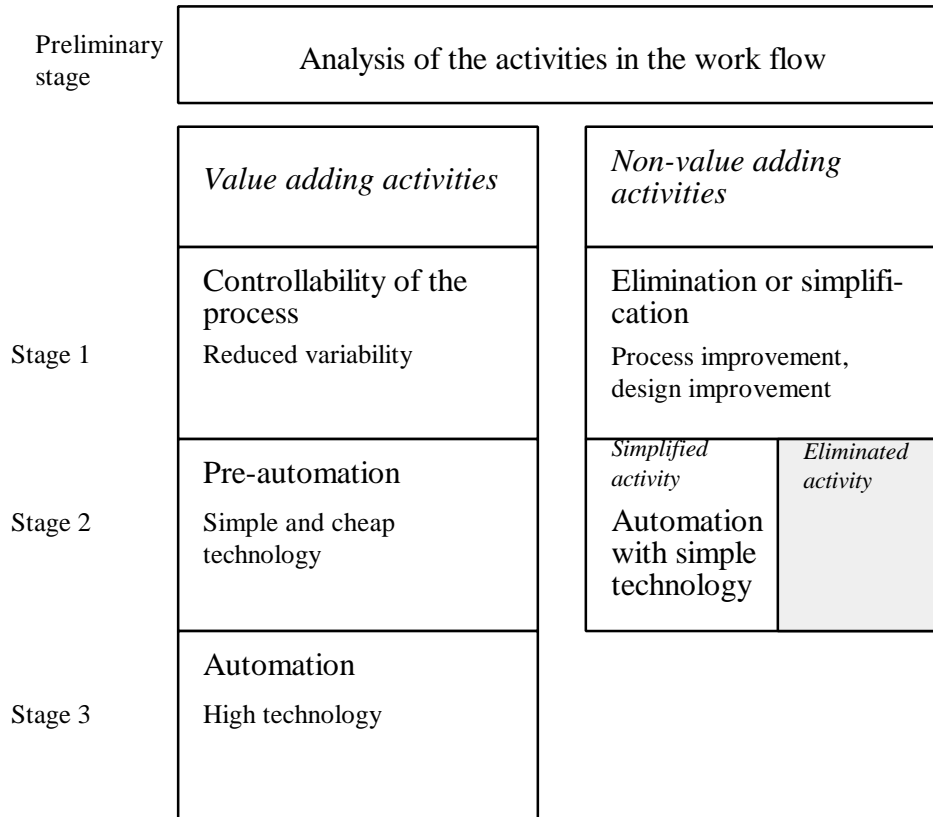


Figure 8. Stagewise development of a production process towards automation (modified from (Béranger 1987)).

Thus, on the way towards automation, the first stage is to enhance the controllability of the process through variability reduction and to suppress non value-adding activities through design and process modifications.

The second stage consists of automating with simple and inexpensive technology. Often the existing machinery is augmented by means of simple mechanical or mechatronic devices, which allow for autonomous operation of the machinery for some period or reduce human activities in the work process.

Only in the third stage, after an accumulation of understanding and process efficiency, will automation with high technology be justified as the next step towards cost reduction.

Continuous improvement should be present in all stages

The role of continuous improvement is significant especially at the stage of enhancement of the controllability of the process and in pre-automation. But also at all stages of automation, the efficiency and yield can be increased by continuous improvement. Thus the overall conclusion is that both the implementation as well as the development of robotics have to be embedded in a process of continuous improvement.

The argumentation presented above, though built upon manufacturing experience, is also generally valid for building construction automation. Due to insufficient attention to

process improvement, processes in construction, in general, are not well controlled. As a consequence of this, the share of waste is considerable in construction. In most construction activity flows, it is more profitable to initiate process improvement activities than to automate parts of the present activity flow. On the other hand, a simplification of the respective activity flow, often a result of process improvement, decreases the investment needs for automation and thus increases its profitability. Process improvement is both economically and technologically a precondition for automation in construction.

Of course there are cases, especially in heavy civil engineering, where operations already are highly mechanized or automation is necessary for safety reasons. Automation with high technology may be the right goal in these cases.

In practice, the need for process improvement has not often been clearly recognized, and consequently there is a twofold attitude to construction automation. A somewhat misplaced optimism is shown especially by researchers⁸, who do not always see the necessity of getting construction under control as the first step towards automation. On the other side, the construction industry views automation with great doubts, because it is well aware of the out of control situation. However, the industry does not usually perceive any remedy for smoothing the way for automation.

Therefore, construction automation research should also investigate the stages preceding automation (i.e. all items in Figure 8). Rather than solely trying to promote technological solutions, attention should also be directed to the development of design principles of construction tools and machines and related material work flows in general. Another necessary role for R&D is to support practical efforts towards enhanced process controllability, suppression of non value-adding activities, and pre-automation with simple technology. The trend will surely be towards construction automation, but in the form of incremental development, rather than through a long leap.

6.4 Research and education in construction

6.4.1 Obsolete conceptual basis

Current academic research and teaching in construction engineering and management lies on an obsolete conceptual and intellectual basis. This situation is shared by many related fields from which construction management has drawn theories, methods and techniques: industrial engineering, accounting, organization theory, and management strategy theory.

As mentioned earlier, the new production philosophy has evolved as an engineering based methodology, and theory formation has been lagging behind actual practice. The new philosophy's critique of established theories has been implicit and it has come from a surprising direction. Not unexpectedly, the response of academic researchers and educators has been slow and skeptical.

However, in some fields this paradigm shift is already clearly underway. In industrial engineering, tens of books on the new paradigm have already been written, some of them textbooks (Black 1991), and corresponding material is increasingly used in curricula. It is not an exaggeration to say that all books have to be written anew, and all old truths have to be reconsidered. Accounting provides another example.

⁸ Including the present writer, before his conversion to flow thinking!

As for construction management and engineering, there is yet hardly any sign of a paradigm shift. However, this field can avoid addressing the same fundamental questions with which the neighboring fields are currently struggling.

The lagging response of academic research and teaching seriously hamper the introduction of the new philosophy in construction. In consequence, theoretical understanding of the new approach does not accumulate; however, such understanding is sorely needed for making the new approach teachable and researchable.

Thus, it is urgent that academic research and education address the challenges posed by the new philosophy. Otherwise, a decreased relevance of academic research will be the outcome.

6.4.2 Lacking foundations of construction management

It was argued earlier, in section 4.1, that our empirical knowledge and theoretical understanding of construction is shallow and fragmented. We know little of what is happening in construction projects; only in the last few years has the extent of quality deviations and costs, for example, been subjected to direct analysis. However, quality costs are only the tip of the iceberg of all non value-adding costs. Construction related theories, or sound action principles based on them, are scarce.

It seems that the distribution of the present research efforts in construction is not balanced. The great majority of long term research undertakings aim at applying new tools from other technological fields, like information technology, artificial intelligence and robotics, to construction tasks, whereas the conceptual and theoretical foundations of construction get rather modest attention. However, as argued earlier, major payoffs could be realized through developing these foundations.

It is not an exaggeration to say that the new conceptualization opens a practically new research frontier. As stated earlier, the development of the new production philosophy has been based on individual vision and pragmatic, shop-floor experiments rather than breakthroughs in the theory. The practical validity of the philosophy has been proved in real life implementations. Thus, rigorous validation and explanation of these principles and methods should be included in the research agenda. Examples of new research themes raised by the new conceptualization include the following:

- concepts and taxonomies for defining design and construction processes
- flow oriented site production planning and control tools
- measures for construction processes
- new non-hierarchical organization forms for site work
- procurement methods which advance process improvement.

6.4.3 Formalization of the foundations

However, increased knowledge of foundations is not sufficient; the foundations have to be formalized. In manufacturing science, this has been suggested by several authors. The Committee on Foundations of Manufacturing states that there is a need for an explicit core set of principles, on the basis of which the manufacturing process, as a totality, could be analyzed, designed, managed and improved (Heim & Compton 1992). Burbidge (1990) urges that hypotheses be formulated that could be subjected to rigorous testing, with a view to their acceptance or rejection. The trend towards formalized paradigms is further supported by developments in artificial intelligence. In model based reasoning, a model, heuristics, etc. are formalized for the subject considered.

The endeavor of Plossl (1991) gives a good example of a formalized foundation. He defines a basic law of manufacturing with four clarifying corollaries (section 2.3). He further presents 30 fundamental principles of manufacturing and 10 strategies for applying them. Another interesting approach promoting axiomatic principles for design is presented by Suh (1990).

These arguments in favor of increased formalization are also directly valid for construction engineering and management.

6.5 Conclusions

The attitude to the new production philosophy in construction provides for a paradox: It contains a promise of tremendous possibilities for improvement and of a solution of the chronic problems of construction; however, the interest of both practitioners and academicians has been at best lukewarm.

All in all, the example of manufacturing and pioneering companies in construction show that there is a body of principles, methods and techniques, which are worthwhile to be understand and adopt in construction. They make up a paradigm shift, that will be a long transformation process of both practice and theory of construction engineering and management. The momentum of this paradigm shift has only started to gather. This situation provides opportunities for early adopters to gain competitive benefits.

7 Summary

A new production philosophy has emerged, with origins tracing back to development and experiments of the JIT production system and quality control in Japan in the 1950's. Now the new production philosophy, regardless of what term is used to name it (world class manufacturing, lean production, new production system, JIT/TQC, time based competition), is the emerging mainstream approach practiced, at least partially, by major manufacturing companies in America and Europe. The new philosophy already has had 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 has been 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 theoretical and conceptual understanding of the new production philosophy is still incomplete.

The core of the new production philosophy is in the observation that there are two kinds of phenomena 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 flow activities 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. This has led to complex, uncertain and confused flow processes, expansion of non value-adding activities, and reduction of output value.

A number of principles for flow process design and improvement have evolved. There is ample evidence that through these principles, the efficiency of flow processes can be considerably and rapidly improved:

1. Reduce the share of non value-adding activities.
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.

Analysis shows that, as in manufacturing, the conceptual basis of construction engineering and management is conversion oriented. 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. As a consequence, there is considerable waste in construction. The problems tend to compound and self-perpetuate.

In project control, firefighting current or looming crises consumes management resources and attention so totally that there is little room for planning, let alone improvement activities. However, because conventional measures do not address it, this waste is invisible in total terms, and is considered to be inactionable. Improvement efforts, like industrialization and computer integrated construction, have often been hampered by their neglect of flow aspects.

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) and output value. For improving these flows, it is a prerequisite that new managerial methods, conducive to flow improvement, are introduced. On the other hand, such construction peculiarities as the one-of-a-kind nature of projects, site production and temporary project organizations 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. Certainly it is a core issue to understand these peculiarities and to be able to avoid or alleviate their detrimental effects.

In the construction industry, attention to the new production philosophy has grown slowly. 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. All in all, the overall diffusion of the new philosophy in construction seems to be rather limited and its applications incomplete.

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. In practice, every organization in construction already can initially apply 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.

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. A new set of measures will be used to pinpoint improvement potential and to monitor progress in performance. Existing development efforts like industrialized construction, computer integrated construction and construction automation will be redefined in order to acknowledge the needs for flow improvement. New organizational solutions for construction projects will be introduced to facilitate flow improvement as well as innovation.

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.

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