APPROACHES TO MANAGING COMPLEXITY IN PROJECT PRODUCTION

Sven Bertelsen[1] and Lauri Koskela[2]

ABSTRACT

Since the seminal contribution by Shewhart, the dominating approach to production is to minimize all variation in order to get the productive activities into control. Thus, the goal is to avoid all such complexity and uncertainty which could disturb this tight control. This approach is applied in lean production, which is considered to be the superior production template of today. It has to be noted that usually our concepts, for example "waste", are based on this understanding of production.

However, there are production situations with inherent complexity and unpredictability not least in project production. The primary goal of the paper is to chart and analyze the different approaches available for coping with these situations. Four different strategies are identified and discussed: reducing complexity, codifying procedures, learning to improvise and buffering.

A secondary goal of the paper is to discuss whether and how the conceptual framework in production management should be further developed for taking these different approaches to project complexity into account.

KEY WORDS

Complexity; Project production; Project management; Waste

INTRODUCTION

Since the seminal contribution by Shewhart (1931), the dominating approach to production management is to minimize all variation in order to get the productive activities into control. Thus, the goal is to avoid all such complexity and uncertainty which could disturb this tight control. This approach is applied in lean production, which with an outset in the Toyota Production System is considered to be a superior production template of today. In general it can be said that the underlying principles in lean production is to maximize the value delivered to the customer and minimize the waste associated with the delivery process (Womack and Jones, 1996). However, this opens the question of defining value and waste, where it may be argued that value is what the customer is willing to pay for[3] and waste is activity not contributing to the generation of this value—even if these concepts are debated (Koskela 2004).

It should be noted that our concepts of 'value' and 'waste' are most often based on the understanding of production as found in manufacturing even though production is not at all always manufacturing, but production undertaken in other settings, which may be completely different as it is often seen in construction.

The paper therefore sets out with a discussion of different kinds of production, particularly mass and project production, but also production seen by the nature of the product and the customer is touched upon. It then turns its focus on the complex world of project production and the uncertainty in different kinds of projects, which often makes it hard to define value and waste. The paper closes with a brief visit to recent work on new approaches to project management within con-

1 Roennebaervej 10, lejl. 108, DK 2840 Holte, Denmark. sven@bertelsen.org

2 The University of Salford, School of Construction & Property Management, Salford M7 1NU, United Kingdom. l.j.koskela@salford.ac.uk

3 The customer is normally willing to pay for the value she attaches to the product or service as long as the price asked for is lower.

struction as developed within the International Group for Lean Construction.

DIFFERENT KINDS OF PRODUCTION

Production is the creation of value through a process, which can be seen as a flow through a series of operations. On its way towards the customer the product passes through this process and meets all of its operations (Shingo, 1988; Koskela, 2000).

However, there exist different kinds of production: One distinction may be between Mass production (manufacturing) and Project Production (craft) as discussed by Ballard (2005) but also the nature of the product and the customer generate different types of production should be taken into consideration as separate dimensions as shown in figure 1.

In this perspective it may be argued that farming was the original form of mass production whereas most equipment were until the industrialization made as craft, that is near the right hand end of the cube. By the industrialization most manufacturing moved towards the mass production end and indeed close to the origo[4] whereas works of art and construction still were produced at the craft end, where art will probably stay forever.

It is a characteristic of enterprises in the project area that they often are complex and dynamic. Bertelsen (2003a and b) deals with this complexity within the construction process and the construction production system and Bertelsen and Emmitt (2005) look in the same way at the construction industry customer in the character of the client. These differences are dealt with in more detail in the following sections.

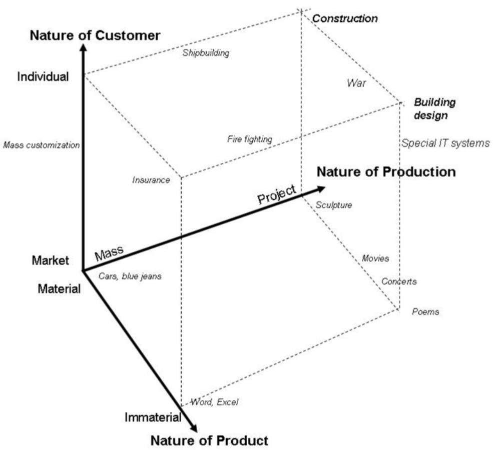

Figure 1: A three dimensional view on production. (The indicated examples are for illustration of the idea only)

MASS PRODUCTION

Mass production or manufacturing is a repetitive process drawing on a series of specialized and well defined operations in a predefined sequence. In undertaking this, the work stations meet a steady flow of products. This flow is defined by the design of the product and thus by the designed-in product value and – with the exception of parallel work stations – only one route through the production is valid for a given product. Not only the delivered value and thus the objective, but also the process is known in almost any detail ahead of start of the actual production.[5] The strategy is therefore to act locally as defined by the procedures for the production. Improvement in productivity takes place by either improving the value—that is, the design—of the output or by reducing waste by relatively small improvements of the operations or the flow. Indeed, Shingo (1988) and Ohno (1988) almost deal with such improvements only. From a flow point of view it can be argued that the route to improvement is to reduce variability. The flow concept can be traced at least back to the Ford manufacturing process (and probably further back to the building of galleys in the Venetian Old Naval Shipyard in the 15th century) where the prime objective to Ford was efficiency in the production process making the products cheaper to the customer (and in the Venetian case to increase the output at the brink of war).

At the end of the last century through increasing wealth focus was turned from the price of the product to its value. A car or a pair of jeans was not anymore a means for fulfilling needs only but instruments sending messages as well and the services surrounding the product became increasingly more important to the customers as the cost of the manufacturing of the product went down. Focus was turned away from the product itself and into its special features. The industry's answer to this was the new concept of mass customization. The requirement for individuality was not met by individual product but with products designed to be individual, that is with difference in color, features or delivery service. Where Henry Ford stated: 'You can have your car in any color you want as long it is black' it became now possible to have it in not only different colors, but also with different engines and auxiliary equipment. Mass customization was born, but still the key word here is 'mass'. Even though Daimler-Benz claims that their Mercedes E-class is available in more

4 The coordinate system's (0,0,0) point.

5 Indeed, the very detailed process specification is one of the characteristics of the Toyota Production System.

that one million varieties it is still an E-class you get.

PROJECT PRODUCTION

Project production is the production of the unique kind of a product or a service and this kind of production is therefore of a completely different nature and inherently much more complex and not least dynamic. This complexity stems from several sources as discussed in Bertelsen (2003b) and Bertelsen and Emmitt (2005). The one-of-a-kindness of a project often gives rise to an uncertainty about the objective as expressed in the final project outcome because the design of the product – and thus of its associated production process – is an integral part of the actual production.

Also—as is often seen in construction—the production system is established for the project in question only by an assembly of otherwise independent parties and is dissolved after the completion of the production. Christensen and Kreiner (1991) discuss in some detail the pursuit of the project's moving target undertaken by such loosely coupled systems. This approach to project production increases the process complexity through the differences in the parties' capabilities and their preferred approach to their task. However, choosing the process is by no means the decision of the participating subcontractors only but is – at least in construction – to a great extent the choice of the craftsman or crew assigned to the project.[6] But even worse, the complexity increases dramatically by the fact that the production system – the project organization – is sharing its resources with any other project the participating parties may be involved in. Bertelsen (2003b) investigates the construction process complexity from three perspectives: The product and its associated process, the production system; and the temporary social system at the construction site, and deals with the implications of the shared resources in more detail. (Bertelsen 2003a)

Production's primary objective: to create value for the customer, makes this complexity in project production even greater. The customer – in construction called the client – is probably at least in building just as complex as the production process and system; and as value is by its nature something personal, a moving target for the project must be the rule rather than an exemption. Even though the objective – and thus the value – may be known in general terms at the outset, it is highly probably that it changes as the project progresses As any project is a sub-project to somebody else's project[7] the project will be – if for no other reason – put into a turbulent situation with a moving target, where frequent changes in objectives and strategy may be the rule rather than the exception. Thus it would be a great mistake not taking the client's complexity into consideration (Bertelsen and Emmitt 2005).

As the process for delivering the value is at best outlined at the outset only, there will often be more than one feasible route towards the target but dead ends exist as well. All the way to the end the process is to a certain extent unknown and therefore unpredictable and improvisation is an important part of the game. Thus the strategy must be to keep the objective—the target—clear but to act based on the local situation. The flow will thereby be characterized by uncertainty, dynamics and high variability and it will often take place on the edge of chaos.[8] The usual approach: Organize-Plan-Do-Correct is insufficient, and an improvement in productivity in project production in this case should either take place through an increase of the knowledge of the actual situation, which means reducing the complexity, or by developing methods better suited to handle the local uncertainty. The success in using the Last Planner approach to production control in construction is one example of applying the latter strategy.[9] (Bertelsen 2002)

In comparison to managing stodgy manufacturing which mainly is an issue about improving flow and reducing waste (Hopp and Spearman 2000), that is increasing order, managing projects – at least those at the other end of the spectrum – is just as much about preventing them getting out of control. (Bertelsen and Koskela 2003)

THE NATURE OF PROJECT PRODUCTION

CLASSES OF PROJECT PRODUCTION

Projects are unique undertakings and even though projects have a lot in common they are also all different. However, behind this one may find different classes, each of which has some features in common but also have differences in their uncer-

6 A carpenter is a man, not a machine, and his work process will therefore depend on his skills, experiences, work situation, tools etc.

7 A quotation from a key note speech made by Dr. Martin Barnes at the 16th World Congress on Project Management, held in Berlin June 2002

8 The term 'Chaos' is used here in the understanding: 'unpredictable in the perspective needed.'

9 Last Planner™ (Ballard 2000b) is a service mark of Lean Construction Institute, US.

tainties – and thus in their nature—as well. Examples may be explorations, product and systems development, fire fighting and wars, sport games, and construction projects.

As an example one may speculate if there are different kinds of projects depending on the nature of the 'client' or the counterpart the project is dealing with? Are war and ball games of one kind with two opposing teams where each part is acting partly based on the other party's actions, and is climbing mountains or making works of art, where only one part acts another kind, or are they all just the same, except the first having a more dynamic a different set of uncertainties? In more general some characteristics of different classes of projects may be as presented in Table 1.

Table 1: Characteristics of classes of projects.

Uncertainty in:	High	Low
Objective	Exploration, basic research	Sports games
Process	Works of art	Fighting fires
Production sequence	Computer programming	Construction
Organization	Peace movement	American football
Ruling system	War	Soccer
Dynamics	Basketball	Road construction
Interaction with others	War	Writing poems

Where do we find construction in this landscape? Should we consider (conceptual) design as one kind of project, and detailed design and construction as a completely different one? Dammand Lund (2004) argues with references to Darsø and Herlaus (2001) the applicability of this understanding. They talk about 'preject'[10] and 'project' as two different kinds of activity in construction. The Seven Cs process model (Bertelsen et al. 2002; Emmitt et al. 2005) has the same underlying understanding but without the same depth.[11] Furthermore, the recent design theory by Hatchuel (2003) seems to indicate a contextual approach where it is distinguished whether new conceptual understanding or new knowledge is needed.

VALUE AND WASTE IN PROJECT PRODUCTION

Waste is any activity not contributing to the creation of value (Shingo 1988; Ohno 1988). A major objective in modern mass production management is to minimize waste as to improving the flow of value towards the customer, which may be possible in mass production. However, in project production there is a preject phase where this is not the right approach. Here the objective should be to expand the value that is to make sure the client gets as much value as possible within the given framework of budget and time. When we on the other hand come to the actual construction phase, the question comes up what is contributing to the value creation in a project production still aiming at a not precisely defined and still moving target? To this comes that value in mass as well as project production is not always associated with the product only but just as much—and often even more—with the process that delivers the product. Even using Shingo's (1988) distinction between necessary and unnecessary waste does not bring us much further. And without a firm understanding of the meaning of value, minimizing waste seems to be a very difficult task. Because of the construction client complexity undefined or conflicting value parameters are an important part of the nature of the construction process, which may lead us to other strategies in project—and not least in preject—management. (Bertelsen and Emmitt 2005).

As discussed, modern production templates such as lean see waste as use of resources not involving transformation or not generating value for the customer. Waste should therefore be reduced as much as possible (Shingo, 1988). Ohno (1988) identifies seven sources for waste including waste of overproduction and waste of errors.

However, waste is mostly defined in terms of short term, operational issues. There are higher level purposes, such as learning, maintaining the production system in working order and avoiding catastrophic consequences for the wider world which may be more important than waste minimization. As Smart & al. (2003) have argued in relation to high reliability organizations, waste minimization cannot be the only or not even the most important pursuit in all situations.

Looking closer it becomes clear that the underlying understanding of production is an ordered

10 The initial steps up to and including conceptual design process (Darsø and Herlaus 2001)

11 One reason for this may be the value and waste associated with rework. Rework is an important element in the conceptual design phase because it is generating value, whereas it is waste mainly in the detailed design and construction phases. Ballard (2000a) speculates along the lines to which extent rework is waste in the detailed design phase.

one, where increasing order and control is aimed at and where errors, faults and accidents are indeed sources of waste. Complex and dynamic systems such as construction on the other hand are not at all ordered and thus call for another understanding of the nature of waste. Nature is rich in waste and waste in this setting may be seen as a prerequisite for evolution (Kauffman 1995). Bak (1996) looks more specifically at errors, faults and accidents as sources for evolution in the form of learning in complex systems. A power law distributed number of faults[12] generate a learning process through frequent small events reducing the likelihood of the real great disasters, argues he. Toyota's fire in the Aisin brake valve plant was an event in an ordered and controlled system nearly breaking down the whole company, which was only solved by an emergent complex system of otherwise independent suppliers taking hand of the situation in less than a week (Wall Street Journal 1997).

MANAGING COMPLEX AND DYNAMIC PRODUCTION

In managing complex and dynamic—and thus potential chaotic—systems there seems to be at least four different strategies as outlined below. In practice all four should be considered and probably elements from them all brought into use.

These strategies are:

- build in buffers (slack, margin) for absorbing the impacts of complexity.
- reduce the complexity or dynamics seen from an operational point of view
- codify the procedures to be used and train in performing these procedures under stress
- improve the system's own capability to act on the given situation without orders from the management

The choice between the four should probably be made in the light of the uncertainties discussed in Table 1.

These four strategies are briefly discussed in the following with a view to construction projects. Of course, in practice the strategies are combined in most cases but to different degrees.

BUFFERING

In this strategy, the impacts of complexity and dynamics are absorbed through passive means, through buffers of various kinds. Thus, there can be redundant systems, time, resource or material buffers, etc. Buffering can also take the form of making-do. This strategy is used in sumo, but clearly at the cost of agility. This is the way construction has traditionally encountered complexity and dynamics.

REDUCING OPERATIONAL COMPLEXITY

This strategy may be implemented by using the same team for more than one project, by using a modular approach and reuse modules as much as possible.[13] Also the use of standardized routines may increase order and predictability, which helps to avoid chaos. Baseball is a sports game with little complexity, and the manufactured home industry has taken a route along the idea of modularization.

CODIFYING PROCEDURES

This increases the systems capability to deal with the complex and dynamic situation and it makes it possible to maintain a high level of training and learn to act on instinct, which reduces the need for predictability in order control the situation at hand. American football has taken this approach just as fire fighting, the traditional army and ordinary construction management.

LEARNING TO IMPROVISE

This strategy comprises an increase of reliability in the individual agent and a distribution of control, which is how nature really works (Kelly 1994). Top down management of the operations is no longer possible, and the system should be made capable of accepting the situation and to use and act upon the information available, the men, equipment and material at hand in new ways as the situation develops. Also learning along the road may be part of the strategy. Adventure games, US Marines, basket ball, and lean construction – to certain extent – use this strategy.

Examples of the use of these strategies in practice are shown in table 2 with an outset in sports games and construction.

12 This means that the frequency of faults plotted against their size in a double logarithmic coordinate system forms a straight line.

13 It has been argued (Vrijhoef and Koskela 1999) that modularization (and prefabrication) increases the total complexity, and so it often does. However, it also changes the complexity from a management point of view by dividing the system into manageable subsystems whereby the actual construction turns into a much simpler assembly process. (Bertelsen 2005)

Table 2. Strategies against complexity and dynamics.

Strategy	Examples[14]	Construction
Buffering	Sumo	Slack and making-do
Reduce the complexity	Baseball	Repeat, modularize
Codify procedures and train	Football	Last Planner
Learning to improvise	Basketball	Delegate, BygLOK[15]

In future work some of the systems mentioned above—war, ball game, fire fighting etc—may be taken as an outset, and a discussion of their characteristics be conducted. In this it should be recognized that they probably all to some degree have undefined or conflicting values even though there may be a clear, overall objective for each of them. If so, which steps increase value and which are waste? Indeed, undefined or wicked value parameters make it impossible to identify waste more than by a probability

CONSTRUCTION PROJECT MANAGEMENT IN PRACTICE

Koskela and Howell (2002) argue that the underlying theory of project management is obsolete and propose new approaches such as

- viewing construction not only as transformation, but also as flow and value generation,
- conceptualizing planning as management-as-organizing,
- conceptualizing execution as language/action perspective
- conceptualizing control based on the scientific experimentation model.

Bertelsen (2004) takes this further based on recent Danish experiences in practice inspired by Macomber and Howell (Macomber, 2001; Macomber and Howell, 2003; Elsborg et al, 2004) and strongly argues for a distributed management approach to managing the complexity. Approaches to understanding project management in this way are management-as-team-building; management-as-service-providing and even management-as-a-nuisance.

CONCLUSION

The general accepted conceptual framework of production seems to be dealing with a special case only—the ordered one of mass production. This sounds very much like a reductionistic approach like that of dealing with linear systems only in a world rich in non-linear systems, which is like understanding all animals as elephants.

The complex and often turbulent world of project production should take the project complexity and dynamics as an outset and design and operate its management systems from that perspective. In doing so, approaches and experiences from seemingly very different trades such as art, war, sports games or firefighting should be gathered and used for learning, and this understanding then transformed into more firm management principles for complex and dynamic project production.

REFERENCES

Bak, P. (1996): *How Nature Works—The Science of Self-Organised Criticality.* Copernicus press.

Ballard, G. (2000a): "Positive vs Negative Iterations in Design". *Proceedings of the International Group for Lean Construction* IGLC 8, Brighton, UK

Ballard, G. (2000b): *The Last Planner System of Production Control,* School of Civil Engineering, Faculcy of Engineering, The University of Birmingham

Ballard, G. (2005): "Construction: One Type of Project Production System". *Proceedings of the International Group for Lean Construction* IGLC 13, Sydney, July.

Bertelsen, S. (2002): "Bridging the Gap—Towards a Comprehensive Understanding of Lean Construction". *Proceedings of the International Group for Lean Construction* IGLC-10, Gramado, Brazil

Bertelsen, S. (2003a): "Complexity—Construction in a new Perspective." *Proceedings of the International Group for Lean Construction*IGLC-11, Blacksburg, Virginia

Bertelsen, S. (2003b): "Construction Complexity Analyzes". *Proceedings of the International Group for Lean Construction* IGLC-11, Blacksburg, Virginia

Bertelsen, S. (2004): "Construction Management in a Complexity Perspective" 1st *International SCRI Symposium*, University of Salford, UK

Bertelsen, S. (2005): Modularization – a new approach in making construction lean*?* Submitted for the 13th annual conference in the International Group for Lean Construction, Sydney, July 2005

Bertelsen, S. and Emmitt, S. (2005): "The client as a complex and chaotic system". Submitted for the 13th annual conference in the Interna-

14 Partly taken from Keidel (1985)

15 Elsborg et al (2004)

tional Group for Lean Construction, Sydney, July 2005

Bertelsen, S; Fuhr Petersen, K and Davidsen, H (2002), *Bygherren som forandringsagent – på vej mod en ny byggekultur* (The Client as Agent for Changes – Towards a New Culture in Building), Byggecentrum, DK

Bertelsen, S. and Koskela, L. (2003), "Avoiding and Managing Chaos in Projects". *Proceedings of the International Group for Lean Construction* IGLC 11, Blacksburg, Virginia

Christensen, S. and Kreiner, K. (1991): *Projektledelse i løst koblede systemer – ledelse og læring i en ufuldkommen verden.* Jurist og Økonomforbundets Forlag

Dammand Lund, L. (2004): "Procesplan for en arkitektkonkurrence" ("Process plan for an architectural competition"). Masterafhandling MBA Byg, 2004

Darsø, L and Herlaus, H (2001): *Innovation in the making*, Samfundslitteratur, 2001.

Elsborg, S; Bertelsen, S and Dam, A (2004), *BygLOK – A Danish Experiment on Cooperation in Construction,* IGLC 12, Elsinore, Denmark

Emmitt, S; Sander, D. and Christoffersen, A.K. (2005): *The Value Universe: A Value Based Approach to Lean Construction.* IGLC 13, Sydney, July 2005.

Hatchuel, A.and Weil, B. (2001): *A New Approach Of Innovative Design: An Introduction To C-K Theory.* International Conference On Engineering Design, Iced 03 Stockholm, August 19-21, 2003

Hopp, W. J. and Spearman, M. L. (2000): *Factory Physics,* McGraw-Hill International Editions, second edition.

Kauffman, S. A. (1995), *At Home in the Universe, The Search for the Laws of Self-organization and Complexity*, Oxford University Press

Kelly, Kevin (1994): *Out of Control—The New Biology of Machines, Social Systems, and the Economic World.* Addison-Wesley Publishing Company

Keidel, R. (1985): *Game Plans—Sports Strategies for Business*. E.P. Dutton, New York

Koskela, L. (2000): *An exploration towards a production theory and its application to construction,* VVT Technical Research Centre of Finland

Koskela L. (2004) Moving–on–beyond lean thinking. *Lean Construction Journal* 2004 **1**(1):24-37

Koskela, L. and Howell, G.A. (2002): *The underlying theory of project management is obsolete*, Project Management Institute

Macomber, H. (2001): "Making and Securing Reliable Promises on Projects", Good2Great Associates, www.good2great.com

Macomber, Hal and Howell, G.A (2003). "Foundations of Lean Construction: Linguistic Action", *Proceedings of the International Group for Lean Construction*, IGLC 11, Blacksburg VA, USA

Ohno, Taiichi (1988), *Toyota Production System, Beyond Large-Scale Production,* Productivity Press, Cambridge Massachusetts.

Shewhart, W.A. (1931). *Economic Control of Quality of Manufactured Product*. Van Nostrand, New York. 501 p.

Shingo, S. (1988): *Non-stock Production,* Productivity Press, Cambridge

Smart, P.K., Tranfield, D., Deasley P., Levene, R., Rowe, A., and Corley, J. (2003). Integrating "lean" and "high reliability" thinking. Proc. Instn. Mech. Engrs 217 Part B: *J Engineering Manufacture.* Pp. 733–79.

Vrijhoef, R. and Koskela, L. (1999): *Roles of Supply Chain Management in Construction.* IGLC 7, Berkeley CA.

Wall Street Journal (8 May 1997). by Valerie Reitman, staff reporter: *Toyota Motor Shows Its Mettle After Fire Destroys Part Plant.* From www.rbbi.com/company/toyota/fire.htm last visited 19 May 2005

Womack, J.P. and Jones D.T (1996). *Lean Thinking*, Touchstone Books