

WE NEED A THEORY OF CONSTRUCTION

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INTRODUCTION

The guidelines for White Papers for Berkeley-Stanford CE&M workshop suggest deriving research needs from the practical needs of the industry. Generally, this is a sound approach. However, I would like to propose that at this particular moment, thinking in the opposite direction is as, or even more important. *My vision is that during the next decade, the formation of a theory of construction will be the single most important force influencing the construction industry.* Such a theory of construction will consist of two parts, firstly a theory of production in general and secondly the application of this theory to the characteristics of construction. Presently, there is no commonly accepted theory of production (Heim & Compton 1992). However, I argue that the various existing theoretical strands can be integrated into a useful theoretical framework, which will give direction for further clarification and experimentation and which is applicable also to construction. In the following, this vision is grounded in more detail.

WHAT IS A THEORY OF PRODUCTION?

Let us first clarify the basic issues. What do we do with a theory of production? What do we require from it?

An explicit theory of production will serve various functions. A theory provides an *explanation* of observed behavior, and contributes thus to understanding. A theory provides a *prediction* of future behavior. On the basis of the theory, *tools* for analyzing, designing and controlling can be built. A theory, when shared, provides a *common language* or framework, through which the co-operation of people in collective undertakings, like project, firm, etc., is facilitated and enabled. A theory gives *direction* in pinpointing the sources of further progress. A theory can be seen as a condensed piece of knowledge: it empowers novices to do the things that formerly only experts could do. It is thus instrumental in *learning*. When explicit, it is possible to constantly *test* the theory in view of its validity. Innovative practices can be *transferred* to other settings by first abstracting a theory from that practice and then applying it in target conditions.

The primary characteristic of a theory of production is that it should be prescriptive: it should reveal how *action* contributes to the *goals* set to production. On the most general level, there are three possible actions: design of the production system; control of the production system in order to realize the production intended; improvement of the production system. Production has three kinds of goal. Firstly, the goal of getting intended products produced in general (this may seem so self-evident that it is often not explicitly mentioned). Secondly, there are goals related to the characteristics of the production itself, such as cost minimization and level of utilization (internal goals). Thirdly, there are goals related to the needs of the customer, like quality, dependability, flexibility (external goals). Furthermore, the theory of production should cover all essential areas of production, especially production proper and product design.

From the point of view of practice of production management, the significance of the theory is crucial: the application of the theory should lead to improved performance. In reverse, the lack of the application of the theory should result in inferior performance. Here is the power and significance of a theory from a practical point of view: it provides an *ultimate benchmark for practice*.

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WHAT DO WE HAVE REGARDING THEORIES OF PRODUCTION?

What scientists have forwarded as theories and what theories have actually used in practice? Throughout this century, the transformation view of production has been dominant. In the transformation view, production is conceptualized as a transformation of inputs to outputs. There are a number of principles, by means of which production is managed. These principles suggest, for example, decomposing the total transformation hierarchically into smaller transformations, tasks, and minimizing the cost of each task independently. The conventional template of production has been based on it, as well as the doctrine of operations management. The transformation view has its intellectual origins in economics, where it has remained unchallenged up to this day. The popular value chain theory, proposed by Porter (1985), is one approach embodying the transformation view. A production theory based directly on the original view on production in economics has been proposed by a group of scholars led by Wortmann (1992).

However, this foundation of production is an idealization, and in complex production settings the associated idealization error becomes unacceptably large. There are two main deficiencies: it is not recognized that there are also other phenomena in production than transformations; it is not recognized that it is not the transformation itself that makes the output valuable, but that the output conforms with the customer's requirements. The transformation view is instrumental in discovering which tasks are needed in a production undertaking and in getting them realized. However, the transformation view is not especially helpful in figuring out how not to use resources unnecessarily or how to ensure that the customer requirements are met in the best manner. Therefore, production, managed in the conventional method, tends to become inefficient and ineffective.

There has existed, already in the framework of early industrial engineering, another concept of production, namely the view of production as flow. The flow view of production, firstly proposed by the Gilbreths (1922) in scientific terms, has provided the basis for JIT and lean production. This view was firstly translated into practice by Ford; however, the template provided by Ford was in this regard misunderstood, and the flow view of production was further developed only from 1940'ies onwards in Japan, first as part of war production and then at Toyota. As a result, the flow view is embodied in lean production. In the flow view, the basic thrust is to eliminate waste from flow processes. Thus, such principles as lead time reduction, variability reduction and simplification are promoted. In a breakthrough book, Hopp and Spearman (1996) show that by means of the queueing theory, various insights, which have been used as heuristics in the framework of JIT, can be mathematically proven.

Still a third view on production has existed from the 1930'ies. In the value generation view, the basic thrust is to reach the best possible value from the point of the customer. The value generation view was initiated by Shewhart (1931) and further refined in the framework of the quality movement but also in other circles. Principles related to rigorous requirement analysis and systematized flowdown of requirements, for example, are forwarded. Cook (1997) has recently presented a synthesis of a production theory based on this view.

Thus, there are three major concepts of production, and each of them has induced practical methods, tools and production templates. Nevertheless, except a few isolated endeavors, these concepts – as candidate theories of production - have raised little interest in the discipline of operations management. As stated above, there has not been any explicit theory of production. The consequential problem is that *the important functions of a theory, as outlined, have neither from the viewpoint of research or practice been realized.*

INTEGRATION OF PARTIAL PRODUCTION THEORIES

It is argued that these three concepts of production are not alternative, competing theories of production, but rather partial and complementary. What is needed is a production theory and related tools that fully integrate the transformation, flow, and value concepts. As a first step towards this, we can conceptualize production simultaneously from these three points of view: transformation, flow and value. A number of first principles stemming from each view can be induced from practice or derived from theory. An overview of this integrated view, called the *TFV theory of production*, is presented in Table 1. However, the ultimate goal should be to create a unified conceptualization of production, instead of three partial conceptualizations.

Table 1. The TFV theory of production.

	<i>Transformation view</i>	<i>Flow view</i>	<i>Value generation view</i>
<i>Conceptualization of production</i>	As a transformation of inputs into outputs	As a flow of material, composed of transformation, inspection, moving and waiting	As a process where value for the customer is created through fulfillment of his requirements
<i>Main principle</i>	Getting production realized efficiently	Elimination of waste (non-value-adding activities)	Elimination of value loss (achieved value in relation to best possible value)
<i>Methods and practices</i>	Work breakdown structure, MRP, Organizational Responsibility Chart	Continuous flow, pull production control, continuous improvement	Methods for requirement capture, Quality Function Deployment
<i>Practical contribution</i>	Taking care of what has to be done	Taking care of that what is unnecessary is done as little as possible	Taking care of that customer requirements are met in the best possible manner
<i>Suggested name for practical application of the view</i>	Task management	Flow management	Value management

Thus the crucial contribution of the TFV theory of production is in extending attention to modeling, structuring, controlling and improving production from all these three points of view. *In production management, the management needs arising from the three views should be integrated and balanced.* Regarding practical management, let us call the domains of management corresponding to the three views as *task management, flow management and value management.*

There is nothing new regarding the constituents of the TFV theory of production; however, it is a new insight that there are three fundamental phenomena in production, which should be simultaneously managed.

APPLICATION TO CONSTRUCTION

In which way we are suffering from deficiencies of theory in construction? I think that there are three broad impacts. Firstly, the chronic performance problems can more or less directly be associated to problems of theory. Secondly, in lack of explicit theory, it has been difficult to implement methods of flow management and value management in construction. Thirdly, our efforts to develop construction, say through industrialization or information technology, have been hindered by the lack of a theory. Let us discuss these themes in turn.

The current practice in construction is based on the transformation view (in practice, the project management methods equal task management). However, as discussed above, in a complex production situation the idealization error associated to the transformation view may become large. This is exactly what happens in practice. Task management, based on the transformation view, assumes that certainty prevails in production. However, it is widely observed that, due to the inherent variability of production in construction, intended task management degenerates into mutual adjustment by teams on site. Indeed, a case study and the results of prior research on contemporary construction show that there are endemic management problems associated with both client decision-making, design management and construction management (Koskela, forthcoming). An interpretation based on the TFV theory reveals that a significant part of these problems are self-inflicted, caused by the prevailing, limited view on production. *Thus, it is not problems of implementation, but the present doctrine itself that is the cause of performance problems.*

Why has the diffusion of, say, lean production, been so slow in construction? The present practice of lean production, having been developed in car manufacturing, can as such only partially be applied to construction. Construction is characterized by such peculiarities as one-of-a-kind production, site production and temporary project organizations. The application of lean production should start from first principles, on the basis of which methods suitable for the peculiarities of construction have to be developed. However, in lack of explicit principles, this has progressed slowly. Analysis of industrial cases shows that it is advantageous to eliminate

these peculiarities, because they add to waste and/or value loss (Koskela, forthcoming). However, even if their elimination is not possible, the TFV production principles can be effectively applied for control and improvement to mitigate the effects of peculiarities. Site production is a good example: it is possible either to eliminate site work through prefabrication or to decrease the interference between various activities through new innovative production control methods, like the Last Planner, to be treated below.

Why various development initiatives, like industrialization, use of information technology in construction, or construction automation, have often failed to produce the results intended? Again, I would claim that the fundamental problem is theoretical. Such initiatives have been based on ideas associated to the transformation view on production, like mechanization for substituting for human labor. However, resultant new production systems have often been more complex, variable and vulnerable in comparison to their predecessors. Thus principles of flow management have been violated, and the increase in total performance will have been little, if any. Indeed, several scholars of construction have pointed out the lack of theoretical foundations in construction as a barrier for progress. Halpin (1994) claims that “we have not gone far enough in seeking a basic framework for the construction of facilities”. Fenves (1996) calls for a science base of application of information technologies in civil and structural engineering. One component of this science base would deal with the understanding of the processes of planning, design, management, etc. that engineers use.

THE WAY FORWARD

Thus, it is suggested that the TFV theory be taken as a foundation for construction. This implies that both task management, flow management and value management is carried out systematically and in mutual balance. Increasing evidence shows that this approach rapidly leads to new understanding and major performance improvement.

Let us take an example. Traditional task management assumes a certain production process. In practice, due to the inherent variability of production in construction, intended task management degenerates into mutual adjustment by the teams on site. However, by the various methods of flow management, the adverse impact of variability on tasks can be mitigated. In reverse, a tighter task management contributes to flow reliability. The method of Last Planner (Ballard & Howell 1998) turns out to combine central elements of task management and flow management for production control in construction (Koskela 1999). In practice, the implementation of the Last Planner has led to manifest performance improvement.

Thus, the joint task of industry and research is to develop construction-oriented new methods for realizing and integrating task, flow and value management as well as associated metrics for all phases of a construction project. The task of research is to create a specific theory of construction, founded on more general theories of production.

OVERVIEW ON PERSONAL INTERESTS

The author has researched this area since 1991. The first output was the report (Koskela 1992). In 1993, the author, together with Glenn Ballard, Luis Alarcón and others, founded the International Group for Lean Construction (IGLC), which has since then held annual conferences aiming at the application of new production models to construction both theoretically and practically. Current work of the author is focused especially on clarification of the production theory and its application to construction design management.

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