PPI POSITION PAPER

A Comparison of Lean Construction with Project Production Management

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ABSTRACT

Project Management aims to address the myriad technical, human, organizational and managerial issues encountered during project execution [1]. Over the past two decades, different variants have emerged, including Lean Project Management, Agile Project Management, Scrum, Theory of Constraints and Extreme Project Management, to name a few. Lean Construction [2,36,54] utilizes concepts originally from Lean manufacturing and applies them specifically to the delivery of projects in the construction sector.

Despite the proliferation of different "flavors" of project management, major capital project outcomes in construction and in other industries remain poor [3 – 5]. Industry practitioners face a confusing array of differing methodologies, each claiming to address poor project performance. The Institute's mission is to explain how Project Production Management (PPM) addresses the gap between today's poor project performance and what is possible, thereby differentiating PPM from other methodologies.

Here, we focus on a comparison between PPM and Lean Construction. We trace the historical evolution of Lean Construction from its roots in Lean manufacturing, highlighting the operations science foundation underlying Lean and PPM. Lean Construction covers aspects of project governance, organization of project stakeholders and the work activities of the organization. In contrast, PPM focuses on the organization and control of project work activities. PPM's deeper focus on the execution of work activities results in quantitative, predictive outcomes, validated by practice, that address poor project execution performance.

Keywords: *Lean Construction; Project Production Management; Muda; Mura; Muri; Production System; Operations Science; Operations Research; Operations Management*

INTRODUCTION

The project practitioner today has access to a vast wealth of knowledge, built up over the past century, that applies to project execution and delivery. For example, the Project Management Institute has codified accumulated knowledge and practice into a formal body of knowledge [1]. To address the evolving size, complexity and scope of projects, variants of project management have also emerged – Lean Project Management, Agile Project Management, Scrum, Theory of Constraints and Extreme Project Management, to name a few. Despite that immense body of accumulated know-how, outcomes achieved on large capital project remain uniformly poor over a wide variety of industries [3 – 5] around the globe.

And so, the quest to refine and improve project execution and delivery continues apace, with new areas of knowledge being developed and introduced regularly, each promising to improve the current poor project outcomes. Industry practitioners face a confusing array of differing methodologies, all claiming to address poor project performance. Part of the Institute's mission is to explain, from a technical basis, how Project Production Management (PPM) addresses the gap between today's poor project performance and what can be achieved, distinguishing PPM from other established and emerging areas of knowledge.

In this position paper, we describe and distinguish Lean Construction, as defined by the Lean Construction Institute [2], from Project Production Management by comparing and contrasting the content and aims of both. Figure 1 below illustrates their historical evolution, emphasizing the operations science foundations of both PPM and Lean, from which Lean Construction then evolved and broadened.

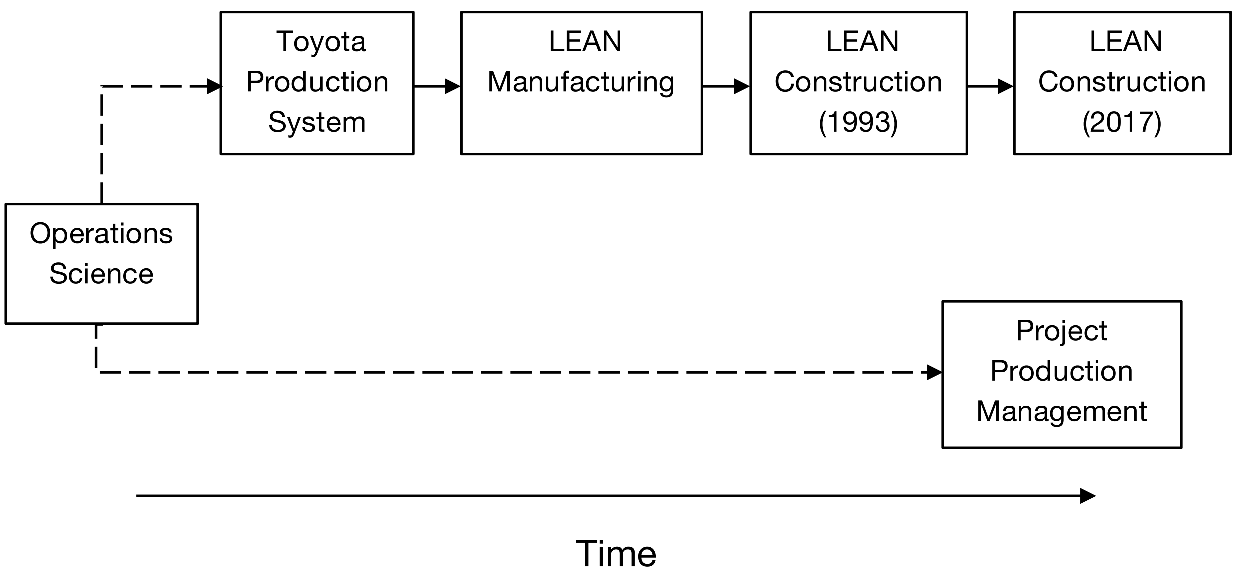

Figure 1: The Operations Science Foundation Underlying Lean and Project Production Management

We begin this article by defining operations science, citing literature from the "reading list" that the Project Production Institute provides its membership. We then review the historical evolution of Lean Construction, illustrated above in Figure 1, with an emphasis on its operations science roots. We trace the various advances in high volume manufacturing through to the Toyota Production System, Lean manufacturing and the broader Lean movement. Although these historical developments did not occur as a logical progression from the subject of operations science, our remarks focus on the literature that first drew the connections between high volume manufacturing, Lean principles and a more general theory of production systems.

Lean Construction, as envisaged by the International Group for Lean Construction in 1993, began by specializing Lean concepts from manufacturing to construction projects. In the Institute's research of the term, we have not found a single universally accepted definition of "Lean Construction" nor a single standard-setting institution – there are several institutions that research and teach the subject of Lean Construction, and so a number of slight variations of Lean Construction have evolved. However, we note that the principals behind the International Group for Lean Construction, founded in 1993, coined the term, and that the IGLC explicitly call their vision "Lean Construction."

Examples of other institutions include the numerous subgroups spawned from the International Group for Lean Construction, such as the European Group for Lean Construction, the Institution for Lean Construction Excellence and numerous universities such as the P2SL Lab at UC Berkeley, Construction Industry Research at Michigan State University and the Center for Lean Projects at Nottingham Trent University. Regardless of whichever specific definition of "Lean Construction" one chooses to follow, a general trend has been to broaden the subject from simply the operations science roots of Lean. For example, one such variation has broadened the topic of Lean Construction into a framework [2] defined by the Lean Construction Institute, one of the institutions researching and teaching Lean Construction, to address other wider-ranging topics encountered in construction project execution, such as integrated project delivery and project governance. In Figure 1, the historical developments are represented by the solid lines, and the dashed lines trace the underlying connections between the different topics to operations science.

Understanding the operations science foundation and the evolution of Lean Construction, from its inception with the founding of the International Group for Lean Construction in 1993 to present-day 2017, helps to illuminate how PPM is different. The distinction may conceptually be described as follows. All projects face issues along three general dimensions [55]: governance, organization of stakeholders and organization of work activities. The Lean Construction framework covers all three dimensions, but in its broad coverage it is not as deep in any single dimension. Moreover, as we explain in this paper, a significant portion of the Lean Construction framework focuses on optimizing current practice in conventional project management processes, rather than bringing forward new techniques and methods.

In contrast, PPM focuses on organization and control of work activities in a project. It provides deeper quantitative and predictive theory on the achievable limits and design of work activities, validated by practice in several settings. The ability to model and simulate work activities to establish the limits of what is and is not theoretically achievable, as well as the ability to infer design criteria to optimize parameters such as throughput, work-in-process, cycle time and use of capacity lead directly to an improvement in cost, schedule and scope performance on projects. This organization and control of work in project activities distinguishes PPM from other methodologies, and from Lean Construction in particular. We conclude by giving several specific examples that differentiate present-day Lean Construction [2] and PPM.

A BRIEF REVIEW OF OPERATIONS SCIENCE

In colloquial usage, "operations management" is the term used to refer to a branch of management dealing with the design and control of the process of production of goods, services and business operations in an enterprise. The term "operations research" is generally used to describe the body of advanced mathematical and analytical techniques, drawn from mathematical modeling, statistical analysis and optimization used to make better decisions in operations management. PPI is notably an intellectual disciple of the view as defined by our partners at Factory Physics and their collaborators – that of a scientific approach and theory [9 – 11] to the management of operations, as explained in this section.

Historically, the problems addressed in operations research are drawn from operations management and are diverse, starting with military planning of logistics in both World Wars and subsequent military operations, extending to a wider range of manufacturing assembly line design, equipment procurement, supply chain and infrastructure planning problems. As a result, when one looks at operations management and operations research texts, one can have the impression that the curriculum is constructed as a "tool kit" of diverse and unrelated techniques useful for a practitioner to apply on a range of problems arising in a variety of contexts. In support, PPI provides an extensive reading list and glossary for the reader to consult. This includes both historical references to trace the evolution of the subject [12 – 16], particularly with emphasis on production systems from advances in manufacturing and what the Institute considers to be the closest "parents" of Project Production Management [6 – 11], as well as key terms.

For an account of the diverse techniques to solve problems in different operational settings – high volume manufacturing, military planning and logistics, inventory management, supply chain design – assembled into a coherent scientific theory of operations, the Institute finds that Project Production Management emerges from references including *Supply Chain Science* and *Factory Physics* [7, 9 – 11]. It is, simply put, the application of operations science to projects viewed as temporary production systems.

The observation of projects as temporary production systems is not new – it dates back at least to Schmenner [8] – but the statement that Project Production Management is the application of the operations science codified in these texts [7, 9 – 11] to these temporary production systems is part of what distinguishes the Institute's position from other practitioners in project management, execution and delivery. What does this statement mean practically?

We cite a discussion in *Factory Physics for Managers* [11, p. 71], which points out that for a theory to be useful, it cannot be too general and it cannot be too specific. It cannot be too general lest it become so shallow that it cannot provide sufficiently powerful predictions. It cannot be too specific, lest it cover too narrow a set of circumstances to be useful. Conventional project management as described [1] is an example of a subject which is so broad as to be too shallow to make useful predictions, an observation made by several authors in earlier literature [35, 41, 42, 45]. Despite considerable effort to expand and refine the subject, project outcomes remain poor, and are not demonstrably predicted by the subject. It is sometimes argued that poor implementation of conventional project management practices is the cause of poor outcomes, but there is no prescription given that yields a predictable improvement in project performance. In contrast, the claim made in *Factory Physics for Managers* [11, p. 71] is that three equations and four graphs are sufficient to be able to understand and predict the fundamental limits of operations performance, and to be able to design operations to be optimum with respect to financial measures such as cash flow and profitability. That is a very concrete example of a theory which is sufficiently broad to be useful, but not so broad as to be shallow. The repeated application of those three equations and four graphs to the temporary production systems that are projects is required to design and control the work activities and in so doing achieve desired project outcomes.

As a practical corollary from operations science vis-à-vis conventional project management, we refer the reader to the Institute's position paper, "New Era of Project Delivery – Project as Production System" [17], which outlines the evolution of project management across three distinct eras, with Era 1 focused on productivity, contrasted by Era 2's project management as "planning for predictability" and Era 3's "Project as Production System" with minimal use of resources. A key point of the paper is to highlight the superiority of controlling Work-in-Process (WIP) and measuring output (such as cycle times), rather than controlling output with a schedule and measuring Work-in-Progress. This is a direct conclusion from operations science, as noted in *Factory Physics for Managers* [11, p. 10], and was one critical aspect in which Toyota developed an advantage in high volume manufacturing. This is an example whereby viewing things through an operations science lens uses a single set of common principles and equations to unify apparently disparate subjects such as high volume manufacturing, projects and production systems. Another example is how operations science brings clarity and precision to Lean, and control protocol terms such as push and pull are discussed in the next section.

THE OPERATIONS SCIENCE FOUNDATIONS OF LEAN

As Lean Construction was originally envisaged as the specialization of Lean concepts applied to construction, it's worthwhile to first review the operations science concepts underlying advances in manufacturing, production systems and Lean principles to explain how PPM is distinguished from Lean Construction. It is the position of the Institute that Lean principles are clarified and made more precise by understanding their derivation from operations science, i.e., Lean is subordinate to operations science. This observation is neither new nor original to the Institute, and substantial peer-reviewed academic literature demonstrating this conclusion is cited [10, 11, 27]. The article "To Pull or Not to Pull: What Is the Question?" is reprinted in this edition of the Journal to accompany this position paper.

There is extensive literature covering the history of advances in manufacturing, ranging from Frederick Taylor's original work on labor productivity in factories, resulting in the "Scientific Management" [12] movement, through Ford's mass production and GM's Large Batch / Flow Production [14], and ultimately Toyota's Production System. Much has also been written about the advent of how the Lean movement came to be, starting with when John Krafcik [18] coined the term "Lean," based on his MIT Master's Thesis. This was done under the auspices of MIT's International Motor Vehicle Program that looked at, among other things, Japanese manufacturing techniques such as JIT and TQM, the Toyota Production System, push and pull systems, etc. The subsequent publications [19 – 22] became among the most widely-cited references popularizing the term Lean, and its variations in the business and industrial sphere. The article, "The Genealogy of Lean Production," [23] traces the history of the term, describing how earlier operations management and academic studies of Japanese manufacturing were conducted, but did not reach popular consciousness until the IMVP program and publication of Womack and Jones' book, *Lean Thinking: Banish Waste and Create Wealth for Your Corporation* [22].

This article is not meant to trace the history of manufacturing advances in detail, nor to trace the history of Lean, as that would take us too far afield. Our purpose here is to focus on how Lean principles arise because of operations science and to highlight the reasons why these results, although published in peer-reviewed academic literature, are not as widely recognized as they ought to be. There are two reasons for this. First, the term "Lean" is quite elastic, because of the proliferation of different sub-movements which have adopted it, along with differing definitions. Second, even taking the set of literature [18 – 22] as *the* reference for Lean, ignoring all other variations, and using the Lean Enterprise Institute founded by Womack and Jones as the standard for Lean principles, the fact is that Lean is not sufficiently precise and clear enough to be satisfactory as a theory that gives strong predictions for satisfactory outcomes on production systems. We explain each of these points in detail below.

While Womack and Jones [19] popularized Lean and are recognized as such, the term "Lean" and what precisely constitutes "Lean principles" and the "Lean movement" have no clear standard or generally accepted meaning because it has been subsequently co-opted by numerous consultants and institutions. This phenomenon has devolved into a competition of different brands of Lean against other brands such as Six Sigma, TQM, and other "enterprise improvement methods" – each promising to be a silver bullet, and all disappointing in their outcomes achieved [31].

There is a misplaced emphasis on the implementation of Lean methods [11, pp. 6 – 9], rather than on understanding *why* such methods work, and, as importantly, in which settings. Thus, enterprises seek new methods resulting from the concatenation of such brands – Lean is followed by Lean Six Sigma, which is followed by Lean Six Sigma TQM, and all are doomed to fail without fundamental understanding of why and when these methods are appropriate and effective.

The vast literature on Lean methodologies has obscured the very literature that sought to provide more clarity and precision into exactly what Lean principles are, and the circumstances in which they are effective. For example, in the 1980s, academics began looking at push and pull [25 – 26] control protocols, observing that extant definitions were qualitative, instead seeking to place these concepts on a more mathematical footing that could yield precise predictions of system behavior. The question is not merely academic. As the authors of *Factory Physics for Managers* point out [11, p. 16], there are differing definitions of pull given in *Lean Thinking* [22] and in the APICS Dictionary. The earlier definition implies pull systems are make-to-order systems, whereas the latter definition is ambiguous and unclear – an example of conflicting definitions from two standard-setting references.

More importantly, neither definition gets to the underlying science of what is going on, as discussed in various articles [24, 27]. In "To Pull or Not to Pull: What Is the Question?", the discussion explicitly relates push and pull to the Work-In-Process generated by the system, crisply defining pull systems as those which limit the work-in-process generated by the production system, whereas push systems do not have that explicit limit. That may not seem obvious, and indeed there is a lengthy discussion explaining the underlying principles that lead to those definitions, but results in the simplicity of reducing these concepts to a more basic construct in operations science, in this case work-in-process, from which the "three equations and four graphs" [11] can be used to predict the consequences and outcomes.

In operations science, there are only a few constructs, related by well-described mathematical relationships [10, 11]. Production systems, described in an accompanying tutorial article, seek to satisfy demand through a sequence of production operations, but inevitably demand is not synchronized with production because the production systems are affected by variability. To correct for misaligned demand, buffers must be introduced into production systems and only three types of buffers exist: inventory (or work-in-process), time and capacity. Thus, there are only three sets of mathematical relationships that govern the individual components and overall system. By reducing the definition of push and pull systems to system behavior with respect to a more fundamental parameter – WIP – simplicity is achieved through the ability to describe these systems with fewer definitions and concepts, resulting in a stronger theoretical basis.

Similarly, the concepts of Mura (unevenness), Muri (overburden) and Muda (the 7 or 8 types of waste) in the Toyota Production System can be reduced to the simpler operations science constructs described. Mura is the operations science concept of *variability,* but it is naïve to seek to eliminate variability without first understanding whether it is beneficial or detrimental [10, 11]. Muri is simply the concept of *capacity utilization*, and leads directly to understanding the effects of high utilization on WIP and cycle time in production systems through the VUT equation or Kingman's Formula. Perhaps the greatest simplification is Muda – which has 7 or 8 different forms – to understand whether one is reducing cycle time or WIP, or increasing throughput in order to reconfigure the production system by redesigning the tasks or policies and control protocols.

As summarized in the literature, lean principles can be described as "steps taken to minimize the buffering costs in a production system" [10, 27]. In the opinion of the Institute, this reduces the set of Lean principles to a conceptually simpler exercise of production system optimization using the mathematical relationships in operations science, with fewer fundamental concepts. While the focus of the Institute is on the application of operations science to project execution, we note that these observations are neither new, nor original. As an example, an article written by N. Majerus [33] describes his study of *Factory Physics* [10] to develop a more precise understanding of Lean principles. Majerus goes on to explain how he used such understanding to apply operations science techniques to improve the Research & Development function at Goodyear, resulting in his book *Lean-Driven Innovation: Powering Product Development at the Goodyear Tire and Rubber Company* [34] that details the application of operations science concepts to Research & Development activities.

LEAN CONSTRUCTION – ITS EVOLUTION FROM 1993 TO 2017

Having described the operations science foundation for Lean principles, we now turn to Lean Construction and compare it with Project Production Management. Our purpose here is to explain the Institute's position that Lean Construction is not a subset of Project Production Management, but neither is Project Production Management a subset of Lean Construction, and certainly not with Lean Construction as it is generally understood at the time of writing in 2017. To form and support this position, the Institute has consulted a body of literature from the 1990s to the early 2000s [35 – 44] to understand what was envisaged for Lean Construction when the International Group for Lean Construction was formed in 1993. To adequately compare PPM and Lean Construction, the Institute has also consulted references to understand what comprises Lean Construction today [2].

In the early 1990's, several researchers and practitioners came together, including L. Koskela, G. Ballard, G. Howell, I. Tommelein and T. Zabelle. The dialogue between this group ultimately culminated in Lean Construction, with the term being coined by Ballard, Howell and Koskela. After Koskela moved to Stanford to research robotics applications in construction, he wrote a technical paper concluding that batch production and structural issues with the complexity of the supply network in construction did not allow technology, i.e. robotics, to be used. Following his investigation, a fruitful body of work from several people emerged [36 – 46], leading to the formation of the International Group for Lean Construction in 1993.

The original focus of Lean Construction was on learning and applying concepts from the Toyota Production System and Lean principles in manufacturing to Construction, with various articles written on this topic [35 – 41]. It is also clear that from a very broad range of perspectives and topics investigated by those who developed Lean Construction, that they recognized several issues mentioned in this position. For instance, several authors [37, 40, 44] recognize that conventional project management [1] lacks a sufficient theoretical basis to form useful predictions. In fact, several articles [35 – 45] outline a progression and a theoretical basis from Lean principles, perhaps best summarized in "The Foundations of Lean Construction" [42]. In addition, the relevance of operations science is explicitly recognized in several papers [36, 39, 41, 42, 45]. For example, "The Foundations of Lean Construction" [42] provides a tutorial on the VUT equation / Kingman's formula for construction, and "The Underlying Theory of Project Management is Obsolete" [45] discusses the advantages of simulation to understand the effects of variability in construction activities and explores various buffer strategies.

We surmise that Lean Construction, as envisaged in 1993, had several similarities with Project Production Management as defined by the Institute. However, over the ensuing 25 years, the concept of Lean Construction and that of Project Production Management (as espoused by the Project Production Institute when founded in 2013) followed diverging directions. The core difference can be understood by asking how "system" is defined in "project delivery system" for Lean Construction versus Project Production Management. Lean Construction increasingly focused on human factors, primarily project governance and organization of project stakeholders, whereas Project Production Management focuses on the configuration and organization of the physical work tasks that get performed in a project.

Put another way, the Lean Construction began to address issues concerned with the "system of people" in the construction process, as defined for instance by the "Lean Project Delivery System" (LPDS) [42]. "The Foundations of Lean Construction" article [42] certainly credits operations science for giving insights into a lean production viewed as a flow. It goes further to propose that three different views of production – transformation, flow (lean) and value generation – are distinct and need to be synthesized into an integrated view to provide a more complete theory of production. The authors define the LPDS construct, concentrating on the relationships between the different phases of a project and the participants.

There is a significant emphasis on human factors such as involving downstream participants in upstream project decisions, aligning the incentives of participants, personnel deferring commitments to the last responsible moment and the allocation of buffers to manage variability. In the view of the Institute, the focus is on optimizing processes in conventional project management, e.g., the practice of early engagement of all stakeholders in preparing a schedule. The discussion on deferring commitments and buffer allocation is largely posed as one of human interaction, rather than the quantitative determination of where buffers should be placed, what types of buffers and how much of each type is needed.

An examination of subsequent papers [48] and the reference book [2], show the fundamental categories of "Transformational Change," "Integrated Project Delivery," and "Lean Project Delivery Methods and Management." The detailed topics in each category touch on aspects of project governance, organization of humans in project activities and organization of physical work activities, with the bulk of content being on the first two. For example, researchers and practitioners on Lean Construction has performed extensive work in the subject of contracts and relationships, as well as integrated forms of agreement between different project stakeholders. These are subjects that touch upon project governance and stakeholder organization. Technologies such as BIM are described for the potential insights they give to stakeholder interaction to detect potential conflicts in design and work activities, and are referenced as tools to use in team structure and planning [2]. A fundamental cornerstone in "Lean Project Delivery Methods and Management" is the Last Planner System® [49 – 50], which is one form of production control used to reduce the variability in handoffs between tasks by controlling the release of work from predecessor tasks to successor tasks. The tool kit of methods and processes in Lean Project Delivery Methods and Management is built around the Last Planner System®. This describes a set of methods for team members to interact with each other by more reliably forecasting the completion of tasks in order to more effectively plan the start of future work, all the while controlling the availability of resources for work completion.

However, this literature does not cover the operations science methods used to organize and control the execution of physical work activities to be performed, which is precisely the focus of PPM – specifically the *process* of *executing the work* as opposed to the *people*. For instance, production systems are mentioned, but not defined. The need to manage variability is acknowledged, but there is no discussion of quantitative ways to assess beneficial and detrimental variability. The Lean Construction literature, regardless of which institution's definition of Lean Construction one favors, lacks an explicit discussion of the three different buffers available to manage variability and how they can be scientifically allocated to optimize production system behavior. In projects where physical work activities are complex, not having this science available is a severe disadvantage, as the operations science framework allows practitioners to understand the limits of what is achievable and subsequently plan the work activities so the optimum is achieved. This is exemplified in two construction case studies. [51 – 52] in which operations science techniques are used in a very concrete manner to optimize production systems.

Lean Construction focuses on the people issues in project delivery, primarily on aspects of project governance and organization of stakeholders. PPM focuses exclusively on the organization and control of physical work execution – it is succinctly captured in a few mathematical relationships, whereas Lean Construction is not. While the subject of Lean Construction spends considerable time on getting teams to understand value, following the "transformation-value-flow" view of production [42], the Project Production Institute subscribes to the discussion on the "*value-added fantasy*" [11, pp. 172 – 176], which criticizes the lack of precision in defining "value-adding" and "non-value-adding," in a slavish imitation of Toyota Production System. There is a lack of hard science to derive the correct metrics of value from the intrinsic mathematical relationships between cycle time, throughput and work-in-process of a production system. PPM clearly fits the definition of a scientific theory because it is simply captured in well-defined mathematical relationships and statistical behavior, with the capability to make verifiable predictions.

CONCLUSION

We have described the academic literature that shows the operations science foundations of Lean Manufacturing and Lean Principles. We then described the close operations science aspects of Lean Construction, as it was originally envisaged when the International Group for Lean Construction was founded in 1993. Although there are some variations in the subject of Lean Construction because of the number of institutions that research and teach the topics, by reviewing subsequent literature, we have explained how in general, Lean Construction has expanded its framework to cover issues of project governance such as contracts, integrated forms of agreement and organization of stakeholders, such as in the Lean Project Delivery System [2].

We contrasted the human focus of present-day Lean Construction with the focus on physical work activities in Project Production Management. PPM is simply the application of operations science to projects by viewing them as temporary production systems. The behavior of such systems is succinctly described using no more than three mathematical relationships, and as a result PPM is a powerful scientific theory to predict the limits of behavior of such systems. Thus, the application of PPM methods and principles optimizes system parameters such as throughput, work-in-process and cycle time, as well as financial parameters such as cash flow and cost. That makes PPM a powerful tool to address the current poor performance of today's major capital projects.

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