Linear vs. Systems Approach to Production Scheduling in Construction

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Abstract
Network-based scheduling methods were not originally developed for managing the production phase in construction projects. They were designed for projects that can be completed with highly linear, predictable and static processes. When network-based scheduling methods are applied to production management of construction, a mis-match is evident. The majority of construction projects continue to be described as dynamic and probabilistic processes. The findings of this exploratory desktop research suggest that the different nature of construction, and also a shift in thinking account for the scheduling methods mis-match. Those developers who take into account the systems nature of production in construction have been at the forefront of developing scheduling methods appropriate to the dynamics of construction. Their efforts are proving effective in matching the nature of construction with the capability of scheduling methods and tools that provide better management and control.

Keywords: production scheduling, mis-match, linear vs. system approaches, LBMS, location based scheduling

1 Introduction

This paper argues that the evolution of production scheduling methodologies in construction can be understood as an approach duality: linear vs. systems. In a linear or deterministic view with network-based scheduling methods there are distinct and minimal connections between cause and effect logic in the scheduling model. The number of elements and their connections are pre-determined, highly predictable and static. Therefore, the emphasis of network-based scheduling is limited to singular The linearity of elements in a model which aims to provide an absolute 'critical path' solution to the problem of resource use. A low number of interconnections between the elements characterize a simple model managed by a linear management method such as critical path management (CPM). CPM development was in the context of manufacturing and engineering projects which led to an application mis-match for production scheduling in construction. In CPM, the scheduling production phase is modeled as a very linear, static and predictable process.

In the systems approach with location-based scheduling (LBS) methods, the construction production is modeled as a system in which the elements have dynamic and probabilistic interactions with one another. A higher number of interconnections between the elements of the scheduling model characterize a dynamic system managed and controlled by a systems thinking approach. The impact of variability in one element of the system is absorbed and controlled harmoniously by the whole system rather than only one element. In dynamic production, there is no predetermined best solution to the problem of resource use. In

contrast, there are several best emergent solutions which can be considered during the production phase through a systems approach.

The acceptance of defining construction production through the systems thinking lens has resulted in new ways of thinking, methods and tools. One of the systems-based approaches is location-based management (LBM) theory in which the focus of management is shifted from individual discrete activities (elements) to task (chain of activities). LBS methodology concentrates on maintaining resource continuity and avoiding waste in production such as interruption, the double-handling of materials, equipment or workers, or rework.

In LBS, the use of the location-breakdown structure creates a higher number of interconnections between the activities in a construction project. LBM methodology unifies all the isolated activities into a chain of subsystems that can dynamically interact with each other and hence flow as a 'system'. In LBS, the activities of the same type are integrated to form a single task which flows through many locations continuously and sequentially. In CPM scheduling, there is only one layer of logic between two activities. The CPM methodology does not recognize the repetition of work in multiple locations across the whole system. In contrast, location-based scheduling adds new layers of logic which add details to both internal task production of location-based tasks and to the external links between the tasks.

This exploratory desktop research uses online and university library resources to consider a different view of construction production to account for different construction scheduling methodologies. The focus is on production scheduling because it is an important methodological solution for the process of construction. Methodology is generally a guideline for solving the problem of resource allocation, with specific components such as methods and tools.

The balance of this paper is structured: section 2 outlines the linear approach and its associated scheduling methodology. Section 3 describes the nature of the systems view of construction. Both sections discuss different lines of thinking and their relations to different scheduling methodologies and concepts. Section 4 provides a summary of the concepts and issues related to the argument that adoption of linear CPM scheduling methodology is a mis-match for the reality of the dynamic systems nature of construction projects.

2 Linear-approach

In this paper, the linear approach refers to the set of particular scheduling methodologies, methods and tools for construction management. In this view, construction production is modeled as a linear entity which has a highly deterministic, static and predictable behavior. The managerial principle aims to provide the absolute best solution to the problem of resource use in managing a project. The minimal number of interconnections between the elements of the model becomes the main obstacle to the recognition of possible higher interconnections in a process.

The linear perception of the production phase can be easily modeled by the languages of mathematics and computer science (Klein & Hirschheim 2001). While there have been continual attempts to provide a solution to the problem of resource use and time in construction, modern scheduling emerged only after the arrival of computers in 1950s. Scheduling is a methodology for arranging and planning a series of elements to be done at or during a particular time or period in a process. In project management, an element is usually referred to an 'activity', 'work' or 'task'. Scheduling methodology organizes and arranges these elements in a model for solving the problem of resource use (Weaver 2007).

Section 2.1 outlines the origins and drivers of network-based scheduling methods as the main representative of the linear world-view. Section 2.2 discusses criticisms of modern construction management methodology based on network-based methods. Lean construction methodology rejects the principles of such methods as they only determine the starting time of elements in a model but do not plan the flow itself. Section 2.3 explains the fact that the development history of network-based methods and their applications in construction project tell us about a mis-match.

2.1 Origins and drivers

Time is a complex problem for managing the limited availability of resources in the production phase of a construction project (Jaśkowsk & Sobotka 2004). In the modern era different methods have been developed. Between 1910 and 1915, the Gantt chart was developed by Henry L. Gantt and Frederick W. Taylor. Their Gantt chart is a graphical technique without any analytical methods. Nevertheless, the Gantt chart was universally adopted to represent the organization of project production and was soon commonly used in the construction industry for communication of a time schedule (O'Brien, J.J & Plotnick 1999).

With the growing complexity of industrial and construction projects and increased focus on management as a discipline, it was necessary to develop an analytical method (Kenley & Seppänen 2009). In the 1950s, computers emerged that could be designed to automate complex analysis and solve complicated problems. Linear programming was one of the models which brought mathematicians and computer programmers together to develop a solution (Salmon 1962). This branch of mathematics mainly concerns the cause and effect of actions on each other in a process.

The linear programming problem is to find the one solution, out of the infinite number of possible solutions, which minimizes (or maximizes) some predetermined linear function of variables. Critical path management (CPM) emerged from linear view to solve the problem of resource use in a process. Similarly, in the same period other research was developed and called Program Evaluation and Review Technique (PERT) (Malcolm et al 1959). The objective of the PERT development was to enhance the scheduling and controlling process of Fleet Ballistic construction in the Cold War.

2.2 Linear thinking and network-based scheduling

In the linear world-view, also called Newton's mechanical world-view, there are distinct connections between cause and effect. Events and processes are static and predictable and have a determined direction of time (Skyttner 2005). Linear thinking thus leads to linear problem and solution concepts. Network-based scheduling as a linear approach relates to networks of activities which obey certain sequencing and duration requirements (Kelley & Walker 1959). Its objective is to find the 'only' minimum time necessary to accomplish all the activities in a process. Traditional CPM uses a single layer of logic which operates only between any two activities. Production occurring inside an activity is described only by duration, and there is no recognition of the repetition of work in multiple locations.

Sheffield et al (2012) categories types of projects and management methods by the number of components and the number of interactions. A low number of interactions and components characterizes a simple system requiring a linear ''waterfall-style'' project management method.

Some scholars have written about the limitations of the linear approach with network-based scheduling methods. In 1992, Koskela encouraged the construction management community to investigate the limitations of network planning methods such as CPM (Koskela 1992). The CPM managerial principle is an obstacle to the recognition of flow processes design and improvement, and thus results in non-optimal flows and an increase of non-value-adding activities. Therefore, network methods are incapable of recognizing workflow of teams or material flows and thus may lead to suboptimal flows and disruptions. Instead, detailed process of late planning, including Last Planner System have been proposed to ensure the continuous flow of work. The main focus of lean construction, in this view, is to make work ready so as to avoid waste. Which could be due to inability to complete activities commenced. Possibly because of the failure of one or more prerequisites to shield production from variation in the planning system (Ballard & Howell 1998).

2.3 Network-based scheduling: a mis-match for construction projects

Network-based scheduling methods were not originally developed for managing construction projects and this led to a mis-match. Catalytic Construction of Philadelphia was the first large construction company that bought CPM in 1961. The construction industry adopted the

same tool without examining its suitability for construction projects. In fact, before a sound theory was developed for scheduling construction projects, the industry adopted the same CPM-based software tools. It was as if the availability of automation dictated the adoption of the methodology, not the methodology pushing the development of tools.

This mis-match was due to the significant difference between planning a manufacturing project and construction project (Kenley 2004). A typical military or NASA project (such as a missile or space vehicle) revolves around a single location assembly of many complex and pre-assembled components, with assembly organized sequentially, but with parallel execution. This situation is suitably planned with network-based methods resulting in a critical path. This context does not describe much of commercial construction which consists of large amounts of on-site fabrication involving continuous or repetitive work.

3 Systems approach

In this paper, the systems approach refers to the set of modern scheduling methodologies, methods and tools used for construction management. In this view, construction production is understood and modeled as a system having a dynamic, probabilistic, relative and less predictable behavior. The systems approach highly values the systems view of construction to provide more interconnections between the elements of a system. In the systems view, the number of interconnections between the elements is maximal. A high number of interactions and a high number of components characterize a more dynamic system requiring a systems thinking project management method. Such a system contains the interacting elements that provide a synergistic, dynamic and harmonious solution to the problem of resource use. The impact of variability in production in a scheduling model is absorbed and controlled by the whole system.

Location-based management and its scheduling methodology has been the most recent attempt to apply systems thinking to production scheduling in construction. Construction projects all have one characteristic that is different from many other projects; location. All construction projects are in a specific location; construction (more and less) takes place at that location. The projects are 'location-oriented', with location being both implicit and explicit during all construction project management. LBM models the construction through the use of location as the unit of analysis. In LBM methodology, location-breakdown structure integrates the isolated relationships between activities into a broader interconnected system.

Section 3.1 outlines the development of series of scheduling methodologies, methods and tools which indicate the tendency for facilitating this new way of thinking. Section 3.2 discusses the nature of systems theory and its relation to construction management. Section 3.3 explains the direct experiences of developing a scheduling model for construction projects. Section 3.4 outlines some of the existing scheduling and BIM software tools which support LBS methodology.

3.1 Origins and drivers

At the end of the 19th century, Professor Karol Adamiecki, who specialized in economics, management and engineering, developed a methodology focusing on work harmonization that was based on a graphical technique called Harmonograms or Harmonograf (Kenley & Seppänen 2009).

In early 1940, Good Year introduced the Line of Balance (LOB) method. The basic principle of this technique is to determine the production rate of finished products in an operation line using a quantity vs. time diagram (Arditi et al 2002). LOB was primarily adopted in production scheduling, but later found vast application in construction industry. Many researchers outlined various advantages of the LOB and Flowline scheduling in comparison to these methods. Several researchers realized that CPM and PERT were incapable of recognizing the significance of workflow and continuity (Selinger 1980), particularly in repetitive construction (Arditi & Albulak 1987).

At the end of the 1990s, the academic research conducted by Helsinki University of Technology in Finland confirmed the significant role of flowline scheduling in increasing

productivity and reducing delays in projects. The research results were used in a software development project to design new software as a tool for planning and control.

Integration of CPM and the results of Kankainen's research projects into a comprehensive software package motivated a new concept that became known as the Location-based Management System (LBMS). Kenley (2004) suggested the term Location Based Scheduling (LBS) for LOB and Flowline scheduling as the methods also strongly suggest location or place in addition to repetition. The term location-based scheduling was proposed to differentiate the emphasis on locations and activities in planning. In location-based methodology, the focus of management is shifted from individual discrete activities to the recognition of work-flow in a construction project.

3.2 Systems thinking and LBS

A system is an interconnected set of elements that are coherently organized in a way that achieves a solution to a problem (Meadows 2008). A system must consist of three kinds of things: elements, interconnections, and a function or purpose. A system in fact is a collection of interacting subsystems that can provide a synergistic output or solution. Systems theory is also related to the concept of holism, a theory about the shared attributes of everything and the methodology of holistic thinking (Bertalanffy 1979).

Location-based management models construction production based on a holistic thinking and systems worldview. The location-based schedule integrates all the activity of the same type and creates a resource flow through different locations. In the world of LBS, the activities which are performed with continuous production through many locations are considered a single task. LBS methodology concentrates on maintaining resource continuity and avoiding waste in production such as interruption, the double-handling of materials, equipment or workers, or rework. LBMS models the production phase based on a dynamic and interconnected system in which elements (activities) are aware of their own and other locations. LBS introduces new layers of logic to CPM which add more detail to both the internal task production of the location-based task, and to the external links between tasks.

Behnam et al. (2016) discuss the linear and systems approach in terms of a control mechanism in construction projects. They state that network-based and location-based scheduling methods focus on two different control ideals; static and dynamic control mechanisms. Management by exception, which CPM and PERT are based on, is an historical default control mechanism based on the perception of control as a static process. However, the new approach claims that a dynamic and proactive systems model is a more effective form of project control.

3.3 Experiences from 'construction'

It is interesting that in a construction project like the Empire State Building (20 years before birth of CPM), the construction practitioners took a scheduling approach which somewhat reflects today's system view of construction. Although it cannot be proven that Adamiecki's location-based thinking was directly adopted in other construction projects in the United States, there seems to be a conceptual relation between his ideas and the methods applied with great success on the construction of the Empire State Building (Kenley & Seppänen 2009). The Starrett Brothers who built the Empire State Building paid special attention to production speed and placed significant importance on the creation of a good team. Their Harmonograms included location by adopting building floors (or even zones) as the unit of control. Similarly, the results from Finnish research projects and the development of alternative software tools reflected the true nature of construction projects, as well as the concerns of construction practitioners about the projects. Again the findings of these research projects highlight the evident mismatch when network-based scheduling methods are applied to production scheduling in construction.

3.4 Software tools

Location-based management system (LBMS) is now considered an integrated network of management system components potentially involving all stages of construction, from design

through to completion. LBMS is not a building information model (BIM) but rather a methodology for interacting with a BIM, placing demands on the BIM for both properties and characterization (breakdown) (Kenley & Harfield 2014).

LBS methodology has now been integrated with commercial software systems such as Vico Office, TILOS and DynaRoad software. Some of the applications of these systems includes reporting through 5D visualization and accurate quantities estimations by location. Vico Schedule Planner creates schedules by using BIM model elements and associating them with tasks and the corresponding materials, resources, and labor; all of which are optimized by location.

The existing network-based software tools should include a location-breakdown structure in their CPM engines in order to implement location-based methodology. Allocation of location allows for: 1. continuous workflow wherever possible within project constraints; 2. planned breaks or multiple crewing to achieve project objectives; 3. alignment of production rates to achieve rhythmic production; 4. enhanced visualization and communication between the subcontractors.

4 Conclusion

The problem of time has been an important question in managing the production phase of construction. Critical path management (CPM) was developed as a solution to the problem of resource use for engineering and manufacturing projects in the 1950s. The construction industry adopted the same tool neglecting the different nature of production in construction projects. In the linear approach with network-based scheduling methods, there are lower number of interconnections and elements in the scheduling model and hence production is modeled as a static and highly predictable process. This resulted in a mis-match and network-based scheduling methods remained the dominant methodology for construction scheduling. However, the continual attempts for seeking alternative methods and tools resulted in a shift in thinking.

The systems approach argues that construction should be viewed as a dynamic system rather than an isolated linear and predictable process which CPM models. Location-based management and its scheduling methodology is a new approach in construction production management. LBS can be considered a systems-based approach, while network-based methods are linear-based.

This paper suggests that a systems approach to scheduling is necessary for better production management and control. A good scheduling model is one that recognizes the dynamic and probabilistic interactions between activities in a construction project. The more connectivity and interconnections between the elements of a scheduling model, the more construction is managed through a system-thinking lens.

An increasing number of scholars write that construction production is a complex system which exists on the edge of chaos. It is recommended to further explore the concept of complexity and chaos in relation to production management and control in construction.

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