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Flow process analysis in construction

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Abstract

It is argued that the flow process analysis essentially provides two new options for improvement of production: elimination or reduction of non value adding activities (also called waste) in flow processes and increase of output value from the customer point of view. The typical categories of waste and value loss in a construction project are analyzed in this framework, and the corresponding improvement or redesign prescriptions for construction flow processes are determined.

1. INTRODUCTION

It has been argued earlier by the authors that flow processes should be the unit of analysis in construction, and that this new conceptual framework leads to profound changes in both theory and practice (Koskela 1992a).

In order to start the application of flow process analysis in construction, we have to be able to highlight - on a generic level - the basic steps and features of such an analysis. In this paper, we endeavour

- to summarize the essential features of flow process analysis
- to identify the main flow processes in a construction project and their interactions
- to analyze the typical categories of inefficiencies in construction flow processes
- to determine the improvement/redesign prescription for construction flow processes implied by the analysis.

2. FLOW PROCESS ANALYSIS

2.1 Flow processes as unit of analysis

Process orientation, with slightly varying emphasis, has recently been advocated by several new approaches, like JIT, TQM, time based management, process re-engineering, and lean production. In the following, we present a simplified, generic model of flow process analysis.

The flow process view combines three different views of production and operations:

- material or information is converted (traditional view)
- material or information flows (Just-in-Time view)
- value is generated through fulfillment of customer requirements (quality view).

Thus, production is seen as flow processes, which are composed of

- conversion activities
- flow activities: moving, waiting and inspection
- customers, for which value is generated.

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The intrinsic flow process goals are to decrease process cost and duration and to increase value for the customers. 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. In opposition to cost and duration, it is difficult, often impossible to measure the absolute value. However, for practical application, measuring the relative value often suffices; for example the value loss in relation to the best practice value or theoretically best value.

An important distinction is based on the insight that not all activities generate value. In flow processes, we distinguish value-adding and non value-adding activities :

- 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.

Note that conversion activities are usually value adding, but not all. Similarly, flow activities are usually, but not always, non value adding.

The improvement of non value adding activities should be focused on their reduction or elimination, whereas value adding activities have to be made more efficient.

Now, the rationale of flow process analysis may be presented as in Figure 1. We have three options for improving production:

- Reducing the costs (and duration) of value adding activities through increased efficiency.
- Reducing the costs (and duration) of non value adding activities (waste), through elimination of these activities.
- Reducing the value loss.

The potential of flow process analysis is embodied in the two latter options; the first one has been customarily used.

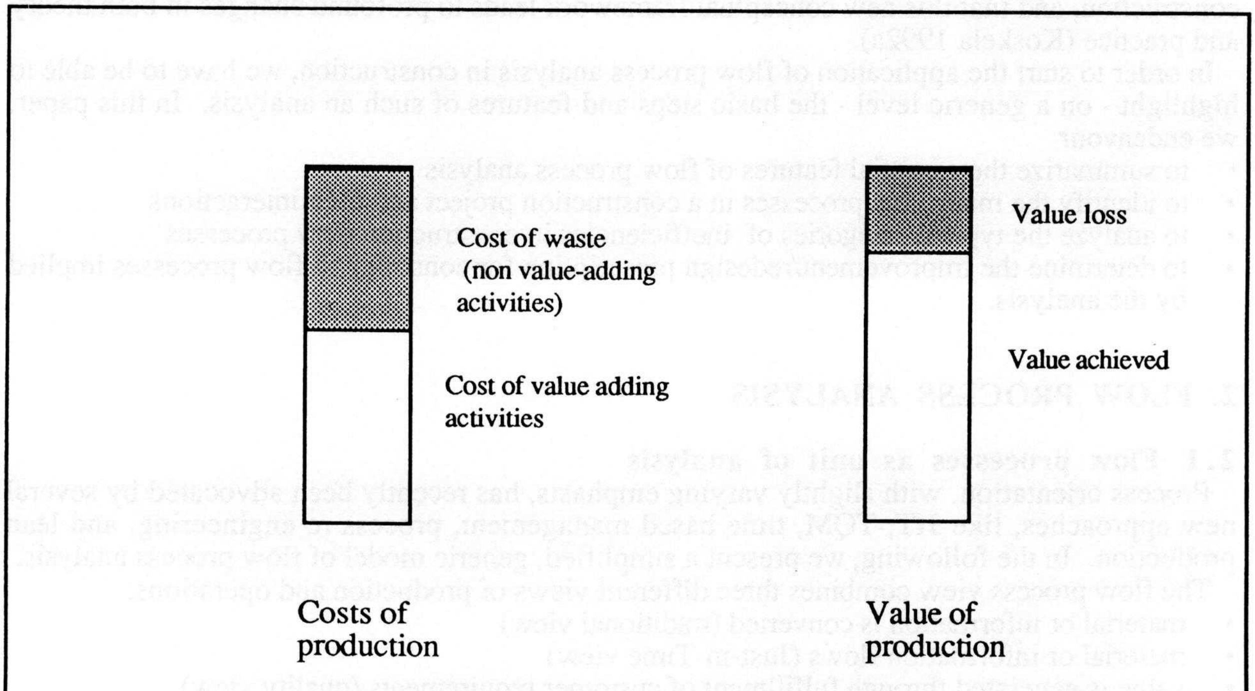

Figure 1. In a flow process analysis of production, the emphasis is on reducing waste and value loss (in relation to best practice value or theoretically best value).

2.2. Causes for waste and value loss

What causes waste and loss of value in the first place? For waste, there seems to be three root causes: design, ignorance and nature.

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 emerge: 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, which may be unnecessarily complicated. The volume of non value-adding activities is not measured and known, so there is no drive to curb them.

It is in the nature of production that non value-adding activities exist. Processes are variable: errors are made, machines break down.

However, with respect to all three causes for non value-adding activities, it is possible to eliminate or reduce the amount of these activities:

- The processes and the organization may be redesigned so that waste is minimized.
- Waste may be measured and controlled.
- Variability can generally be reduced by various means.

For loss of value, the causes seem to be rather similar. Especially, the traditional organizational design leads to a situation where cost minimization of each activity is emphasized rather than customer requirements. Again, redesign can be used to rectify the situation.

2.3. Principles and practice of flow process analysis

A number of principles exist for controlling, designing and improving flow processes (Koskela 1992a). Some of the most fundamental are as follows:

- Increase output value through systematic consideration of customer requirements.
- Eliminate non value-adding activities.

Among the more operational principles, the following are very important:

- Reduce variability. Output variability increases the amount of non value adding activities in subsequent phases of production; also for the customer, a uniform product is better.
- Reduce cycle times. This forces the reduction of inspection, wait and move time, which most often dominate in cycle times.

In practice, flow process analysis proceeds through identification of major macro-processes, like order delivery, product development, manufacturing. These are further divided into micro-processes, which can be analyzed separately. The processes are then charted and measured: especially the waste (rework, material waste, accident costs, idle time due to waiting etc.) and value loss should be analyzed and their causes investigated. Improvement goals are stated and corresponding action is planned, based on relevant principles and aiming at a redesigned process or continuous improvement of the existing process.

2.4 Why does the conventional approach fail?

The conventional approach has basicly divided production into parts, and maximized the efficiency or minimized the costs of these parts. However, the more aggressively the cost of each individual activity is controlled, the less is focused on the impact of this activity on other activities. Thus, loss of customer value is generated, equalling waste in subsequent activities. On the other hand, there have been no conceptual means to recognize the internal waste in each activity and the need to eliminate it. *Thus, the conventional approach has not only failed to recognize waste, but rather it has actively increased it.*

3. FLOW PROCESS ANALYSIS OF CONSTRUCTION PROJECTS

3.1. Flow processes in a construction project

There are two main processes in a construction project, which directly generate value for the client: design process and construction process.

The design process is - in a conversion sense - a stagewise refinement of specifications 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 and iterative improvement of the design solution. In a flow sense, design process is the flow of information between different stages and participants. In a value sense, design can be understood as the capture and the conversion of the client requirements to a design solution providing the best performance.

The construction process is composed of the material flows to the site, including fabrication in factory and processing and assembling on site. Partly overlapping with material flows, there are work processes (temporal and spatial flows) of construction teams and machinery on site. In a value sense, construction can be understood as the provision of the building as specified in the framework of time and cost targets. As a supporting process there is a 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.

In practice, these processes have to be further divided into individual subprocesses and their supporting processes.

3.2. Waste and value loss

Let us consider design and construction from the point of view of waste and value loss. For the sake of simplicity, waste will be measured by cost; time (duration) could be analyzed in a similar manner.

The formation of waste and value loss in a construction project is analyzed in Table 1 and in Figure 2.

Note that value loss leads to waste in subsequent processes: in this case value loss of design from the point of view of construction. Thus, the total cost and duration is impacted by the value generated to internal customers.

Also it is worthwhile to note the difference between design and construction. The primary focus in design is on minimizing value loss, whereas in construction it is on minimizing waste.

Beyond a certain point, the waste inherent in the construction process becomes self-perpetuating, due complicated interaction between various subprocesses. The many disturbances lessen the motivation for orderly planning of the construction process, which further causes wastes. The whole project becomes unpredictable.

The significance of this analysis is due to the fact that especially the share of waste is usually quite high; also the loss of value (compared to best practice) is often considerable (for initial evidence, see Koskela 1992a).

Thus, the reduction of waste and value loss in construction projects, leading to *lean construction*, is a very attractive improvement option in itself, providing often a larger potential than technological improvement alternatives. On the other hand, there are indirect benefits: better controlled processes facilitate the development and the introduction of new technology (for wider argument, see Koskela 1992b).

Table 1. Waste and value loss in main flow processes of a construction project.

Process	*Waste (adding to cost and time)*	*Value loss*
Design	Rework (due to design errors, omissions or brief deficiencies detected during design) Non value-adding activities in information and work flows, such as waiting for instructions, approval etc.	Value loss from the point of view of the client is determined by - how well the implicit and explicit requirements have been captured and converted into a design solution - the level of optimization and synergy achieved - the impact of design errors that are discovered during start-up and use. Value loss from the point of view of the construction process (internal customer) 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
Construction	Rework due to design or construction errors,variations etc. Non value-adding activities in the material and work flows, such as waiting, moving, inspecting, duplicated activities, accidents, and material wastage	Value loss from the point of view of the client is determined by - the impact of defects discovered during start-up and use - impact of a failure to reach cost and time targets

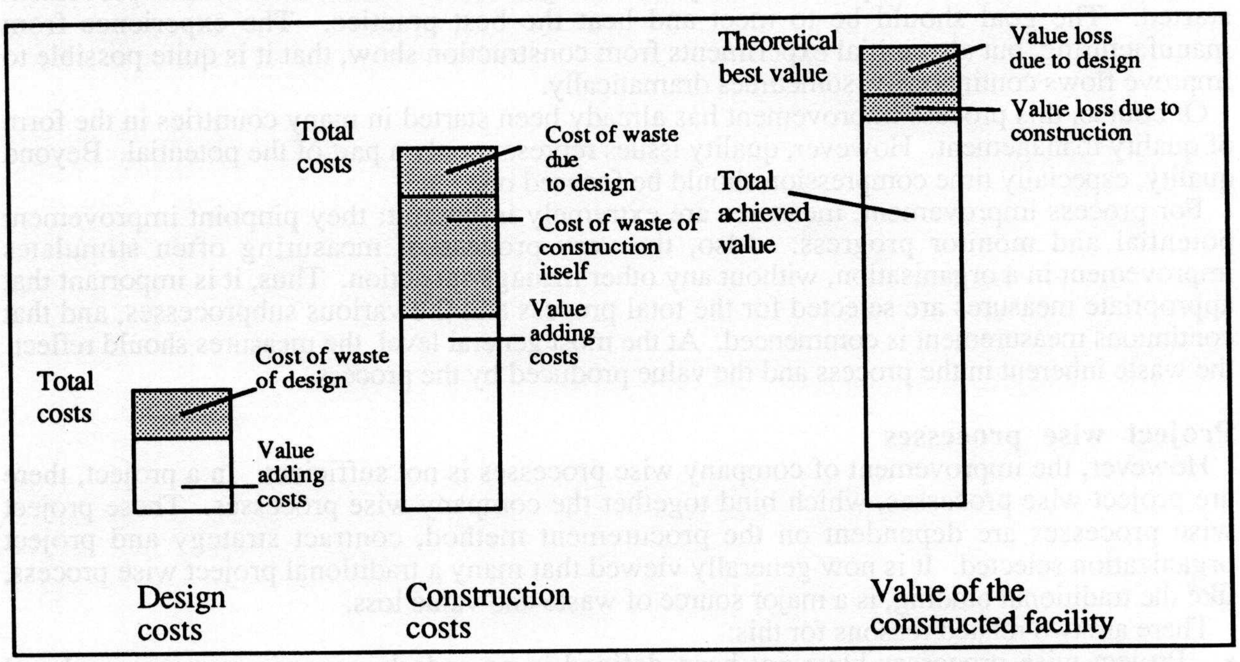

Figure 2. Formation of waste and value loss in a construction project.

3.3. Improvement of flow processes in construction

On basis of the well known types of waste and value loss in a construction project, it is possible to derive generic flow process improvement needs. In the design process, there seems to be four generic needs for improvement:

- The client requirement analysis has to be carried out more systematically up-front, in order to decrease the detrimental impact of variations in later phases.
- There has to be more design iterations (for improving the initial design, rather than correcting errors), and they have to be implemented as early as possible.
- The requirements of construction, regarding both constructability and documentation, have to be emphasised more.
- There should be less errors in the output of design.

As for the construction process, a considerable part of improvement will already flow from improved design, as stated above. Inside the construction process, there are following generic improvement needs:

- The work processes have to be developed to be error-free, predictable and productive.
- The material flows have to be developed to decrease wastage and multiple handling.
- The construction planning procedures have to be developed for the sake of better support for work processes and material flows.

These improvement needs require action on four frontiers: improvement of company wise processes, improvement of project wise processes, product development, and development of related techniques and methods.

Company wise processes

The most immediate and also competitively attracting area is the improvement of present processes across the organizations of the industry: design offices, contractors, subcontractors, material manufacturers and suppliers etc. It is often advisable to extend this effort, beyond the internal processes, to more permanent interorganizational processes, especially the supply chain.

Thus, key processes should be identified, waste and value loss assessed and their causes analyzed. On basis of this, processes may be redesigned and/or their continuous improvement started. The goal should be to meet and beat the best practice. The experience from manufacturing, but also initial experiments from construction show, that it is quite possible to improve flows continuously, sometimes dramatically.

Of course, this process improvement has already been started in many countries in the form of quality management. However, quality issues represent only a part of the potential. Beyond quality, especially time compression should be focused on.

For process improvement, measures are extremely important: they pinpoint improvement potential and monitor progress. Also, the very process of measuring often stimulates improvement in a organisation, without any other managerial action. Thus, it is important that appropriate measures are selected for the total process and the various subprocesses, and that continuous measurement is commenced. At the most general level, the measures should reflect the waste inherent in the process and the value produced by the process.

Project wise processes

However, the improvement of company wise processes is not sufficient. In a project, there are project wise processes, which bind together the company wise processes. These project wise processes are dependent on the procurement method, contract strategy and project organization selected. It is now generally viewed that many a traditional project wise process, like the traditional bidding, is a major source of waste and value loss.

There are two related reasons for this:

- Project wise processes have not been defined in an orderly manner, nor managed and measured.
- The principles of flow process design are violated, for example by fragmenting processes.

Correspondingly, there are two possible solutions:

- Project wise processes may be defined better, for example, by means of a Project Quality Plan, and they can be managed better, by means of construction management professionals.
- New organizational forms, which are in line with processes, may be defined and tried out.

Note that a radical redesign of project wise processes often requires changes in the business structure of the industry.

Product development

Another option for construction process improvement is related to intermediate and final products of construction. Complicated and error-prone material flows and work processes may be caused by a particular design of intermediate products (like windows, prefabricated structural components etc.) or by on site construction techniques. In these cases, the redesign of a product so that the entire flow from manufacturing to site installation is simplified, is appropriate.

Also it is possible to develop the whole building as a product. Of course this is obvious in the case of (prefabricated) system building. But as well for other types of building, it may be possible to create concept buildings, that is pre-engineered solutions, which reduce design effort and provide benefits of learning and continuous improvement. Pre-engineered, standardized solutions may also be developed for parts of the building.

Methods, techniques and tools

Finally, new methods, techniques and tools which support flow oriented analysis have to be adopted and developed. These include, for example,

- concurrent engineering
- methods for measuring waste and value loss
- systematized requirement analysis
- quality function deployment techniques
- systematized constructability analysis.

Last, but not least, we have to mention the potential of information technology based tools and solutions. Product data models, simulation, visualization, computer based co-operation and many other computer aided tools can be used to improve and redesign flows in construction.

3.4. What can a client do?

Process improvement usually requires a timeframe which extends beyond a lifetime of a construction project. For the project, flow processes from different companies are combined, often only for one run. What can a client do to ensure the success of his present project?

From the viewpoint of a particular one-of-a-kind project, the goal is to attain the level of cost, duration and value of the best existing practice. Consequently, it is important to

- select a procurement method which demonstrably supports process control and improvement; the achievement of high quality outcomes may be ensured through incentives
- assure the process capability (as demonstrated by continuous improvement in regard of waste and value) of design practices and contracting companies to be selected for the project
- require the use of specific tools and methods which suit the particular project's needs regarding process control and improvement.

4. CONCLUSIONS

The flow process analysis, even in its rudimentary form, illuminates thus such mechanisms in construction, which have hitherto been ill understood and defied intuition. It also provides a basis for action.

One conclusion to be drawn from the preceding discussion is that the scientific foundations of construction have been lacking or deficient, at best. Construction has been poorly understood theoretically. In lack of theory, also empirical investigations have failed to produce clarifying insights. And lastly, due to deficient understanding and misplaced concepts, many a development effort in construction has been ill conceived and therefore not effective. The concepts of the flow process analysis provide one building block to new scientific foundations of construction.

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 understood and adopted 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.

We feel that the benefits of these new foundations can be best captured through initiatives on three levels:

- The present best practices of the flow process analysis and lean construction have to be diffused and implemented among the industry, and the clients should, in their own interest, actively promote them.
- Tools and methods for supporting lean construction should be further developed (for interesting initial work, see (Ballard 1993), (Cooper 1993) and (Howell & al. 1993)). Especially, information and automation systems should be developed to advance process improvement, rather than for their own sake.
- The scientific foundations of construction should be developed.

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