

## **Comparative Analysis of Planning with the Critical Path Method, Last Planner System, and Location-Based Techniques in Brazil, Finland, and the United States**

Natalie M. Scala, Ph.D.<sup>1</sup>, Vincent Schiavone, M.S.<sup>2</sup>, Hylton Olivieri, Ph.D.<sup>3</sup>, Olli Seppänen, Ph.D.<sup>4</sup>, Thais da C. L. Alves, Ph.D.<sup>5</sup>, Min Liu, Ph.D.<sup>6</sup>, Ariovaldo Denis Granja, Ph.D.<sup>7</sup>

<sup>1</sup>Associate Professor and Graduate Program Director, Department of Business Analytics and Technology Management, Towson University, Towson, MD 21252. ORCID: <https://orcid.org/0000-0003-2851-134X>. Email: [nscala@towson.edu](mailto:nscala@towson.edu) *Corresponding author*

<sup>2</sup>Formerly, Graduate Assistant, Department of Business Analytics and Technology Management, Towson University, Towson, MD 21252. Email: [vincem.schiavone@gmail.com](mailto:vincem.schiavone@gmail.com)

<sup>3</sup>Professor, Institute for Technological Research, São Paulo, Brazil. Email: [hylton.olivieri@gmail.com](mailto:hylton.olivieri@gmail.com)

<sup>4</sup>Associate Professor, School of Engineering, Dept. of Civil Engineering, Aalto University, Espoo 00076, Finland. ORCID: <https://orcid.org/0000-0002-2008-5924>. Email: [olli.seppanen@aalto.fi](mailto:olli.seppanen@aalto.fi)

<sup>5</sup>Associate Professor, AGC – Paul S. Roel Chair in Construction Engineering and Management, Dept. of Civil, Construction and Environmental Engineering, San Diego State Univ., San Diego, CA 92182. ORCID: <https://orcid.org/0000-0001-7928-9190>. Email: [talves@sdsu.edu](mailto:talves@sdsu.edu)

<sup>6</sup>Professor, Dept. of Civil and Environmental Engineering, Syracuse Univ., Syracuse, NY 1324. ORCID: <https://orcid.org/0000-0002-3070-7109>. Email: [mliu92@syr.edu](mailto:mliu92@syr.edu)

<sup>7</sup>Associate Professor, Construction Management Research Laboratory, Dept. of Architecture and Building, Univ. of Campinas, Campinas, São Paulo 13083-852, Brazil. ORCID: <https://orcid.org/0000-0002-2964-5609>. Email: [adgranja@unicamp.br](mailto:adgranja@unicamp.br)

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## **Abstract**

The Critical Path Method (CPM), the Last Planner System (LPS) and location-based methods, such as the Line of Balance (LB) are discussed extensively in the technical literature about schedules. However, no discussion exists focusing on the differences and similarities of these methods in terms of their use in different countries. Using chi-squared and Fisher's exact tests, this research compared three countries (Brazil, Finland, and United States) and the methods to evaluate both intra- and inter-country implementation to gain additional insights about their use. Results suggest statistically significant intra- and inter-country differences regarding how these methods are used, with a specific focus on mechanics in the countries, offering important information to address their various scheduling needs. The results reflect the current state of practice; engineering and construction managers should understand different ways of understanding scheduling. Such understanding can lead to more efficient communication with collaborators and when incorporating foreign teams in projects. The study identifies the need for further scientific explanation as to why these methods are used in the manner they are intra-country as well as adaptations made in inter-country relationships.

*Keywords:* Scheduling, critical path method, Last Planner System, location-based scheduling

## **Introduction**

The Last Planner System (LPS), the Critical Path Method (CPM), and location-based methods like the Line of Balance (LB) have been used for managing production planning and control across the construction industry, for about 30, 60, and 90 years, respectively (Ballard & Howell, 1994a,b; Kelley & Walker, 1959; Willis & Friedman, 1998). Studies on any of these techniques individually have abounded in the construction engineering and engineering management literature (e.g., Ballard & Howell, 1994a,b; Jaafari, 1984; Kenley & Seppänen, 2010; Prendergast & Gobeli, 1991; Partovi & Burton, 1993). Additionally, analyses of their use in combination (Seppänen, et al., 2010; Lucko, et al., 2013; Brittle, et al. 2018; Olivieri, et al., 2016b; AlNasseri & Aulin, 2015) or those comparing and contrasting their similarities and differences (Olivieri, et al., 2018, 2019) are gaining more interest from both academics and practitioners. These techniques are not mutually exclusive, and shortcomings of one method can be addressed by strengths of another. For instance, LBMS includes a social process which partly overlaps with the LPS as it involves project participants in schedule generation. The various systems can be combined or used in isolation (Olivieri, et al., 2016b). However, for that to happen, the practices used to develop project schedules using each of these techniques must be understood so that practitioners attempting to employ these methods in combination are aware of how they align and differ in executing the scheduling process. Furthermore, the CPM has been used extensively across industries as a project scheduling method, while historically the LPS and LB have been primarily used in the construction industry (Lucko, et al., 2013).

Construction management research has been criticized for its lack of impact, as its research problems and methods have not been aligned with its practical developments (Koskela, 2017). One reason for this apparent lack of relevance in production planning and control could be that best practices for actual implementation stray quite far from theory. For example, Galloway (2006)

analyzed the use of the CPM in the United States and noted limited consistency among practices used within the country. Similar studies have been conducted on the LPS (e.g., Fernandez-Solis, et al., 2013) and LB (e.g., Kim, et al., 2014). These studies have found implementation challenges related to these methods within individual countries. Regardless of these noted challenges, new research on each method is being published; however, these typically feature case studies from just a single country at a time. Without understanding the differences between countries, it is difficult to understand to which contexts the research results can be generalized. Therefore, comparisons between different contexts are useful for both theory and practice to shed light on any specific differences.

With that in mind, this study compares these three techniques (CPM, LPS, and LB) by considering how schedules are planned using responses obtained from a survey with data representing three different countries on three different continents: Brazil, Finland, and the United States. Our initial assumption is that, although the same methods are used in these countries, their emphasis on implementation and practice differs.

Specifically, we examine the use and application of the methods in the three countries by analyzing differences in their implementation. These differences are used to develop initial hypotheses that are then statistically tested using a survey instrument that was implemented in the three countries. The test results shed light on how construction projects are managed within countries and how the CPM, LPS, and LB methods are used. The practical contributions and industry implications of this work include an assessment of the current state of practice in the three countries and a discussion of both the strengths and shortcomings of the three methods. No previous study has been conducted that analyzes such characteristics or how they manifest across different countries, especially in the context of construction.

Brazil, Finland, and the United States were chosen for this study because these countries have “...several documented case studies of each type of planning and controlling system. Furthermore, collecting data across multiple countries can allow for future work of cross-culture analysis” (Oliveiri, et al., 2019, p.4). This paper begins to address the cross-culture inter- and intra-country analysis first proposed by Olivieri, et al. (2019). There are also marked differences between the three countries (i.e., size, population, culture, construction methods, contracts, GDP, etc.) which would allow for a comparison of how countries with these differences and approaches to construction would use these methods. Additionally, this was a sample of convenience with available access to extensive networks that could maximize the distribution of the surveys in the three countries.

## **Literature Review**

To frame the analysis, we begin with a review of the three methods considered in this study in terms of their use, strengths, and shortcomings.

### ***The Critical Path Method***

Schedules developed using the CPM are based on networks of activities or tasks that are linked based on the logic and sequencing needed to complete a project. The CPM method incorporates many concepts in its use, such as the work breakdown structure, critical path, free and total float, and visualization via Gantt charts (Olivieri, et al. 2016b; 2018). CPM schedules are often contractually required, and failure to abide by the logic and sequencing of tasks illustrated in CPM-based schedules can lead to construction project disputes. Additionally, well-known project management metrics are grounded in the relationships between CPM-based schedules and resource curves used to evaluate project performance, such as Earned Value Analysis (PMBOK, 2017). The relationship between the project duration, as defined by the critical path, and costs has

also been explored to reduce time to completion (Sayer, et al., 1960). Costs, risks, and delays have also been examined in construction as a particular subset of engineering projects (Pehlivan & Oztemir, 2018). Additionally, in Galloway's (2006) study on the CPM, the majority of respondents (75% or more) indicated the method was used to support control functions during and after construction, inform decision-making regarding execution, serve as the basis for the development of lookahead schedules, coordinate subcontractors, and perform schedule impact and delay analysis.

Despite the many shortcomings of the CPM (Jaafari, 1984; Koskela, et al., 2014), the method is the preferred choice of construction owners and contractors, even if the method is not properly understood in practice (Alves, et al., 2020). CPM was originally based on activity-on-arrow deterministic scheduling but is now commonly practiced as activity-on-node scheduling; this research adopts the industry software standard activity-on-node approach. CPM shortcomings have been attributed to the human side of project management, including the lack of experience or willingness of contractors, variations in output rates, the use of multiple contracts to accommodate large scopes of work, and a lack of detailed design (Jaafari, 1984). However, its popularity within the construction industry appears unchanged: even when alternative methods are used, the CPM is still employed to generate or validate schedules. Because of this and to address shortcomings, attempts have been made to jointly use the CPM alongside other methods (e.g., the LPS and LB) (Olivieri, et al., 2016a,b).

### ***The Last Planner System***

The Last Planner System (LPS) of production control, which was developed in the United States by Glenn Ballard and Gregory Howell (1994a,b) in the early to mid-1990s, addresses the last planners, who are the direct managers physically closest to the construction site, in an effort

to improve the reliability of the plans given to the workers. The LPS was adopted as one of the first systems aimed at production control (Ballard, 2000b) to achieve basic stability of the whole production system (Smalley, 2005).

The LPS method, as originally conceived in the 1990s, is not a scheduling method like the CPM. However, it has evolved over the past 25–30 years, and, in its current form, features the use of one of its levels, pull/phase planning, to simultaneously define work packages alongside their scheduling based on a backward “pull” mechanism (Ballard, 2000a,b). The LPS method also supports the scheduling function in the development of plans with different levels of detail in order to achieve project milestones. Milestones represented in the project master schedule, typically produced using the CPM or LB, become the starting points for the collective development of plans made by the trades and professionals executing the work. Using the pull planning logic, project participants are asked for tasks to be completed for each milestone to be achieved. Those directly involved with major phases of the project indicate what needs to be done and what resources they need from previous tasks to complete their work, thus establishing a “pull” mechanism between those who need resources and those providing them. The pull planning or phase scheduling component of the LPS (Ballard, 2000a,b), as well other enhancements in the system, have become increasingly popular in the United States and other countries over the past 10 years (Daniel, et al., 2015), and the LPS is commonly used to support the delivery of cost effective, safe, and timely projects (Demirkesen & Bayhan, 2019, 2020). In fact, the basic tenets and tools associated with the LPS can be used to support the delivery of engineering projects beyond construction (e.g., Jünge, et al., 2015, Sivaganesh & Ratnayake, 2018).

However, the LPS has documented shortcomings. These can be traced to, for instance, inconsistent implementation of its components (Daniel, et al., 2015, 2017), large amounts of

generated data that require handling by an appropriate information management system (Lagos, et al., 2019), and the lack of meaningful indicators at the project level (Hamzeh, et al., 2019).

### ***Location-Based Methods***

Location-based management systems (LBMS) are a comprehensive new production control system for construction that focuses on project planning, scheduling, and control, as well as time, cost, and quality in its implementation (Kenley & Seppänen, 2010). The LBMS is a broader approach / concept and may be considered the latest evolution of location-based methods, like LB schedules. Location-based methods make use of location knowledge as an integral part of the planning process. In this sense, the LB technique is one sort of location-based approach (Kenley & Seppänen, 2010), with a strong emphasis on repetition. Initially, the location-based system approach considered the characteristic elements of production planning only and not the control process (Kenley, 2004). Later on, the elements of production planning and control were combined and gave rise to the LBMS system (Kenley & Seppänen, 2010). In general, LBMS planning aims to maximize the flow of crews and locations workflows, thereby facilitating resource smoothing, reducing the number of planning elements required, and improving the visualization of the schedules (Olivieri, et al., 2018). In production control, the LBMS calculates schedule forecasts, which are then used to perform proactive production control aimed at decreasing cascading delays (Seppänen, et al., 2014). The same crew can complete a task in a location with no interruptions and share the same external dependencies to other tasks (Kenley & Seppänen, 2010). The LBMS differs from other location-based methods by including CPM precedence logic and attempting to achieve a better distribution of resources. The system automates the creation of CPM logic by using five different logic layers that automatically form repeating logic between the same tasks at different locations (Kenley &

Seppänen, 2010). The layered logic greatly simplifies the schedules and decreases the number of planning elements involved (Olivieri, et al., 2018).

In summary, each method has strengths and shortcomings that become apparent in the management of projects in practice. At the same time, cultural and learned behaviors of the project's planning team influence both the choice of method and its subsequent application in various countries. The next section discusses implementation within the analyzed countries.

### ***Methods Used in Brazil, Finland, and the United States***

The three countries analyzed in this study have different histories in terms of how they use and manage CPM, LPS, and LB. This review provides some background on the use of these methods in Brazil, Finland, and the United States. This review incorporates peer-reviewed literature as available. However, most of the best practices are described in industry publications within each country and documented through empirical experience. Practical industry documentation, which includes materials written in Portuguese and Finnish, have been reviewed by the authors and incorporated in this review.

#### ***Brazil***

In general, traditional planning based on the CPM approach is still the dominant method in the Brazilian construction industry to date; it is also used across industries (e.g. Laurindo & Monteiro de Carvalho, 2005). The CPM is widely used by construction companies for the management of construction projects (De Filippi, 2017) due the popularity of the Project Management Institute (PMI) methodology and body of knowledge (PMBOK, 2017). Furthermore, CPM schedules are required contractual documents for both public and private projects. In housing projects, CPM schedules and cash flow projections are usually required to obtain production financing from public agencies (CEF, 2020).

Typical CPM schedules for construction projects in Brazil are developed based on a detailed work breakdown structure, which results in hundreds of tasks (Olivieri, et al., 2018). Construction companies with PMI management roots tend to develop project schedules emphasizing the logic links between tasks in order to focus on planning and control analysis based on the critical path. Although construction production rate tables exist (e.g., CEF, 2017a,b,c; TCPO, 2012), durations of tasks are usually defined by predictions based on previous similar projects, consulting subcontractors (Olivieri, et al., 2018), and quantities of work. Typical tasks involved in high-rise building construction, for example, are based on short-length durations of up to 10 working days.

The LPS and LB typically characterize the planning and scheduling system of lean-oriented construction companies as well as those using a mix of strategies in their projects (e.g., Kemmer, et al., 2008; Lucko, et al., 2013; Olivieri, et al., 2016a,b). In practice, both methods have been used in the same project; however, practitioners often have difficulty in deciding which system to use when making decisions (Olivieri, et al., 2016b). Therefore, hybrid and integrated models that combine the CPM, LPS, and LB to capitalize on these approaches' strengths have been adopted by some construction companies in Brazil (Olivieri, et al., 2018).

Regarding the LPS, while its first applications date back to 1993 (Ballard, 2000a,b), the system has been used in Brazil since the late 1990s with the aim of improving the performance of production systems (e.g., Formoso, et al., 1998). Master schedules composed of few tasks are not commonly used for managing production planning and control. However, phase schedule initiatives (Ballard, 2000a; 2016) have been adopted by construction companies in Brazil, thus transitioning from traditional to lean management. Considering LPS short-term analysis, namely commitment planning, task durations are usually defined by contractors' experiences and then

validated by subcontractors, with adjustments made where necessary. Because LPS schedules break tasks down into smaller packages, these schedules therefore contain more tasks than CPM and LB schedules. Consequently, task durations are normally planned to fit one work week. While the LPS's short-term plans are suitable to obtain the commitment of subcontractors and are used for decision-making at operational levels, CPM schedules in Brazil are normally used to support decision-making at the tactic and strategic management levels.

In Brazil, LB techniques and tools are introduced for the purpose of improving the flow of resources and labor as well as the overall construction schedule (Olivieri, et al., 2018). In LB schedules, task durations are usually defined by contractors and validated by subcontractors, with the consideration of previous similar projects as well as critical processes, quantities, locations, and production cycle times. Task durations are mostly determined based on predicted production cycle times and key processes, which usually last between one and two weeks. Finally, site teams are supposed to break down tasks into progressive levels of detail, define the production rates and required resources, and size trade crews with the subcontractors. As a result, schedules usually contain hundreds of tasks.

### *Finland*

In Finland, the standard scheduling practices used in the industry are described in the publications of the Confederation of Finnish Construction Industries. In the organization's scheduling best-practice book (Koskenvesa & Sahlstedt, 2017), the CPM is introduced as a historical method, stating that it was the primary scheduling tool used until the 1980s and 1990s. The book identifies lean construction, along with the LPS, as more modern methods of managing operations. Critical paths are not considered current best practices. According to the book, the key aspects of project master schedules include identifying tasks, quantities, resources, and

consumption rates and then using those definitions to calculate task durations. The book emphasizes basing durations on accurately calculated quantities and resources for each defined project location and using industry-standard productivity rates if no other rates are available. The Finnish construction industry has developed a productivity database (Ratu), which includes consumption rates for all main types of construction work (DigiRatu, 2020). The key criteria for evaluating schedules include clarity, understandability (prioritized over the number of tasks in the schedule), and calculations of durations.

According to the description of a Finnish contractor's standard scheduling process, logical dependencies are planned to ensure feasibility of the schedule; master schedules have 15-20 most important tasks scheduled with location-based approaches, with the remaining tasks scheduled using CPM and presented in Gantt Charts (Soini, Leskelä, & Seppänen, 2004). The proposed way to check logic is to visualize the schedule in a flowline diagram and look for overlapping tasks in the same location (Koskenvesa & Sahlstedt, 2017). In project disputes in Finland, the project schedules have lacked clearly defined logic or a critical path, so analysis of these are mostly developed by experts during litigation after the project has been completed. The lack of contemporaneous information and agreement related to logic has complicated dispute resolution, as parties mostly tend to consider variations between actual and planned dates rather than logic and durations. This lack of attention paid to documentation during the construction phase is probably due to the fact that litigation is not common in Finland.

Contractually, most Finnish construction contracts use generic terms and conditions agreed upon by owners and contractors (Oksanen, Laine & Kaskiaro, 2011), and these generic contracts do not include clauses regarding scheduling requirements. The owners typically have additional requirements for schedules, but the CPM is not mandated. A typical set of requirements includes

calculating durations based on quantities and resource-loading, ensuring adequate buffers in the schedule, and creating monthly schedule reports. Presenting schedules in a flowline format is also often mandated. The schedule reports are typically presented in a Gantt chart format, which identifies early and late tasks via a progress line drawn through the schedule with explanation of any deviations.

When location-based scheduling is used, the emphasis is on planning for continuous flow and calculating the optimum crew size for each task based on quantities and productivity rates. Resulting flowline figures are visually evaluated by planners and, in practical implementations, rarely include logical links. The planners account for dependencies between tasks mostly visually by ensuring the flowlines do not cross. The published book of Finnish best practices and the reported Finnish case study propose limiting the number of flowlines to 20–30 to ensure schedule clarity (Koskenvesa & Sahlstedt, 2017; Soini, Leskelä, & Seppänen, 2004).

The LPS is mostly implemented for its social process, as it brings together designers, managers, tradespeople, owners, and suppliers to define the plans. Pull scheduling or reversed phase scheduling and weekly planning are emphasized and widely implemented in leading construction companies (Koskenvesa & Koskela, 2012). Last Planner is often combined with location-based methods (Seppänen, Ballard, & Pesonen, 2010). Because the LPS is seen mostly as a collaborative scheduling technique, its use in projects typically decreases the emphasis on duration calculations and instead emphasizes durations provided by subcontractors. On the other hand, the level of detail in LPS schedules is typically much higher than that of other schedule formats, as the contractors will include all tasks required to complete a phase.

*The United States of America*

The use of CPM schedules in the United States is a contractual requirement of owners for construction projects. After signing the contract, owners expect to receive a CPM schedule, which is used to guide completion of the construction tasks within a defined timeframe (e.g., 10–30 days). Critical tasks are recognized as those in the project’s critical path, and language is added to contracts to address any potential delays and impacts on those tasks, as indicated in well-known contract series used in the United States (e.g., AIA, 2022; ConsensusDocs, 2022). As CPM schedules are contractual documents that support time and cost management, thousands of tasks are represented in the master schedule submitted to the owner by the contractor (Alves, et al., 2021). The durations of these tasks usually rely on company data or trade/industry publications. Additionally, the tasks are logically linked, and the critical path is clearly indicated.

While the CPM is ubiquitous in the U.S. construction industry (Galloway, 2006; Olivieri, et al., 2019), the LPS has been gaining more acceptance from U.S. construction organizations as an alternative method for driving the execution of plans based on input from those closest to the tasks. LPS implementation has been supported by the Lean Construction Institute (LCI) in the United States since the 1990s. However, its popularity received a boost in the U.S. in the early 2000s due to the incorporation of the LPS in integrated project delivery (IPD) contracts developed in Northern California by an owner organization (Lichtig, 2005). Recently, the ConsensusDocs 300 series added a contractual Lean Addendum (305) that details a number of lean construction tools and processes, including the LPS, which can be used alongside any delivery method (Darrington, 2019). Related studies, such as Demirkesen and Bayhan (2020), identify best practices to successfully implement lean in construction, potentially leading to greater adoption and acceptance of the LPS in the United States.

Given the prevalence of the CPM and its required use per contractual terms, the LPS is usually implemented in conjunction with CPM schedules. Milestones defined in the CPM schedule are used as starting points for the development of pull plans for major phases throughout the project (Alves, et al. 2021). From there, lookahead schedules of four to six weeks are usually derived, with tasks organized on large boards each representing one week; these boards then display sticky notes detailing the tasks organized by day. These boards comprise the weekly work plans of the project, and they are adjusted weekly to both reflect the current state of tasks at the project site and update the constraint log (Ballard & Tommelein, 2021; Umstot & Fauchier, 2017).

The Line of Balance was successfully used in the construction of the Empire State Building in the United States in the early 1930s (Willis, 1998). It is the oldest of the techniques analyzed in this study and also originally developed in the United States. While the LB supported the tight coordination of deliverables, established flow, and produced a constant “beat” (*takt*) for the delivery of the Empire State Building (Bascomb, 2003; Sacks & Partouche, 2010), its use in the United States is minimal compared to the CPM and even its younger counterpart, the LPS (Olivieri, et al., 2019). Fewer tasks are represented in LB schedules compared to in CPM schedules, and, to facilitate flow, task durations are defined based on the quantities to be delivered within pre-defined time intervals.

## **Hypotheses**

Understanding how the three countries use these methods as well as the background of each method led to framing the hypotheses and scope of the analysis. The key differences observed from the literature and inter-country and intra-country comparisons are highlighted in Exhibit 1.

*Insert Exhibit 1 here.*

Most of the differences are driven from country descriptions related to numbers of tasks in schedules, how durations are derived, and whether logic links were used. Based on these differences in implementation and use, nine hypotheses were defined for this analysis. This study and its related hypotheses were derived from a combination of factors:

1. There is no study in the literature comparing these methods across different countries. Even the literature of a single country as exemplified by Galloway (2006) does not account for additional methods.
2. Information about any of the methods is not available at the level of detail presented for any single method studied.
3. When comparisons across different methods were made in previous literature, they were focused on a single country or a more modest number of respondents (e.g., Olivieri, et al. 2016b, Brittle, et al., 2018).
4. The inter-country and intra-country comparisons of these methods stem from the literature argument presented in Olivieri, et al. (2019) that was expanded upon in this research to include inter-country and intra-country discussions. The development of the hypotheses to be investigated also relies on empirical industry and practice experience with these methods.

Therefore, this study tests inter-country and intra-country differences for the methods, enabling a more nuanced analysis. The null hypotheses of interest are defined below.

### ***Hypotheses Related to the CPM***

H1a: There are no differences regarding the number of tasks in CPM schedules.

H1b: There are no differences regarding the use of logic links in CPM schedules.

H2: There are no differences regarding how durations are defined in CPM schedules.

H3: There are no differences regarding average task durations in CPM schedules.

#### ***Hypotheses Related to the LPS***

H4: There are no differences regarding how task durations are defined in LPS schedules.

H5: There are no differences regarding average task durations in LPS schedules.

H6: There are no differences regarding the number of tasks in LPS schedules.

#### ***Hypotheses Related to LB***

H7: There are no differences regarding how task durations are defined in LB schedules.

H8: There are no differences regarding average task durations in LB schedules.

H9: There are no differences regarding the number of tasks in LB schedules.

To examine the accuracy of these statements, a statistical approach was taken. The results of these analyses reveal patterns and differences in the use of these methods within the countries (intra-country) and differences between them (inter-country). The discussion then provides context to the results, including hypotheses that should be rejected.

#### **Research Method**

Each hypothesis was investigated using the chi-squared or Fisher's exact test to identify  $p$ -values and potential pairwise statistical significance in methods both intra-country and inter-country. Detailed discussion of the survey design, dataset, and analysis methods follow. An illustration of the process undertaken for entire research design can be found in Exhibit 2.

*Insert Exhibit 2 here.*

#### ***Survey Creation and Data Preparation***

This study built from survey data first presented in Olivieri, et al. (2019). The survey design employed six steps defined by Forza (2002) that, when followed, enable the collection of usable and accurate data. These six steps are (1) linking to theory; (2) design; (3) pilot testing; (4)

collecting data for theory testing; (5) analyzing the data; and (6) generating a report. The survey first assessed respondent backgrounds and demographics to consider their professional experience in production planning and control systems, companies, and culture. Respondents were then asked to identify use of any of the three planning methods (CPM, LB, and LPS) in their work. For each method used, a set of follow-up questions was then displayed inquiring about specifics. Topics in the follow-up questions included contractual requirements, critical path analysis, managing contracts, management of delay and change, continuous flow and the continuous use of resources, improving production control, identification of the root causes of delays, treatment of interference between activities, reduction in uncertainty and constraints, and improving production control. If the method(s) were not used by the professional in practice, then the follow up questions about the method(s) were not displayed. Additionally, a short definition of each method was included in the survey to ensure understanding and reduce conceptual doubt (Olivieri, et al., 2019). The method-specific questions included in the survey were based on other studies in the literature, including Tavakoli and Riachi (1990), Galloway (2006), and Khanh and Kim (2016). The full survey can be found in the Appendix.

The survey was initially written in English and then translated into multiple languages, including Portuguese (Brazilian) and Finnish, for distribution in the U.S., Brazil, and Finland. The translation was done by native and English-bilingual speakers of each language and then validated by two additional native speakers of each language to ensure no loss of meaning. A small pilot study was then conducted, comprised of master's students in the United States and Brazil, with appropriate adjustments made based on the pilot participant feedback. Purposeful sampling (Patton, 1990) was used to distribute the survey to architects, engineers, and managers working within construction management, with the goal of obtaining at least 100 usable responses from

each country. Qualtrics was used as the online data collection platform, and the survey was open for responses between January and June of 2017. Distribution occurred via social media platforms (i.e., LinkedIn and ResearchGate), professional networks, construction companies, universities with construction programs, and construction industry institutes within the three countries (e.g., the Construction Industry Institute in the United States and both the Construction Industry Trade Union and Brazilian Chamber for the Construction Industry in Brazil). Participants received the survey in their native language. No incentives were used to promote or increase the response rate, and no specific organization or field was targeted. The distributed survey was reviewed and classified as exempt by the Institutional Review Board at Towson University (protocol number: 1612011775).

### ***Sample Size and Demographics***

A total of 736 responses were initially received; the data was then cleaned for unanswered questions, responses from outside these three countries of interest, incomplete data, and answers from respondents who either did not provide informed consent or did not report the use of at least one planning method. Listwise deletion addressed missing data associated with usable responses from these three countries. The final sample size for this analysis was 430 in total, with 168 responses from Brazil, 132 from Finland, and 130 from the United States. Exhibit 3, adapted from Olivieri, et al. (2019), illustrates the demographics of the respondents from each country.

*Insert Exhibit 3 here.*

Olivieri, et al. (2019) specifically studied theoretical hypotheses related to project management and project production management with this data, grouping the data by method (CPM, LPS, and LB) and only considering statistical differences between the methods in general (not by country). This paper's analysis constitutes a different approach to the existing dataset and

establishes practical insights based on inter-country and intra-country use and differences. The results of this analysis are focused on practitioners and identify opportunities for method use and improvement in industry. Olivieri, et al. (2019) were the first to compare the CPM, LPS, and LB using a single instrument, and we extend the novel use of this single instrument to include both cross-country and cross-method analyses. Therefore, although the same dataset was the basis for each analysis, multiple sets of results could be obtained from the hypotheses of Olivieri, et al. (2019) and the intra-country and inter-country hypotheses proposed in this paper.

### ***Analysis Using Chi-Squared and Fisher's Exact Test***

The analysis was performed using chi-squared and Fisher's exact tests, which compared the countries for a single method (inter-country) as well as the methods within a single country (intra-country) to gain insights and identify differences in use and implementation.

Chi-squared statistical tests were applied to the data for each hypothesis. The assumption in a chi-squared test is that the null hypothesis assumes no differences or that the data are independent. Then, the null hypothesis is rejected with a significantly low  $p$ -value, thereby concluding enough evidence to support that the data are not independent or that some differences exist within the dataset. The Fisher's exact test is used when any bin or pairwise count in the chi-squared contingency table is less than or equal to five; the Fisher's test is a substitute statistic for the chi-square under the conditions of a small sample size. The chi-squared test can be unreliable with small sample sizes within the bins of its table. Microsoft Excel was used to calculate all tests.

### **Results**

To ease and provide clarity to the discussion, the hypotheses are grouped by keywords or schedule characteristics when conducting the analysis. These groups are *the number of tasks included in the schedules* (H1a, H6, H9), *the way in which durations are defined* (H2, H4, H7),

and *average task durations* (H3, H5, H8). Results are reported in Exhibit 4, with both intra-country (left hand side) and inter-country (right hand side) analyses. Differences related to *logical links* (H1b) are hypothesized for just the CPM due to the design of the method; those results are shown in Exhibit 5. For all chi-squared and Fisher's *p*-values in Exhibits 4 and 5, asterisks denote significance.

*Insert Exhibit 4 here.*

### ***Number of Tasks in the Schedules (H1a, H6, H9)***

- H1a: There are no differences regarding the number of tasks in CPM schedules.
- H6: There are no differences regarding the number of tasks in LPS schedules.
- H9: There are no differences regarding the number of tasks in LB schedules.

The null hypotheses were rejected for all methods, indicating statistically significant inter-country differences (Exhibit 4, Number of Tasks). In Finland, the CPM schedules were described (60% of respondents) as planned with a low level of detail and typically included fewer than 100 tasks. Meanwhile, in the United States, 67% of the respondents reported more than 500 tasks in their schedules, and a high proportion (43%) reported more than 1000 tasks. The Brazilians were in the middle, reporting the inclusion of more tasks than in Finland but fewer than in the United States. The LPS and LB showed similar trends, with the U.S. respondents tending to report more tasks than their counterparts in Finland and Brazil.

There were no statistically significant intra-country differences in terms of the number of tasks in the United States or Finland. This finding might be related to these countries using software packages which automate generation of these schedules and allow for the manipulation of large numbers of activities, regardless of the method used. However, the number of schedule tasks statistically differed in Brazil depending on the scheduling method used. In particular, CPM

schedules in Brazil tended to include many more tasks than LB schedules, which normally include 100 or fewer tasks. CPM schedules in Brazil are used for schedule and project management, tied to contractual requirements and payments, and developed using software packages; whereas LB schedules are not contractually required and are usually developed manually or with the use of MS Excel. In fact, LB schedules in Brazil, as described in the literature (see Kemmer, et al., 2008; Lucko, et al., 2013), support production management at the site and serve as visual management tools to communicate where trades are at any given point and which work packages, usually defined based on LPS recommendations, are being executed. The LB method requires users to evaluate and balance the duration and pace for completing multiple tasks simultaneously, making its use challenging with a higher number of tasks. Also, including too many tasks in LB schedules defeats the purpose of representing the broad flow of project tasks. Evaluating, balancing, and displaying too many tasks could explain industry respondents' preference for fewer tasks in LB schedules. On the other hand, the CPM is a useful tool and commonly accepted standard for reporting and communicating schedule deadlines. It is used heavily when the number of tasks and participants increases, because it becomes critical to monitor and track deadlines with greater schedule complexity. See Exhibit 4 for the analysis.

***Definition of Activity Durations (H2, H4, H7)***

- H2: There are no differences regarding how durations are defined in CPM schedules.
- H4: There are no differences regarding how task durations are defined in LPS schedules.
- H7: There are no differences regarding how task durations are defined in LB schedules.

The null hypotheses were rejected for all methods, indicating statistically significant inter-country differences. Note that, in Exhibit 4 (Activity Durations), the full definitions of the bins,

reflecting how practitioner respondents derived durations, are (a) through experience only, (b) based on quantity and production rates, (c) by asking subcontractors, (d) using combination of these approaches, or (e) other. When using the CPM, U.S. project managers mostly reported using a combination of approaches (87% of respondents), while the Finnish and Brazilian respondents tended to rely more on single approaches (a combination of approaches was reported by 54% and 53% of respondents, respectively.) The distributions of responses for CPM durations were almost identical for Finland and Brazil. When the CPM was used, Finnish and Brazilian respondents reported relying on either experience (23% and 24%, respectively) or quantities and productivity rates (21% and 19%, respectively) to establish durations.

When the LPS was used, U.S. respondents still tended to utilize a combination of approaches to determine durations (74%). However, when using the LPS, both U.S. and Finnish respondents reported relying more on subcontractors as sources of duration data (13% and 17%, respectively). In contrast, Brazilian respondents relied more on quantity and productivity rate information when determining durations in LPS schedules (29%), and no Brazilian respondents relied solely on subcontractor input when using the LPS.

When the LB was used, Finnish respondents tended to base durations on quantity and productivity rate information (49%), while respondents from the United States and Brazil relied on this much less: 23% and 19% respectively. This result suggests that Finnish respondents were more proficient in deriving LB task durations based on quantity and productivity rates, and this aligns with the differences in scheduling contract requirements. Rather than using quantities and productivity rates, U.S. and Brazilian respondents reported the tendency to use a combination of approaches (77% and 60%, respectively), and Brazilians had the highest percentage of respondents relying on experience only (17%).

There were statistically significant intra-county differences in determinations of activity durations in both the United States and Finland. No such relationship was found for Brazil. In the United States, when using the CPM or LB, no respondents reported asking subcontractors for their input to determine activity durations. A similar trend was found for Finland, with only 1% of CPM projects using subcontractor input to determine activity durations. No Finnish respondents reported asking subcontractors when using LB, but 17% of respondents asked for subcontractor input when using the LPS. This might indicate that the LPS is a method that favors subcontractor opinion in the determination of activity durations for schedules. This social process is emphasized in the implementation of the Last Planner System in Finland, with commitments sought from subcontractors. This is a key element for reliable planning because subcontractors are those who best know how long it will take to complete an activity.

Another aspect to note, in both the United States and Finland, was the emphasis on quantities and productivity rates when using LB. In the United States, quantities and productivity rates were seldom described as being used as the main method for duration determination when schedules were made using the CPM or LPS (8% and 4%, respectively). However, 23% of respondents using LB indicated duration determination based on quantity and productivity information. Similarly, in Finland, quantity and productivity rate information was less frequently used in combination with the CPM or LPS (21% and 14%, respectively), but 49% of the respondents reported using quantities and productivity rates when scheduling with LB. In general, LB focuses on quantities and productivity rates, which was reflected in these results but, interestingly, not for Brazil, where the share of LB users determining durations based on quantities was not higher than the other methods.

#### ***Average Task Durations (H3, H5, H8)***

- H3: There are no differences regarding average task durations in CPM schedules.
- H5: There are no differences regarding average task durations in LPS schedules.
- H8: There are no differences regarding average task durations in LB schedules.

All inter-country null hypotheses were rejected; statistically significant differences exist between the countries in terms of the average durations of activities within a single method (Exhibit 4, Average Task Durations). When using the CPM, both U.S. and Brazilian respondents tended to favor durations of one to two weeks (59% and 52%, respectively). Finland was noticeably different, with a majority of CPM users reporting long durations of over two weeks (59%). Very few Finnish CPM schedules had an average duration of less than a week (7%), while the United States (14%) and Brazil (23%) had more responses in this time frame.

A similar trend was found for the LPS. Finnish respondents tended to report longer durations when using the LPS (42% for over two weeks). Interestingly, the U.S. respondents using the LPS frequently reported durations of less than a week (58%). Although short average durations were relatively common in both Brazil and Finland (29% and 26%, respectively), significantly smaller shares of respondents indicated shorter durations in these countries compared to the United States.

Inter-country differences in average durations when using LB were the most significant at  $p < 0.001$ . No U.S. respondents using LB reported average durations of more than two weeks, while 53% of respondents from Finland and 23% of respondents from Brazil reported long durations in their LB schedules. There were just 13 LB users in the U.S. group, and they were evenly split between durations of less than a week (46%) and one to two weeks (54%). Short durations of less than a week were rare in Finland (14%) and Brazil (20%). With this method,

respondents from the United States preferred shorter average durations; respondents in Finland preferred longer average durations; and respondents in Brazil were in the middle.

However, it should be noted that the average duration survey question could have been interpreted differently in different contexts. In Finnish best practices, a task is viewed as one continuous operation (e.g., frame walls) moving to multiple locations; thus, it is desirable to maximize its duration to achieve continuous work. In the United States, the respondents may have interpreted the question as referring to the duration at each location rather than the continuous operation as a whole.

When examining intra-country differences, only the United States was statistically significant: LPS and LB users tended to report shorter durations than CPM users. LB schedules typically feature many repeating locations with short durations per location. When the LPS is used, managers tend to plan and coordinate activities over time spans of less than a week and manage them more frequently. Interestingly, no such trend in duration was observed in Finland or Brazil.

### ***Logical Links (H1b)***

- H1b: There are no differences regarding the use of logic links in CPM schedules.

The inter-country null hypothesis was rejected for the CPM (Exhibit 5). Comparisons of the logical links in the LB and LPS were omitted from the exhibit, as just the CPM is generally associated with logic links. LB and LPS can also be implemented without a technical system based on logical precedence relationships. As a result, a statistical comparison of logical links for these methods may be misleading. Because just the CPM is considered in H1b, intra-country analysis was also omitted. Respondents from the United States and Brazil tended to report logic links for all tasks (86% and 83%, respectively). In contrast, just 10% of Finnish respondents reported the use of logic links in CPM schedules, thus demonstrating significant differences between Finland

and the two other countries. The lack of logic links means most Finnish schedules cannot be used to calculate the impact of delays. This could be because, in Finland, litigation is not common, and interpersonal trust is rated one of the highest in the world (Andreasson, 2017). Case study research has shown that communication and collaboration also improve trust in Finland (Uusitalo, et al., 2021). Therefore, logical links between tasks are not emphasized as much in Finland for documentation and litigation purposes.

*Insert Exhibit 5 here.*

### **Conclusions and Implications for the Engineering Manager**

This study sheds light on how Brazil, Finland, and the United States use the CPM, LPS, and LB, with a specific focus on the mechanics of these methods characterized by the number of tasks involved, the use of logic links, how durations are defined, and the average task durations in the schedules. All inter-country null hypotheses were rejected, indicating statistically significant differences between the countries in the use of the scheduling methods. When examining intra-country differences, the following additional relationships were also significant between the methods:

- Differences in the number of tasks were significant in Brazil.
- Differences in activity duration determination were significant in the United States and Finland.
- Differences in the average task duration were significant in the United States.

These results reflect the current state of practice. The contributions of this research include an investigation based on practitioner input in the United States, Finland, and Brazil that considers the methods that are being used, how they are used, and how practitioners address scheduling and planning of construction tasks within these countries. As documented in the literature reviewed,

the methods are used in all three countries, with the CPM being the most prevalent of the three methods, followed by the LB and LPS. In all countries, the inter-country statistical significance of the hypotheses points to a very important finding: despite the fact the three methods investigated are described in the technical literature and considered as standards across the industry, they are not used consistently across these three countries. The results suggest no standard implementation practice or use across these three countries; local culture might play a major role in how these methods are applied.

Future research can investigate additional cultural and industry-specific contexts and the corresponding impact on method usage. Future work could also examine potential inter- and intra-country differences in typical industry use of the methods and practices. Such an analysis could examine specific industries and areas identified in Exhibit 3 and drill down to potential differences at these detailed levels both within and between countries. The method and the hypotheses developed in this research could be used by others to expand the population to different countries and continents while also diving into the details of different industry sectors.

The value of this study can be attributed to the originality and 'first of its kind' nature to support further scientific explanation as to why these methods are used the way they are intra-country as well as adaptations made in the investigated inter-country relationships. Extending this approach and data may provide additional insights for academic theory beyond research that supports industry practitioners. Future work can also address limitations of this study, which include the impact of industry and area in identifying both inter- and intra-country differences within the methods. Another limitation of the study is the sample investigation of just three countries; the inclusion of data from other countries and continents may also contribute to the identification of potential differences in the use of the methods.

The biggest differences were observed between Finland and the other countries in the study (Brazil and the United States). In the published Finnish contractor best practices (Koskenvesa & Sahlstedt, 2017), logic links are not emphasized, the CPM is regarded as a historical scheduling method, and lean construction is emphasized. Contracts in Finland do not require the use of the CPM, while, in both the United States and Brazil, the CPM is a contractual requirement. This may explain the higher emphasis in Finland on scheduling systems related to project production management as well as productivity rates and data from subcontractors.

This study's contributions to the literature include the investigation of how these three planning methods are used differently in Brazil, Finland, and the United States. The historical background of each country, the best practices of industry associations, and contractual requirements seem to explain most of these differences. When studying these methods, researchers should be aware that context may have a major impact on the generalizability of the results outside a country of interest. Moreover, engineering and project managers should be aware there are very different ways of understanding scheduling. These results prepare engineering and project managers for more efficient communication with collaborators when planning projects in foreign countries or incorporating foreign planners in their teams. Moreover, industry associations should recognize their important role in shaping the scheduling practice in their respective countries and engage in multi-cultural dialogue to share best practices between countries. Overall, the increasing focus on how countries use these methods will improve practice and suggest areas for future research.

### **Data Availability Statement**

All data supporting the findings of this study are available from the corresponding author upon reasonable request.

## Disclosure Statement

No potential competing interest was reported by the authors.

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## **Author Bios**

**Dr. Natalie M. Scala** is an associate professor and director of graduate programs in supply chain management in the College of Business and Economics at Towson University. She earned Ph.D. and M.S. degrees in industrial engineering from the University of Pittsburgh. Her work in elections security earned a University System of Maryland Board of Regents Award for Excellence in Public Service, the system's highest faculty honor. She is a former associate editor for *Engineering Management Journal*.

**Vincent Schiavone, M.S.**, is a 2020 graduate from Towson University's Supply Chain Management Master's Program, as well as a 2015 Towson graduate with a bachelor's in Project Management and Business Analysis. Vincent has been a part of various research teams at Towson University to include acknowledgements in publications for naval sea-basing, election security, and collaborative scheduling. His career experience spans various industries to include government contracting, real estate, grants and subcontracts management, and global supply planning.

**Dr. Hylton Olivieri** is specialized in construction management and has +20 years of experience working in large Latin America construction companies and teaching in master programs. His Ph.D. thesis from University of Campinas (Brazil) explored the integration of Critical Path Method, Location-Based Management System and Last Planner System applied in buildings. In 2018 he concluded a postdoctoral program at Aalto University (Finland). He has the certification Project Management Professional (PMP) and MBA in Construction Management.

**Dr. Olli Seppänen** is an Associate Professor at the Aalto University School of Engineering, Department of Civil Engineering. His field of expertise is operations management in construction. His research interests include lean construction, real-time production control, location-based management systems, lean design management, construction logistics and digitalized construction operations.

**Dr. Thais da C. L. Alves** specializes in construction management and project-based systems, including the use of lean production to improve the performance of delivery systems, and how people organize and collaborate. She is engaged in improving Engineering education through the use of serious games and initiatives to broaden access and diversity in Engineering. She is currently the AGC - Paul S. Roel Chair in Construction Engineering and Management at San Diego State University.

**Dr. Min Liu** is the Yabroudi Endowed Professor in Sustainable Civil Infrastructure at Syracuse University. She was the Chair of American Society of Civil Engineers (ASCE) Construction Research Council from 2020 to 2021. She is the Associate Specialty Editor for *ASCE Journal of*

*Management in Engineering* and Assistant Specialty Editor for *ASCE Journal of Construction Engineering and Management*. She received the 2021 ASCE Thomas Fitch Rowland Prize.

Associate Professor **Dr. Arioaldo Denis Granja** received a Ph.D. degree in Civil Engineering from the University of Campinas (Unicamp), Brazil and a M.Eng. from the University of Applied Sciences, Cologne, Germany. His current research interests span target costing, integrated project delivery and target value design; creating and delivering value to users; cost reduction and reallocation; location-based management systems; valuing managerial flexibility using real options; and synergies between living labs and lean in social housing.

**Exhibit 1.** Proposed differences between countries

Method	Related Hypotheses	Countries		
		Brazil	Finland	U.S.
CPM	H1a	CPM schedules include hundreds of tasks	CPM schedules include less than a hundred tasks	CPM schedules include hundreds of tasks
	H1b	CPM schedules include logic links for most tasks	CPM schedules do not include logic links for most tasks (i.e., they are really Gantt charts)	CPM schedules include logic links for most tasks
	H2	Durations are mostly defined by predictions based on previous similar projects, consulting subcontractors, and quantities	Durations are mostly based on quantities, production rates, and resources	Durations are mostly based on company-owned databases and/or trade/industry publications
	H3	Task durations are often short	Task durations are often long	Task durations are often long
LPS	H4	Durations are usually defined by experience and consulting subcontractors	Durations are based on discussions with project participants during pull planning sessions	Durations are based on discussions with project participants during pull planning sessions
	H5	Tasks durations are normally planned to fit one work week	Task durations are shorter than a week	Tasks durations are normally planned to fit one work week
	H6	There are more tasks in LPS than CPM and LB schedules	There are more tasks in LPS than CPM and LB schedules	There are more tasks in LPS than CPM and LB schedules
LB	H7	Durations are mostly defined by predictions based on previous similar projects, consulting subcontractors, and quantities	Durations are mostly based on quantities, production rates, and resources	Durations are mostly based on quantities, production rates, and resources
	H8	Task durations are determined based on the production cycle times, which are usually between one and two weeks	Task durations are often long (each trade is understood as one task)	Task durations are often long (each trade is understood as one task)
	H9	Schedules contain hundreds of tasks	Number of tasks is less than 100 (20–30 task types proposed in best practices)	Number of tasks represented is lower than those in CPM schedules

**Exhibit 2.** Research method and strategy

<b>Id</b>	<b>Topic</b>	<b>Description</b>	<b>Outcomes</b>
1	Survey data from Olivieri et al. (2019)	Step 1: Linking to theory	Exploring theory about CPM, LPS, and LB
		Step 2: Design	Based on other studies in the literature (e.g. Tavakoli and Riachi, 1990; Galloway, 2006; Khanh and Kim, 2016)
		Step 3: Pilot testing	Graduate students in the United States and Brazil
		Step 4: Collecting data for theory testing	Qualtrics platform: Brazil, Finland, and U.S.
		Step 5: Analyzing the data	736 responses received; final sample size $n = 430$
		Step 6: Generating results	Statistical differences between CPM, LPS, and LB
2	Hypotheses	Null hypotheses of interest defined for CPM, LPS and LB	Hypotheses related to the CPM: H1a, H1b, H2, H3
			Hypotheses related to the LPS: H4, H5, H6
			Hypotheses related to the LB: H7, H8, H9
3	Chi-Squared and Fisher's Exact Tests	Applied to the data for each hypothesis	Inter- and intra-country analyses
4	Results	Grouped the hypotheses	The number of tasks included in the schedules (H1a, H6, H9)
			The way in which durations are defined (H2, H4, H7)
			Average task durations (H3, H5, H8)
			Logical links (H1b)

**Exhibit 3.** Demographics of survey respondents (adapted from Olivieri, et al. 2019)

Topic	Total Responses (% in parentheses)	Country Breakdown (intra-country % of responses in parentheses)		
	Primary Industry	U.S.	Brazil	Finland
Buildings	316 (73.49)	68 (51.91)	130 (77.84)	118 (89.39)
Infrastructure	25 (5.81)	6 (4.58)	11 (6.59)	8 (6.06)
Pharmaceutical	21 (4.88)	7 (5.34)	12 (7.19)	2 (1.52)
Oil and Gas	20 (4.65)	16 (12.21)	4 (2.40)	0 (0)
Other	19 (4.42)	12 (9.16)	4 (2.40)	3 (2.27)
Power	15 (3.49)	11 (8.40)	3 (1.80)	1 (0.76)
Healthcare	7 (1.63)	5 (3.82)	2 (1.20)	0 (0)
Process	5 (1.16)	4 (3.05)	1 (0.60)	0 (0)
Transportation	2 (0.47)	2 (1.53)	0 (0)	0 (0)
Aerospace	0 (0)	0 (0)	0 (0)	0 (0)
	Type of Organization	U.S.	Brazil	Finland
Contractor or Subcontractor	161 (37.44)	54 (41.54)	12 (7.14)	95 (71.97)
Engineering	87 (20.23)	15 (11.54)	53 (31.55)	19 (14.39)
Owner	76 (17.67)	19 (14.62)	52 (30.95)	5 (3.79)
Construction Management	72 (16.74)	28 (21.54)	37 (22.02)	7 (5.30)
Other	25 (5.81)	11 (8.46)	11 (6.55)	3 (2.27)
Designer	2 (0.47)	0 (0)	2 (1.19)	0 (0)
Government	4 (0.93)	3 (2.31)	1 (0.60)	0 (0)
Supplier	3 (0.70)	0 (0)	0 (0)	3 (2.27)
	Position in Organization	U.S.	Brazil	Finland
Project Manager	74 (17.21)	16 (12.31)	15(8.93)	43 (32.58)
Executive Officer	68 (15.81)	34 (26.15)	25 (14.88)	9 (6.82)
Project Engineer	65 (15.12)	6 (4.62)	31 (18.45)	28 (21.21)
Scheduler	61 (14.19)	27 (20.77)	28 (16.67)	6 (4.55)
Other	55 (12.79)	19 (14.62)	27 (16.07)	9 (6.82)
Department Head	47 (10.93)	22 (16.92)	16 (9.52)	9 (6.82)
Superintendent	31 (7.21)	3 (2.31)	20 (11.90)	8 (6.06)
Staff Position	29 (6.74)	3 (2.31)	6 (3.57)	20 (15.15)
	Organization Size	U.S.	Brazil	Finland
Under 50 Employees	76 (17.67)	12 (9.23)	52 (30.95)	12 (9.09)
50 -100 Employees	62 (14.42)	10 (7.69)	28 (16.67)	24 (18.18)
101-500 Employees	89 (20.70)	27 (20.77)	35 (20.83)	27 (20.45)
501 – 1000 Employees	45 (10.47)	8 (6.15)	16 (9.52)	21 (15.91)
1001 – 5000 Employees	84 (19.53)	38 (29.23)	17 (10.12)	29 (21.97)
Over 5000 Employees	74 (17.21)	35 (26.92)	20 (11.90)	19 (14.39)
	Area*	U.S.	Brazil	Finland
Planning and Control	268 (23.41)	93 (27.60)	102 (24.82)	73 (18.39)
Management	243 (21.22)	85 (25.22)	93 (22.63)	65 (16.37)
Budgeting	158 (13.80)	48 (14.24)	64 (15.57)	46 (11.59)
Production	138 (12.05)	21 (6.23)	45 (10.95)	72 (18.14)
Quality or Technology	112 (9.78)	27 (8.01)	29 (7.06)	56 (14.11)
Supply Chain	96 (8.38)	29 (8.61)	30 (7.30)	37 (9.32)
Consultancy	62 (5.41)	16 (4.75)	20 (4.87)	26 (6.55)
Product Development/Specification	48 (4.19)	11 (3.26)	19 (4.62)	18 (4.53)
Other	20 (1.75)	7 (2.08)	9 (2.19)	4 (1.01)

\*Note: Respondents were permitted to choose more than one expertise area.

**Exhibit 4.** Chi-squared and Fisher's Exact Test analyses

Number of Tasks											
Intra-Country Analysis						Inter-Country Analysis					
Country	Answers	CPM	LPS	LB	<i>p</i> -value	Method	Answers	U.S.	Finland	Brazil	<i>p</i> -value
		<i>n</i> = 111	<i>n</i> = 47	<i>n</i> = 13	0.2269			<i>n</i> = 111	<i>n</i> = 80	<i>n</i> = 106	0.0000***
U.S.	Under 100	5 (5%)	10 (21%)	1 (8%)		CPM	Under 100	5 (5%)	48 (60%)	24 (23%)	
	101 – 501	32 (29%)	14 (30%)	5 (38%)			101 – 501	32 (29%)	26 (33%)	38 (36%)	
	501 – 1000	27 (24%)	10 (21%)	5 (38%)			501 – 1000	27 (24%)	1 (1%)	7 (7%)	
	1001 – 5000	31 (28%)	6 (13%)	1 (9%)			1001 – 5000	31 (28%)	1 (1%)	21 (20%)	
	5001 – 10000	12 (11%)	5 (11%)	0 (0%)			5001 – 10000	12 (11%)	0 (0%)	10 (9%)	
	10000+	4 (4%)	2 (4%)	1 (8%)			10000+	4 (4%)	4 (5%)	6 (6%)	
		<i>n</i> = 80	<i>n</i> = 44	<i>n</i> = 67	0.1748			<i>n</i> = 47	<i>n</i> = 44	<i>n</i> = 31	0.0001***
Finland	Under 100	48 (60%)	33 (75%)	40 (60%)		LPS	Under 100	10 (21%)	33 (75%)	10 (32%)	
	101 – 501	26 (33%)	8 (18%)	23 (34%)			101 – 501	14 (30%)	8 (18%)	11 (35%)	
	501 – 1000	1 (1%)	2 (5%)	3 (4%)			501 – 1000	10 (21%)	2 (5%)	3 (10%)	
	1001 – 5000	1 (1%)	1 (2%)	1 (1%)			1001 – 5000	6 (13%)	1 (2%)	3 (10%)	
	5001 – 10000	0 (0%)	0 (0%)	0 (0%)			5001 – 10000	5 (11%)	0 (0%)	4 (13%)	
	10000+	4 (5%)	0 (0%)	0 (0%)			10000+	2 (4%)	0 (0%)	0 (0%)	
		<i>n</i> = 106	<i>n</i> = 31	<i>n</i> = 58	0.0237*			<i>n</i> = 13	<i>n</i> = 67	<i>n</i> = 58	0.0003***
Brazil	Under 100	24 (23%)	10 (32%)	33 (57%)		LB	Under 100	1 (8%)	40 (60%)	33 (57%)	
	101 – 501	38 (36%)	11 (35%)	13 (22%)			101 – 501	5 (38%)	23 (34%)	13 (22%)	
	501 – 1000	7 (7%)	3 (10%)	2 (3%)			501 – 1000	5 (38%)	3 (4%)	2 (3%)	
	1001 – 5000	21 (20%)	3 (10%)	9 (16%)			1001 – 5000	1 (9%)	1 (1%)	9 (16%)	
	5001 – 10000	10 (9%)	4 (13%)	1 (2%)			5001 – 10000	0 (0%)	0 (0%)	1 (2%)	
	10000+	6 (6%)	0 (0%)	0 (0%)			10000+	1 (8%)	0 (0%)	0 (0%)	

**Activity Durations**

Intra-Country Analysis					Inter-Country Analysis						
Country	Answers	CPM	LPS	LB	<i>p</i> -value	Method	Answers	U.S.	Finland	Brazil	<i>p</i> -value
		<i>n</i> = 110	<i>n</i> = 46	<i>n</i> = 13	0.0019**			<i>n</i> = 100	<i>n</i> = 71	<i>n</i> = 101	0.0000**
U.S.	Experience	3 (3%)	3 (7%)	0 (0%)		CPM	Experience	3 (3%)	16 (23%)	24 (24%)	
	Rates	9 (8%)	2 (4%)	3 (23%)			Rates	9 (8%)	15 (21%)	19 (19%)	
	Subcontractors	0 (0%)	6 (13%)	0 (0%)			Subcontractors	0 (0%)	1 (1%)	3 (3%)	
	Combination	96 (87%)	34 (74%)	10 (77%)			Combination	96 (87%)	38 (54%)	54 (53%)	
	Other	2 (2%)	1 (2%)	0 (0%)			Other	2 (2%)	1 (1%)	1 (1%)	
		<i>n</i> = 71	<i>n</i> = 42	<i>n</i> = 55	0.0000***			<i>n</i> = 46	<i>n</i> = 42	<i>n</i> = 28	0.0344*
Finland	Experience	16 (23%)	5 (12%)	5 (9%)		LPS	Experience	3 (7%)	5 (12%)	6 (21%)	
	Rates	15 (21%)	6 (14%)	27 (49%)			Rates	2 (4%)	6 (14%)	8 (29%)	
	Subcontractors	1 (1%)	7 (17%)	0 (0%)			Subcontractors	6 (13%)	7 (17%)	0 (0%)	
	Combination	38 (54%)	24 (57%)	23 (42%)			Combination	34 (74%)	24 (57%)	13 (46%)	
	Other	1 (1%)	0 (0%)	0 (0%)			Other	1 (2%)	0 (0%)	1 (4%)	
		<i>n</i> = 101	<i>n</i> = 28	<i>n</i> = 52	0.8427			<i>n</i> = 13	<i>n</i> = 55	<i>n</i> = 52	0.0053**
Brazil	Experience	24 (24%)	6 (21%)	9 (17%)		LB	Experience	0 (0%)	5 (9%)	9 (17%)	
	Rates	19 (19%)	8 (29%)	10 (19%)			Rates	3 (23%)	27 (49%)	10 (19%)	
	Subcontractors	3 (3%)	0 (0%)	1 (2%)			Subcontractors	0 (0%)	0 (0%)	1 (2%)	
	Combination	54 (53%)	13 (46%)	31 (60%)			Combination	10 (77%)	23 (42%)	31 (60%)	
	Other	1 (1%)	1 (4%)	1 (2%)			Other	0 (0%)	0 (0%)	1 (2%)	

**Average Task Durations**

Intra-Country Analysis					Inter-Country Analysis						
Country	Answers	CPM	LPS	LB	<i>p</i> -value	Method	Answers	U.S.	Finland	Brazil	<i>p</i> -value
		<i>n</i> = 111	<i>n</i> = 48	<i>n</i> = 13	0.0000***			<i>n</i> = 111	<i>n</i> = 74	<i>n</i> = 105	0.0111*
U.S.	< 1 week	16 (14%)	28 (58%)	6 (46%)		CPM	< 1 week	16 (14%)	5 (7%)	24 (23%)	
	1 to 2 weeks	65 (59%)	10 (21%)	7 (54%)			1 to 2 weeks	65 (59%)	25 (34%)	55 (52%)	
	> 2 weeks	30 (27%)	10 (21%)	0 (0%)			> 2 weeks	30 (27%)	44 (59%)	265 (25%)	
		<i>n</i> = 74	<i>n</i> = 43	<i>n</i> = 66	0.1324			<i>n</i> = 48	<i>n</i> = 43	<i>n</i> = 31	0.0126*
Finland	< 1 week	5 (7%)	11 (26%)	9 (14%)		LPS	< 1 week	28 (58%)	11 (26%)	9 (29%)	
	1 to 2 weeks	25 (34%)	14 (33%)	22 (33%)			1 to 2 weeks	10 (21%)	14 (33%)	16 (52%)	
	> 2 weeks	44 (59%)	18 (42%)	35 (53%)			> 2 weeks	10 (21%)	18 (42%)	6 (19%)	
		<i>n</i> = 105	<i>n</i> = 31	<i>n</i> = 56	0.9172			<i>n</i> = 13	<i>n</i> = 66	<i>n</i> = 56	0.0000***
Brazil	< 1 week	24 (23%)	9 (29%)	11 (20%)		LB	< 1 week	6 (46%)	9 (14%)	11 (20%)	
	1 to 2 weeks	55 (52%)	16 (52%)	32 (57%)			1 to 2 weeks	7 (54%)	22 (33%)	32 (57%)	
	> 2 weeks	26 (25%)	6 (19%)	13 (23%)			> 2 weeks	0	35 (53%)	13 (23%)	

Three asterisks\*\*\* denote significance at 0.001; two asterisks\*\* denote significance at 0.01; one asterisk\* denotes significance at 0.05.

**Exhibit 5.** Logical links between tasks in CPM schedules, inter-country analysis

Method	Answers	U.S.	Finland	Brazil	<i>p</i> -value
CPM	Yes	95/110 (86%)	7/72 (10%)	81/98 (83%)	0.0000***
	No	15/110 (14%)	65/72 (90%)	17/98 (17%)	

Three asterisks\*\*\* denote significance at 0.001.

## **Appendix. Survey, adapted from Olivieri, et al. (2019)**

### **Section 1: General questions**

1. Please indicate your country

United States • Brazil • China • Finland • Other

2. What is your primary industry?

Buildings (residential and commercial) • Infrastructure (highway, roads, city or municipal infrastructure, etc.) • Oil and gas • Power • Healthcare • Transportation • Process • Aerospace • Pharmaceutical • Other

3. What type of organization do you represent?

Owner • Construction contractor or subcontractor • Government • Construction management • Engineering • Designers • Supplier • Other

4. How large is your organization?

Under 50 employees • 50-100 employees • 101-500 employees • 501-1000 employees • 1001-5000 employees • Over 5000 employees

5. What is your position within your organization?

Superintendent • Department head • Project manager • Project engineer • Scheduler • Staff position • Executive officer • Other

6. In what area do you work? (Choose all that apply)

Management • Planning and control • Budgeting • Supply chain management / procurement • Production • Quality or technology • Product development or specification • Consultancy • Other

7. Which of the following planning and control systems do you usually use? (Choose all that apply)

• Critical Path Method (CPM) • Last Planner System (LPS) • Location-Based (LB) planning and control methods.

### **Section 2: Critical Path Method (CPM)**

8. What is your main reason for using the Critical Path Method (CPM)?

It is a beneficial planning tool that makes projects more efficient and cost effective • Contract requirements • Change management • Claims documentation • Other

9. What computer software do you specify to develop CPM schedules? (Choose all that apply)

Ms-Project • Primavera • TCM Planner • Asta Powerproject • PlaNet • Other

**10.** What is the typical average duration in days of the activities that comprise your schedule?

Less than one week • One week to less than two weeks • Two weeks or greater

**11.** What are the typical number of activities that comprise the schedule?

Under 100 activities • 101-500 activities • 501-1000 activities • 1001-5000 activities • 5001-10000 activities  
• Over 10000 activities

**12.** How often do you require updates of CPM schedules?

Daily • Weekly • Monthly • Bimonthly • Other

**13.** When using CPM, how is the duration of construction activities/projects determined?

By experience only • Based on quantities and production rates • Asking subcontractors • Combination of above • Other

**14.** When using CPM, does every task link logically to other task(s)?

Yes, in all of the tasks • No, only in some of the tasks

**15.** When using CPM, how do you manage lags (time contingencies to protect the project)? (Choose all that apply)

Inserting lags between activities • Inserting lags in the end of the project • Considering capacity lags (additional manpower or equipment) • I don't use lags because time contingencies are already considered in the activities' durations • I never use lags

**16.** When using CPM, how often do you analyze the critical path?

Frequently • Moderate frequency • Infrequently • Never • Other

**17.** Do you usually manage resources through the CPM schedule?

Yes, manpower level • Yes, trade breakdown • Yes, money (available/spent) per activity • All of the above  
• Yes, other • No

**18.** Do you manage cost through the CPM schedule?

Yes • No • Sometimes

**19.** How often do you make decisions based on CPM information?

Frequently (at least once a day) • Moderate frequency • Infrequently • Never • Other

**20.** Is your CPM scheduling developed by:

In-house personnel • Outside consultant • Combination of in-house and consultants

**21.** What are the benefits obtained from using CPM? (Choose all that apply)

Improves scheduling • Improves estimating / bidding • Reduces delays • Time savings • Helps train future project managers • Improves workflow (crews working without interruptions) • Improves production control • Minimizes disputes between contractor and owner • Positive psychological effect on employees • Increases control over risk and uncertainty • Faster response to problems • Improves communication among the workforce • Improves constraints analysis • Improve root causes analysis of deviations and action plans • Cost savings • Improves understanding of the project • Improves project control after work starts • Improves planning before work starts • Improves daily management of activities

**22.** What are the disadvantages of CPM? (Choose all that apply)

No major disadvantages • Not responsive to the needs of top management • Logic abuses • Requires excessive work to implement • It is not appropriate for construction projects • Does not consider constraints in a right level • Not responsive to the needs of field personnel • Costs too much • Does not consider subcontractors activity / input • It is used only to evaluate the critical path • It is very hard to analyze workflow • Requires too much dependency on specialists • Other

**23.** How do the following items work in your current CPM schedule? (I don't know / I don't use this function; definitively works very well; Works well; must be improved; definitively must be improved)

Master schedules • Workflow (crews working without interruptions) • Risks and uncertainties analysis • Delays analysis • Resources analysis • Lags or float analysis • Management of subcontractors • Constraints analysis • Transparency • Effective production control • Root causes analysis of deviations and action plans • Clear understanding of what must be done • Effective daily management of activities • Work breakdown structure level of detail • Enough understanding of the project • Control after work starts • Communications between crews and team • Employees commitment

### **Section 3: Last Planner System (LPS)**

**24.** What is your main reason for using Last Planner System (LPS)?

It is a beneficial planning tool that makes projects more efficient and cost effective • Contract requirements • Change management • Claims documentation • Other

**25.** Which computer software do you use to implement LPS? (Choose all that apply)

VisiLean • Touchplan • Vplanner • BIM360 Plan • Excel spreadsheets • Other

**26.** What is the typical average duration in days of the activities that comprise your schedule?

Less than one week • One week to less than two weeks • Two weeks or greater

**27.** What are the typical number of activities that comprise the schedule?

Under 100 activities • 101-500 activities • 501-1000 activities • 1001-5000 activities • 5001-10000 activities  
• Over 10000 activities

**28.** How often do you require updates of the following LPS components? (Daily; Weekly; Biweekly; Monthly; Bimonthly; Never / I don't use this component)

Milestones schedule • Phase schedules • Weekly Work Plan (WWP) • "Make work ready" analysis • Lookahead planning • Percentage Plan Completed (PPC) measurement

**29.** When using LPS, how is the duration of construction activities/projects determined?

By experience only • Based on quantities and production rates • Asking subcontractors • Combination of above • Other

**30.** When using LPS, does every task link logically to other task(s)?

Yes, in all of the tasks • No, only in some of the tasks

**31.** How often do you usually analyze the critical path in LPS?

Frequently • Moderate frequency • Infrequently • Never • Other

**32.** Do you usually manage resources through the LPS?

Yes, manpower level • Yes, trade breakdown • Yes, money (available/spent) per activity • All of the above  
• Yes, other

**33.** Do you manage cost through LPS?

Yes • No • Sometimes

**34.** How often do you make decisions based on LPS information?

Frequently • Moderate frequency • Infrequently • Never • Other

**35.** What are the benefits obtained from using LPS? (Choose all that apply)

Improves scheduling • Improves estimating / bidding • Reduces delays • Time savings • Helps train future project managers • Improves workflow • Improves production control • Minimizes disputes between contractor and owner • Positive psychological effect on employees • Increases control over risk and uncertainty • Faster response to problems • Improves communication among the workforce • Improves constraints analysis • Improves root causes analysis of deviations and action plans • Cost savings • Improves understanding of the project • Improves project control after work starts • Improves planning before work starts • Improves daily management of activities • Other

**36.** What are the disadvantages of LPS? (Choose all that apply)

No major disadvantages • Not responsive to the needs of top management • Requires specific softwares •

Requires excessive work to implement • Does not consider constraints at a right level • Not responsive to the needs of field personnel • Costs too much • Bureaucratic process to obtain measurements • It is used to only evaluate field production • Requires too much dependency on specialists • It is not appropriate to evaluate long term plans • Other

**37.** How do the following items work in your current LPS system? (I don't know / I don't use this function; definitively works very well; Works well; must be improved; definitively must be improved)

Milestones schedule • Phase schedules • Weekly Work Plan (WWP) • "Make work ready" analysis • Lookahead planning • Percentage Plan Completed (PPC) measurement • Constraints analysis • List the work to be performed for the following week • Indicate the dates of execution and the team in charge • Check the quality criteria (sequence, scope and practical) • Agreement on the program for the initial phase • Identify the work that should be done • Availability of materials and components • Daily management of activities • Production control • Root causes analysis of deviations and action plans • Workflow (crews working without interruptions) • Resources management • Risks analysis

#### **Section 4: Location-Based systems (LB)**

**38.** What is your main reason for using Location-Based (LB) planning and control methods?

It is a beneficial planning tool that makes projects more efficient and cost effective • Contract requirements • Change management • Claims documentation • Other

**39.** What computer software do you specify to develop LB? (Choose all that apply)

Vico Schedule Planner • TCM Planner • TILOS • DynaRoad • Excel spreadsheets • Other

**40.** What is the typical average duration in days of the activities that comprise your schedule?

Less than one week • One week to less than two weeks • Two weeks or greater

**41.** What are the typical number of activities that comprise the schedule?

Under 100 activities • 101-500 activities • 501-1000 activities • 1001-5000 activities • 5001-10000 activities • Over 10000 activities

**42.** When using LB, which of the following components do you usually use? (Choose all that apply)

Location Breakdown Structure (LBS) • Workflow analysis • Risk analysis • Resource analysis • Actual progress data • Forecasts and alarms

**43.** How often do you require updates of the following LB components? (Daily; Weekly; Biweekly; Monthly; Bimonthly; Never)

Activities • Actual resources • Actual hours spent • Start and finish dates • Interruptions • Actual quantities

• Risks • Production rates • Activities sequences

**44.** When using LB, how is the duration of construction activities/projects determined?

By experience only • Based on quantities and production rates • Asking subcontractors • Combination of above • Other

**45.** When using LB, does every task link logically to other task(s)?

Yes, in all of the tasks • No, only in some of the tasks

**46.** Using LB, how often do you usually analyze the critical path?

Frequently • Moderate frequency • Infrequently • Never • Other

**47.** Do you usually manage resources through LB?

Yes, manpower level • Yes, trade breakdown • Yes, money (available/spent) per activity • All of the above • Yes, other • No

**48.** Do you manage cost through the LB?

Yes • No • Sometimes

**49.** How often do you make decisions based on LB information?

Frequently • Moderate frequency • Infrequently • Never • Other

**50.** What are the benefits obtained from using LB? (Choose all that apply)

Improves scheduling • Improves estimating/bidding • Reduces delays • Time savings • Helps train future project managers • Improves workflow • Improves production control • Minimizes disputes between contractor and owner • Positive psychological effect on employees • Increases control over risk and uncertainty • Faster response to problems • Improves communication among the workforce • Improves constraints analysis • Improves root causes analysis of deviations and action plans • Cost savings • Improves understanding of the project • Improves project control after work starts • Improves planning before work starts • Improves daily management of activities • Other

**51.** What are the disadvantages of LB? (Choose all that apply)

No major disadvantages • Not responsive to the needs of top management • Requires specific softwares • Requires excessive work to implement • Does not consider constraints at a right level • Not responsive to the needs of field personnel • Costs too much • Bureaucratic process to obtain measurements • It is used to only evaluate field production • Requires too much dependency on specialists • It is not appropriate to evaluate long term plans • Other

**52.** How do the following items work in your current LB schedule? (I don't know / I don't use this function;

definitively works very well; Works well; must be improved; definitively must be improved)

Master schedules • Workflow (crews working without interruptions) • Risks and uncertainties analysis • Delays analysis • Resources analysis • Lags or float analysis • Management of subcontractors • Constraints analysis • Transparency • Effective production control • Root causes analysis of deviations and action plans • Clear understanding of what must be done • Effective daily management of activities • Work breakdown structure level of detail • Enough understanding of the project • Control after work starts • Communications between crews and team • Employees commitment