CONSTRUCTION: ONE TYPE OF PROJECT PRODUCTION SYSTEM

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ABSTRACT

The application of lean concepts and techniques to construction often seems to be driven by the idea that construction is, or should be, a type of manufacturing. In the U.S., and broadly in the international community, lean construction has been taken up with the idea that the project is a more fundamental form of production system than the factory. For the author, construction is one of many types of projects for which theorists and practitioners are developing theory and tools, alongside air and sea shipbuilding, performing arts productions, software development, product development, fabrication (job) shops, oil field development, health care delivery and work order systems such as plant maintenance.

This paper reports developments in thinking since the author's 1998 IGLC paper on this topic, including a critique of the current model for categorizing production systems, specification of conditions in which job shops can be redesigned as flow lines, a critique of the value concept derived from Gilbreth's model of flow and waste, and the role of buffers in experimentation and learning.

KEY WORDS

Designing, Production, Project, Project production system, Value, Waste

INTRODUCTION

The application of lean concepts and techniques to construction often seems to be driven by the idea that construction is, or should be, a type of making or manufacturing[2]. However, in the U.S., and broadly in the IGLC community, lean construction has been taken up with the idea that the project is a more fundamental form of production system than the factory.

Construction is one of many types of projects for which researchers are developing theory and tools, alongside performing arts productions, software development, product development, fabrication (job) shops, oil field development, health care delivery and work order systems. Figure 1 shows buildings as one type of product in a continuum between pure designing and pure making, each of which can exist without the other, but as such are extreme cases, much like trivial cases in the mathematical sense. This paper is devoted to understanding the implications of this difference in starting point—from construction as a type of manufacturing or from project production systems that integrate designing and making.

A section on types of production systems precedes presentation of two other types of project production system; namely, software development and oil field development. Then three major implications of starting from conceptualizing construction as a type of manufacturing are presented, after which conclusions are drawn.

TYPES OF PRODUCTION SYSTEMS

Production theory and practice has sprung from thinking about repetitive manufacturing. As a result, design has been subordinated to making, and value generation has been subordinated to waste reduction. This can be seen in the standard typology of production systems, which is at root a categorization of types of manufacturing or making, not of production systems understood as integrated designing and making of artifacts.

Definitions of production system types have their roots in Rutherford and Hayes' 1979 *Har-*

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2 Even though the Egan Report explicitly offers manufacturing's product development as the model to be imitated rather than the factory, this is still an appeal to imitation, not to theory-led practice.

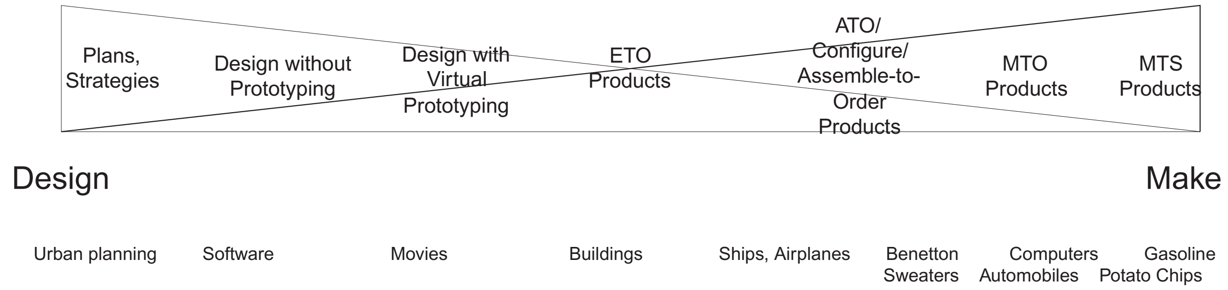

Figure 1: Product Types
ETO=engineered-to-order, ATO=assembled-to-order, MTO=made-to-order, MTS=made-to-stock

vard Business Review articles (Rutherford & Hayes, 1979a and 1979b), in which they organized types in terms of both product and process characteristics. Roger Schmenner (Schmenner, 1993) adds projects to the Rutherford & Hayes typology, locating them on one extreme, where products are unique and flows are "very jumbled" (see Figure 1). Job shops are just next to projects because they produce custom products, typically in small lots, and thus have products following different routings simultaneously in a single production system. Batch flow shops come next, the difference being that they produce standard products, either in response to customer orders (make-to-order), which makes them more like job shops, or for stocking inventories of finished goods (make-to-stock).

The degree of customization of the product is considered only in terms of the degree of repetition, without reference to the process of design and its relationship to making. It is quite obvious that production theory heretofore has been essentially theory about making, and one for which the norm is making multiple copies of a previously produced design. Design is treated as something 'manufacturers' can abstract away from and disregard.

OTHER FORMS OF PROJECT PRODUCTION SYSTEM

SOFTWARE DEVELOPMENT

There are initiatives in the world of software development that resonate strongly with lean construction methodologies; e.g., agile software development, Xtreme Programming and the Scrum method of organizing and managing software development teams (Highsmith, 1998; Schwaber and Beedle, 2002). Last Planner™ has been successfully applied to the management of software development, and lean construction has inspired software development thinkers to apply lean thinking to their domain[3] (Poppendieck and Poppendieck, 2003).

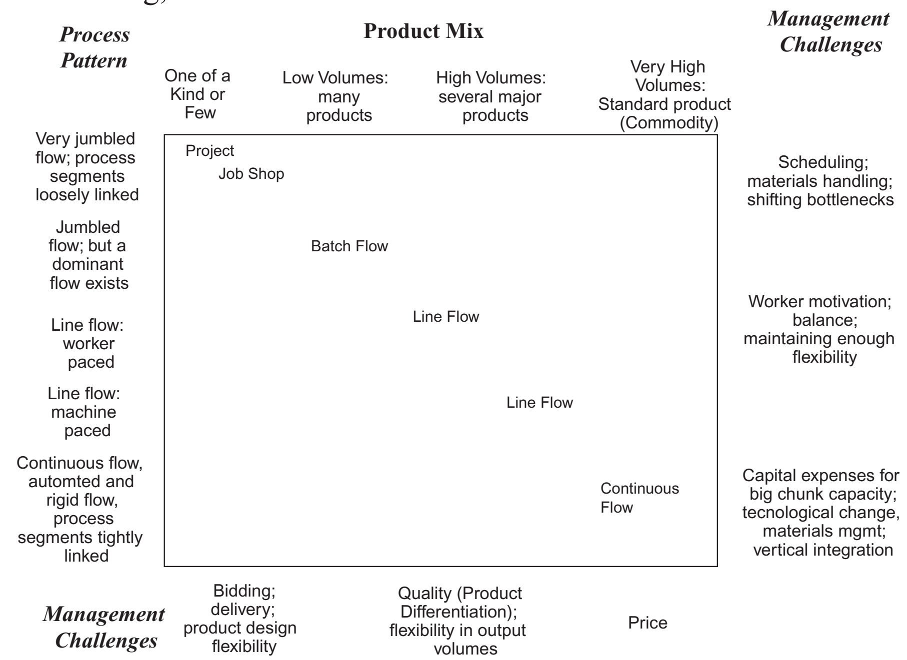

Figure 2: Types of Production Systems (Schmenner, 1993)

3 Glenn Ballard and Mary Poppendieck co-led a tutorial on lean software development at the 2002 Extreme Programming (XP) Conference in Alghero, Sardinia.

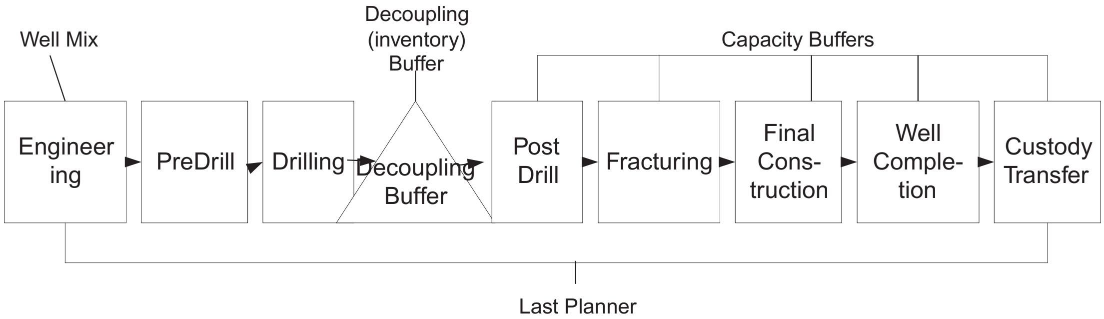

Figure 4: Techniques for leveling work load in oil field development

Software does have a material form of existence, but its production is almost entirely design. As such, it struggles with how to understand customer values and with how to deliver those values. Construction may have more to learn from software development than it has to teach—at least regarding value. However, software development appears to be much in need of the kind of production control that has recently emerged in construction. Even the Scrum methodology advocated by Schwaber and Beedle does not address coordination between multiple development teams, whereas that is precisely the focus of Last Planner.

OIL FIELD DEVELOPMENT

In 2001, the author began working with a large oil field development firm in California—name withheld by request. The firm was drilling 700+ shallow wells per year in a rapidly depleting field. The data points in Figure 3 represent the cycle time for wells, from beginning to drill to the time oil or gas began to flow into the pipeline; i.e., from the time they started to spend money to the time they started to make it.

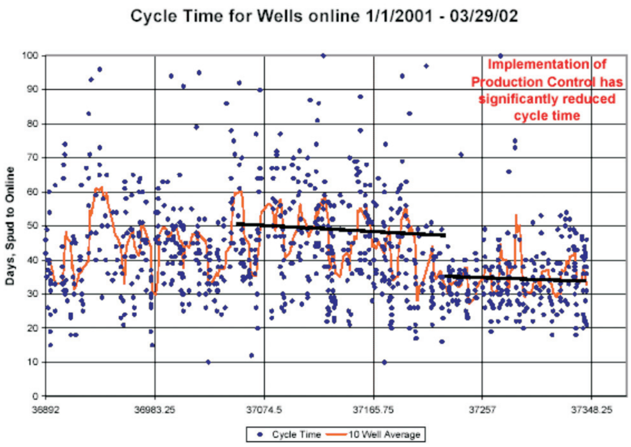

Figure 3: Cycle time for oil wells

Prior to the implementation of lean concepts, cycle times were extremely variable, prompting an estimate of 30% excess capacity as a result of these surges in demand on their processes. This was later proven accurate, but only after the reduction in cycle times and in variability shown at the later dates in the figure. Average cycle time dropped from 50 to 36 days. Cost reduction followed more slowly, but eventually reached the 30% level.

Figure 4 shows schematically what techniques were applied to the production system, which represents a type of system in which multiple projects are routed through roughly similar processes.

- Last Planner™ was used to increase the predictability of workload on each process.
- The batch size of wells released at once was radically reduced, and Engineering proved able to structure the mix of wells to approximate the average demand rate on the system; i.e., the 2.1 wells per day needed to achieve the annual target of 700+ wells.
- As we know from construction, when you dig in the ground, there's always surprises. That holds for drilling wells, too, which proved to have the greatest variability in processing duration and hence in release rate. To buffer the impact of that variability on downstream processes, we created a decoupling buffer of drilled wells. The number of drilled wells rose and fell with Drilling's output, but we released drilled wells to downstream processes at the 2.1 wells per day rate.
- Lastly, we structured scheduled work times to leave a capacity buffer in each of the processes downstream of drilling. Overtime provides approximately a 20% buffer, and has the charming feature of being paid for only when used. Interestingly, we had to arm wrestle some teams into giving up work schedules of 7 days a week/12 hours a day!

The firm is now moving into standard work and pushing work flow control down to the direct worker level.

There are several theoretical innovations behind this case, including conceptualization of oil field development as a multiproject production system, and subsequently the application of work structuring and production control principles and techniques. We suspect that there are many other production systems to which the structure and management methods are applicable.

IMPLICATIONS OF TREATING CONSTRUCTION AS A TYPE OF MANUFACTURING

We have looked at two types of project production systems above. The question remains: Does construction belong in the same category or not? If not, what are the implications? We will now present and explore the following implications of treating construction as a type of manufacturing:

- There is no need for theory development
- Line flows are equated with lean production and learning is neglected
- Designing and value generation are subordinated to making and waste elimination

THE NEED FOR THEORY

If construction is a type of manufacturing, and if the received wisdom concerning manufacturing is accepted, then theory has no role to play in lean construction. It's just a matter of applying concepts and tools previously developed in manufacturing. As a matter of fact, however, there have been key turning points in theory and understanding; points where assumptions previously held to be true were found to be false:

- Learning to see work flow
- Production system design
- Relational contracts
- Buffering for experimentation

Our field of study belongs to technology, not to science. Our ultimate objective is rather to change the world than to understand a world that does not care how we think about it. However, it is obvious that learning and understanding is critical for changing the world, and equally obvious that learning advances most rapidly when experiments fail or we otherwise discover that what we believed to be true was not.

Theories are proposed explanations; the best explanation we have at a point in time. If we do not make our theories explicit, we cannot learn from experience. Following are four big learnings for the author and colleagues—all resulting from discovering that we had previously been wrong.

Learning to see work flow

Our initial thinking about production control in construction was based implicitly on the idea of reducing delays in craftworker activities, and thus increasing labor utilization and productivity. Once we started experimenting on projects, and with the advantage of early understanding of the Toyota Production System, we realized that work flow reliability was the proper concept and that reliable work flow impacts the productivity of downstream players. That impact is more important than the improvement in productivity of any single player. This completed the shift in focus from productivity and resource utilization to work flow as the instrumental cause for performance improvement, and the shift from the operation or crew to the project (or even multiple projects) as the ultimate object of improvement efforts.

Practical significance: Unit productivity is still today the (detrimental) industry standard.

Production systems are designed

In the author's early experience with construction, he had no idea that a project was something that could be designed. Everyone always did what they had done before and projects just happened. Sometimes you got lucky and they went well—sometimes the opposite.

Once we learned that production systems could be designed, and conceived projects as temporary production systems, we began to understand the need to design systems adequate to dynamic projects: projects that are quick, uncertain and complex .

Practical significance: still today, project production systems are rarely consciously and systematically designed.

Relational contracts

Greg Howell and I started the Lean Construction Institute in 1997, when partnering was a hot topic. We had experienced partnering as an outside-the-contract attempt to persuade project players that cooperation was a better business strategy than fighting, as everyone was suffering from claims and litigation. That approach worked in three conditions, when the team collaborated on changing how work was done (and so were better able to manage their dynamic projects), when they got lucky (sometimes things go well), and when the projects were sufficiently stodgy (slow, simple, and certain) that neither luck nor a change in production system were needed for project success. So we chose not to start with contracts and organizational relations, but rather with developing a lean project delivery system adequate to the demands of dynamic projects.

Though there is still much to be done, since the formation of IGLC in 1993, the Lean Project Delivery System has been rather fully developed, so we are turning our attention to contracts as the tools for forming teams and structuring organizations. We have discovered that a very similar struggle is being waged in the field of contract law to that between lean and non-lean forms of production system.

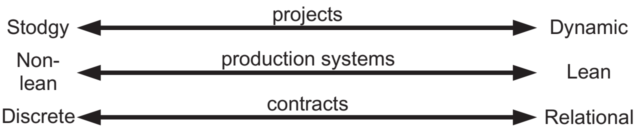

Figure 5: Aligning Projects, Production Systems and Contracts

Some time in the late '90s, Greg Howell became aware of the writings of Ian MacNeil (Campbell, 2001), the prime advocate of the concept of relational contracting. Very much in the way we have located projects on a spectrum running from stodgy to dynamic, MacNeil locates contracts on a spectrum running from discrete to relational. He argues that the classic theory of contract is based on the idea of discrete transactions and ignores the agreements needed to enable and sustain relationships in more complex contracting situations.

Practical significance: Project production systems are by their nature temporary. Consequently, a key competence is the ability to structure and restructure those systems and the organizations that operate them. As "lean" names the systems adequate to dynamic projects, so "relational" names the contracts adequate to structuring the corresponding organizations. Unfortunately, the construction industry remains wedded to the concept of discrete contracts, and even when relational forms of contract are used, they are rarely coupled with changing the way work is done; i.e., with production system redesign.

Buffers and Experimentation

Our most recent discovery concerns buffers. We have understood for quite awhile now that buffers of various types (inventory, capacity, time) can be located and sized to protect production systems against variability. But we thought of variability exclusively as something unwanted, something imposed upon the system in the form of defects, durations and breakdowns. Now we see that systems should and can be buffered to enable experimentation without the risk of commercial failure. Naturally, our learning came from Toyota. At NUMMI, the Toyota-GM joint venture in California, they operate two eight hour shifts separated by a 4 hour period, which is used for maintenance and also as a time to make up for any shortfall in production arising from external or internal variability. NUMMI is always experimenting and sometimes experiments result in interruptions to assembly lines. The 4 hour period between shifts allows them to learn from failures without impacting their business. In terms of Ohno's well known dictum to *Lower the river to reveal the rocks,* we are just now understanding how that can be done without putting a hole in your boat!

We've just begun to think how that same strategy might be applied on projects. An early thought is to assign additional objectives to projects beyond their financial contribution and their conformance to contractual terms. Building the appropriate type and amount of buffer into schedule or budget would allow experimentation with new methods and techniques. The good news is that lean construction companies will benefit from the difference between their actual production risk and the market valuation of that risk as long as they keep their nose ahead of the pack. Establishing a buffer for experimentation may be simply a matter of investing some portion of those excess profits in the further development of capability.

Practical significance: It would be a better form of flattery were the construction industry to imitate Toyota's dedication to learning rather than pretend that construction can be converted into manufacturing.

JOB SHOPS, LINE FLOWS AND LEAN PRODUCTION

The second implication of conceiving construction as a type of manufacturing is that the essential nature of the Toyota Production System is obscured. Most publications appear to equate lean production with line flows. Indeed, it might be said that a key objective of the Toyota Production System (Ohno, 1988) is to transform batch flows into line flows through such techniques as one piece flow and pull. Ballard, et al. (2003) describes one construction industry application of this approach, where the work in a precast concrete factory was restructured into production cells, each dedicated to a product type such as walls, beams, or columns. As long as the labor content and lead times of products does not vary too greatly, the production of these products can be organized as labor-paced line flows, with production cells periodically restructured to accommodate a changing product mix[4].

To the knowledge of the author, nothing is published on the application of lean techniques to job shops as such; i.e., when the job shop cannot be

4 The problem posed by product mix is to balance the advantages of line flow (reduced cycle times, lower work-in-process inventory, greater flexibility, etc.) with the loss of capacity when there is a varying work load on the system. The greater the variation, the greater the loss. The problem posed by varying quantities of products with similar routings is the traditional setup problem; i.e., how to reduce and how to recover the cost of restructuring the production system.

restructured as a line flow.[5] Hopp & Spearman's *Factory Physics* uses batch flow systems on which to develop their 'science of manufacturing', looking to make them more like line flow or continuous flow processes, and neglecting job shops altogether. Conner's *Lean Manufacturing for the Small Shop* (Conner 2001) proposes to show how to make job shops lean, but assumes that products can be grouped into families sharing similar routings and assigned to production cells; i.e., assumes they can be restructured as line flows. *Creating Mixed Model Value Streams* (Duggan, 2002), another text presumably devoted to application of lean to job shops, is introduced by Jeffrey Liker, who says, "You must isolate a product family with some limits on the ranges of variation in cycle times, or establishing flow will be hopeless." (Foreword, p. xii).[6] From the perspective of these authors, line flow and lean are synonymous.

The Toyota Production System converts job and batch flow shops into line flows, but some fabricators supplying construction projects cannot convert their shops to line flows, and the assembly process on site can rarely be structured as a line flow over very many tasks or 'work stations'. If lean means line flow, then construction cannot be (very) lean. But we understand lean in terms of the lean ideal and the pursuit of TFV goals, which allows construction to deserve the name "lean" to the extent those goals are pursued and achieved.

Spear and Bowen's 1999 HBR article on the Toyota Production System, Fujimoto's 1999 book, and most recently Jeffrey Liker's *The Toyota Way* all send the same message; namely, that the power of TPS extends well beyond manufacturing and the factory floor. It emanates rather from a fundamental and powerful philosophy of business management in which the key driver is a fearless dedication to learning.

Figure 6: Gilbreth's concept of flow

VALUE IN LEAN PRODUCTION

Limiting lean to manufacturing limits lean to waste reduction, and promotes misinterpretation of the concept of value. In terms of Koskela's Transformation/Flow/Value theory (Koskela, 2000), Flow and Value are conflated. This conflation goes back at least to Gilbreth, whose concept of flow left value defined only in opposition to waste. His flow model (see Figure 6) clearly is intended to represent making, with the product passing through the states of being processed, being moved, being inspected, being reprocessed (rework), or waiting. Only processing is said to add value; i.e., is necessary for transforming materials into the product desired by the customer. Value is understood only in opposition to waste and not in its own terms.

Attempts to apply this same conceptual approach to design naturally substitute information for material as the 'stuff' passing through the various states. However, if that has value which contributes to the realization of purpose, design is only incidentally a matter of processing information. Design is rather the creating, understanding and realization of purposes. A better image for design than transforming stuff (processing information) is a conversation, from which something new and different emerges than was brought to the table by any participant—and conversations are not in themselves a matter of processing information, though information processing is necessary as a means.

Attempts to model design as a type of making have been less than satisfactory, and fail to bridge the gulf between designing and making, a gulf that will exist until we jettison the fraudulent equation of lean with making, and the inevitable neglect of design and a proper concept of value that equation entails. The challenge is to understand designing as a process of value generation, and to learn how to integrate designing and making without sacrificing the essential nature of either.

CONCLUSION

Hopefully, you will have seen that lean construction, far from something we can now go beyond, is an ideal we've hardly begun to attempt, and certainly are far from having achieved. But of course, I am not speaking of the mechanical application of lean manufacturing concepts and techniques to construction. For continuing development of theory and practice, we must conceive construction not as a type of manufacturing, but rather as a type of project production system.[7]

5 An apparent exception is Wortmann, et al.'s *Customer-driven Manufacturing,* which does address project and job shop production, but which unfortunately does not attempt to apply concepts or techniques derived from or inspired by the Toyota Production System or lean production.

6 Portions of this discussion of production systems is drawn from Brink and Ballard, 2004.

7 If anything, as the extent of customization increases, manufacturing becomes more like construction, though admittedly, certain aspects of construction should move into the realm of repetitive making. This 'confusion' is rather an indicator of the need for a more fundamental theory of production than one that addresses only making.

Treating construction as a type of manufacturing obviously neglects design, and arguably subordinates value generation to waste reduction, which inverts their proper relationship. In contrast, the production system approach enables a rich dialectic between theory and practice, and a fertile conversation between designers and builders. The gains made thus far are as nothing to what lie ahead.

REFERENCES

Ballard, Glenn (2000). *The Last Planner System of Production Control.* PhD thesis, Dept. of Civil Engineering, University of Birmingham, Birmingham, U.K., June, 2000.

Ballard, Glenn, Nigel Harper, and Todd Zabelle (2003). "Learning to See Work Flow: Application of Lean Production Concepts to Precast Concrete Fabrication." Journal of Engineering, Construction and Architectural Management, 10(1), Blackwell Publishers, Oxford, U.K. pp. 6–14.

Ballard, Glenn and Mary Poppendieck (2002). "Lean Software Development". One day tutorial at the 2002 XP Conference, Alghero, Sardinia.

Ballard, Glenn and Todd Zabelle (2000). "Lean Design: Process, Tools and Techniques". *Lean Construction Institute White Paper 10,* October 20, 2000, 15 p.

Brink, Todd and Glenn Ballard (2004). "SLAM—a case study in applying lean to job shops". *Proceedings of the 2005 ASCE Construction Research Congress,* San Diego, CA, April, 2005.

Campbell, David editor (2001). *The Relational Theory of Contract: Selected works of Ian MacNeil.* Sweet & Maxwell, London, U.K. 412 p.

Conner, Gary (2001). *Lean Manufacturing for the Small Shop*. Society of Manufacturing Engineers, Dearborn, MI. 258 p.

Duggan, Kevin J. (2002). *Creating Mixed Model Value Streams: Practical Lean Techniques for Building to Demand.* Productivity Press, New York, NY. 206 p.

Fujimoto, Takahiro (1999). *The Evolution of a Manufacturing System at Toyota.* Oxford University Press, Oxford, U.K., 380 p.

Hayes, Robert H. and Steven C. Wheelwright (1979a). "Link Manufacturing Process and Product Life Cycles". Harvard Business Review, Harvard Business School, Boston, MA, January–February, 1979.

Hayes, Robert H. and Steven C. Wheelwright (1979b). "The Dynamics of Process-Product Life Cycles". Harvard Business Review, Harvard Business School, Boston, MA, March-April, 1979.

Highsmith, James A. (1998). *Adaptive Software Development: A Collaborative Approach to Managing Complex Systems.* Dorset House Publishing, NY, NY. 358 p.

Hopp, Wallace J. and Mark L. Spearman (2000). *Factory Physics, 2nd ed*. McGraw-Hill, New York, NY. 698 p.

Koskela, Lauri. (2000). *An exploration towards a production theory and its application to construction.* VTT Publications, Espoo, Finland. 296 p.

Liker, Jeffrey (2004). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer.* McGraw-Hill, New York, NY. 330 p.

Macomber, Hal and Gregory Howell (2003). "Foundations of Lean Construction: Linguistic Action". *Proceedings of the 11th annual conference of the International Group for Lean Construction*, Blacksburg, VA.

Ohno, Taiichi (1988). *The Toyota Production System: Beyond Large-Scale Production*. Productivity Press, Portland, OR. 143 p.

Poppendieck, Mary and Tom Poppendieck (2003). *Lean Software Development: An Agile Toolkit.* Addison Wesley, The Agile Software Development Series, New York, NY. 203 p.

Schmenner, Roger W. (1993). *Production/Operations Management, 5th ed*. Prentice Hall, Englewood Cliffs, NJ. 825 p.

Schwaber, Ken and Mike Beedle (2001). *Agile Software Development with Scrum.* Prentice Hall, Series in Agile Software Development, Upper Saddle River, New Jersey. 158 p.

Spear, Steven and H. Kent Bowen (1999). "Decoding the DNA of the Toyota Production System". *Harvard Business Review,* September-October, 1999, pp. 97–106.

Wortmann, J.C., D.R. Muntslag and P.J.M. Timmermans (1997). *Customer-driven Manufacturing.* Chapman and Hall, London, 464p.