The Gold Standard: Developing a Maturity Model to Assess Collaborative Scheduling

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ABSTRACT

Purpose: The overall contribution of this work is to provide a usable maturity model for collaborative scheduling (CS) that extends the literature, identifies inconsistencies in schedule development, and improves collaboration in the construction industry.

Design/Methodology/Approach: Via subject matter expert elicitation and focus groups, the maturity model establishes five pillars of collaboration—scheduling significance, planners and schedulers, scheduling representation, goal alignment with owner, and communication. The maturity model is then validated through iterative feedback and chi-squared statistical analysis of data obtained from a survey. The five pillars are tied to the literature and previous work in CS.

Findings: The analysis shows that current industry projects are not consistent in collaboration practice implementation, and the maturity model identifies areas for collaboration improvement. The study's contributions to the body of knowledge are (1) developing a maturity model-based approach to define and measure the current level of collaboration and (2) discovering the level of consistency in scheduling collaboration practice implementation.

Originality: The construction engineering and management (CEM) literature does not contain targeted models for scheduling collaboration in the context of maturity and, broadly speaking, neither does the literature at large. The literature also lacks actionable items as presented for the maturity model for collaborative scheduling (MMCS).

Practical Implications: The findings provide a benchmark for self-evaluation and peer-to-peer comparison for project managers. The model is also useful for project managers to develop effective strategies for improvement on targeted dimensions and metrics.

Keywords: Collaboration, schedule, alignment, maturity model

INTRODUCTION

Collaboration in project scheduling and management is crucial for project success. The schedule can serve as a basis for payment, subcontractor coordination, and project control (Mubarak, 2015), and, due to its close link to project performance (Kog *et al*., 1999), scheduling is vital in construction management. Unfortunately, despite a distinctive interdisciplinary nature, which includes work from multiple project participants, schedules are traditionally developed in an isolated fashion by a single individual, who often holds the title of "scheduler" and is frequently based at the headquarters of construction companies and owner organizations in charge of capital project development (Alves *et al*., 2020).

Schedulers often single-handedly develop the schedules using proprietary databases, published manuals from trade organizations, and information collected from trade partners with whom their organization might or might not have worked before, to name a few sources. As a result of this practice, schedules might not properly represent the actual nature of the work to be done and might not get buy-in from the trades, as they can lack input from knowledgeable practitioners who are most notably the “last planners” closest to the work (Ballard, 2000). This resistance to promoting collaboration among project participants and their supply chains is often associated with the prevalence of traditional project delivery methods, preventing innovation and learning (Daniel *et al.,* 2017).

Conversely, when construction schedules are developed collaboratively using systems such as the last planner system (LPS) and other methods to support scheduling collaboration (e.g., Scrum), the observed benefits include, but are not limited to, improved productivity of trades (Liu *et al*., 2011), properly accounting for and representing stakeholder needs in schedules (Mossman, 2018), and an increase in project planning reliability (Javanmardi *et al*., 2018). Moreover, construction projects rely on collaboratively developed schedules to become more efficient, for teams to become better at detecting flaws, and to improve stakeholders’ understandings of problems (Ballard *et al.,* 2019).

In this environment, the construction engineering and management (CEM) literature does not contain targeted models for scheduling collaboration in the context of maturity. Broadly speaking, and considering the literature at large, studies have examined maturity models (MMs) in collaboration (e.g., Boughzala and de Vreede’s (2015) collaboration maturity model—Col-MM). A separate set of publications present or analyze existing MMs and related constructs. For instance, Rosenstock *et al.* (2000) reviewed existing models and proposed a custom model to help an organization address gaps, prioritize areas of excellence, and monitor actions to attain higher levels of maturity; they suggested that custom models are more dynamic. Additionally, Andersen and Jessen (2003) suggested that maturity should be measured along three dimensions: knowledge to carry out tasks, attitudes toward carrying out related tasks, and actions to follow through and implement across three levels of maturity: project management (individual projects), program management (combination of related projects), and portfolio management (combination of projects with distinct characteristics, whether related or not). Another example is the Highways England Lean maturity assessment (HELMA), which evaluates the adoption of Lean tenets in their supply chain (HE, 2018). Mollasalehi *et al.* (2018) bring together Lean and building information modeling

(BIM) into an MM but do not specifically outline the characteristics and statements to be assessed. As a result, the literature has not seen a marrying of collaboration with an actionable MM (Tarhan *et al.,* 2016).

This study directly addresses industry needs by developing a usable MMCS so that practitioners can understand the current level of collaboration on their project, along five dimensions or pillars, and identify steps to take to improve collaboration. This study also employs statistical analyses to investigate relationships between practices in order to assess the level of collaboration found in industry.

TOWARD THE DEVELOPMENT OF COLLABORATIVE SCHEDULES IN CONSTRUCTION

This study defines CS as "a comprehensive process that aligns and engages stakeholders throughout the life cycle of the project in order to coordinate activities and resources on a project and achieve its goal" (CII, 2021a). The definition supports the move away from schedules being developed by isolated individuals toward a collaborative process that engages project stakeholders to deliver the project expected by the owner. Along these lines, this literature review is categorized into five main areas of interest regarding collaborative schedules, which have been preliminarily investigated by Alves *et al.* (2020); this study builds from that work. These areas emerged during the study, through development of and inputs from focus groups, and are later used in the development of the MM, namely: schedules and planners, schedule representation, schedule significance, communication, and goal alignment with owner.

Schedulers and Planners

The development of construction schedules by isolated individuals is likely rooted in the fact that the temporary organization tasked with delivering the construction project usually has little time to develop collaborative schedules that fully consider the input of multiple parties and the collective knowledge they can bring to the project. For instance, contractors in the United States shall "promptly" provide a full project schedule once a project is awarded, according to a popular standard contract developed by a professional organization in the United States (e.g., AIA, 2017).

Typically, the scheduler is detached from the construction site and might not be fully aware of the project details necessary to produce a schedule that properly captures the reality of the work to be done (Alves *et al.,* 2020). The planner is usually on the front lines of the project close to where activities are developed and has direct knowledge of the work being put in place (Ballard, 2000).

Direct access to and knowledge of the work undertaken supports work definition and preparation as well as constraint analysis, ultimately impacting project performance (Lagos and Alarcon, 2021).

Scheduling Representation

As the industry evolves into using newer scheduling methods, which are more collaborative than the traditionally used critical path method (CPM), practitioners continue to struggle to support and encourage implementation of these methods in practice. Furthermore, most academic research on planning has focused on specific tools and techniques, negating a focus on planning activities, control processes, tasks, and roles, and leading to opportunities to advance theory and practice (Koskela and Howell 2002; Alves *et al*., 2020). Such opportunities have existed since at least the 1980s, when the problem was discussed by Laufer and Tucker (1987) and continues to be relevant to the literature discussion. Thus, a focus on how schedules are developed and represented is important to advance the use of CS to improve transparency and promote accountability (Lin and Golparvar-Fard, 2021).

Scheduling Significance

Scheduling is but one part of the planning process used to manage construction projects, and it is supported by the data collection effort and conversations necessary to define tasks, their related needs, constraints, and timelines (Laufer *et al*., 1994; Mossman and Ramalingam, 2021). Once the schedule is complete, it needs to be deployed to trades using plans, which should have their execution monitored (Laufer and Tucker, 1987; Hamzeh, 2009; Ballard et al., 2019). While the planning process in general has been discussed as a socio-technical process (Ballard, 2000; Ballard and Tommelein, 2016), the production of schedules has been addressed more consistently from the technical side in CEM scholarship. According to Ballard and Tommelein (2016, p.8), "(p)roduction systems are both social and technical," which reinforces a culture to address them from two angles: (1) the needs and perspectives of those managing these systems and (2) the technical components used to make the systems work.

CS methods and the social element of scheduling have been gaining popularity in the past 20 years as the LPS of production control advocates for a more holistic view of the planning process involving those who do or closely supervise the work to develop schedules and plan the work (Ballard, 2000). The LPS employs a coordinated effort that involves those directly doing or supervising field work during the planning of activities over time. Trades participating in a given phase of a project use a milestone schedule as the baseline to plan tasks using a backward scheduling process (pull planning), moving from milestones to each preceding task to be completed. Later, as execution approaches, tasks are screened for constraints and made ready to support a smooth flow of work. Finally, the last planners, who are those closest to field execution, work on defining weekly work plans that are distributed to the trades with their progression tracked and causes for non-completion documented. In every step, last planners and project participants engage in conversations during planning meetings and strengthen a network of commitments as they agree to work on tasks and negotiate various aspects related to their work (Ballard, 2000; Ballard and Tommelein, 2016).

CS practices, which are part of the LPS, alongside methods and tools to promote collaboration, have been addressed in benchmark documents (Ballard and Tommelein, 2016; Ballard *et al*., 2019), best practice recommendations (LCI, 2018), MMs related to the implementation of Lean construction (Nesensohn, 2017; HE, 2018; Cano *et al.*, 2020), and the development of integrated project delivery systems (CII, 2019), to name a few. These documents define collaborative practices, highlight the importance of these practices, and make recommendations for their implementation. Some of these practices documented in the literature are also addressed in the MM presented in this study.

Communication

The establishment of strong social networks, which connect project participants and allow them to communicate closely through defined channels and short information paths, is associated with improved key performance indicators (Castillo *et al*., 2018). Practitioners in these networks can also be brought together to collectively identify, share their perspectives on, and propose solutions to mitigate risks that may or may not materialize in the project, as well as remove constraints ahead of execution to avoid delays and the unnecessary use of resources (Ebbs and Pasquire, 2018). Along these lines, Ebbs and Pasquire (2018) devised a method labeled "flow walk" to help project stakeholders collaboratively identify risks and constraints related to eight flows, namely: information, equipment, materials, people, prior work, external conditions, safe space, and shared understanding. Their method relies on the ability of the team to identify, validate, categorize, prioritize, and rank risks and constraints; this method exemplifies a way to foster communication among project stakeholders and develop usable information to support the scheduling process.

Communication is emphasized in the management of production systems, as recommended by Ballard (2000) in his description of the LPS, a widely recognized collaborative planning and scheduling system. The LPS relies heavily on the following: (1) the constant interaction of those directly carrying out tasks with those planning and supervising them, (2) promoting accountability through public commitment to tasks when planned, and (3) understanding that variation in production systems should be accounted for (Ballard and Tommelein, 2016). Conversations and the specific language used to communicate plans drive action from the time a request is made, a promise or acceptance to perform is affirmed, and finally a declaration of completion is stated, followed by a declaration of satisfaction based on conditions of satisfaction (CoS) defined by the team (Flores, 2012). Finally, conversations need to happen in psychologically safe environments, where project participants can express their views without fear of retaliation (Edmondson, 1999).

Goal Alignment with Owner

"Aligned teams work from the 'same sheet of music'" (CII, 2009, p.8). Team members interact with the owner and one another to develop a shared understanding of the CoS for the project to succeed, course-correcting when necessary (Mossman and Ramalingam, 2021). Team alignment during the pre-project planning stage, when master schedules are usually developed, requires, among other things, that stakeholders are properly represented, priorities are clearly defined and known to the team, and open and effective communication is in place (CII, 2009).

Schedules that are aligned with the owner's goals represent how projects are built and also take into account the owner's needs in the form of deadlines, performance expectations, trade-offs, and logistics decisions, to name a few. These needs are captured in the schedules by involving the owner's representatives during the development of the schedules and capturing their expectations in the form of activities and milestones publicized to the project team. A properly developed schedule considers, for instance, the owner's cash flow availability for the project, the need for minimal disruption to the owner's existing operations, the owner's preferred suppliers' lead times, seasonal needs, commissioning tasks, and specific processes for the approval of design documents and occupation of the project.

MATURITY MODELS TO SUPPORT CONTINUOUS IMPROVEMENT IN CONSTRUCTION

The dictionary definition of *maturity* involves "the quality of being mature," and among the definitions of *mature*, the following are of interest for the discussion of an MM: "having completed natural growth and development" (ripe), "having attained a final or desired state," and "of or relating to a condition of full development" (Merriam-Webster, 2021). These definitions allude to a process of growth and continuous improvement that is complete when the element achieves full development or a desired state.

The MMCS developed in this study follows the path and structure of important MMs available in the literature. This section initially focuses on two influential works from the industry at large that support the rationale behind the MMCS, and it discusses a third influential model with a focus on project management tenets espoused by the Project Management Institute, which influenced other models in the CEM literature. Additional MMs are available in the literature at large and the CEM literature to address supply chain issues (e.g., Meng *et al*., 2011), the implementation of Lean (e.g., Nesensohn, 2017; HE, 2018; Cano *et al*., 2020), BIM (e.g., Liang *et al*., 2016), and safety practices (e.g., Albert *et al*., 2014), to name a few recent ones. These models share similar roots and format with the one presented herein. Thus, this review focuses on the models that serve as benchmarks for the MMCS developed in this study.

Reference Maturity Models Developed for the Industry at Large

The first model of interest is Crosby (1979), who pioneered the definition of maturity levels for an organization. He considered quality management as the main focus of improvement, moving toward more mature levels from the low *uncertainty* level, through *awakening*, *enlightenment*, *wisdom*, and all the way to the top *certainty* level. Crosby's model is based on a grid with statements defined for each level across measurement categories and considers attitudes toward the management of quality, including management understanding and attitude, quality organization status, problem handling, costs of quality as a percentage of sales, quality improvement actions, and a summary of company quality posture.

Another relevant MM for this discussion is the capability maturity model (CMM) for software processes, developed in the late 1980s and 1990s by Carnegie Mellon's Software Engineering Institute (Paulk *et al*., 1993). The CMM defines five levels from *initial*, through *repeatable*, *defined*, *managed*, and, finally, *optimizing* to categorize software process maturity. Key process areas are defined for each level, and, differently from Crosby's (1979) grid with similar measurement categories across the five levels, the CMM involves different areas at each level.

As one of the most comprehensive MMs in the CEM literature, the project management process maturity (PM2) model addresses the maturity level of an organization regarding project management (PM) knowledge areas (e.g., cost, time, human resources management, communications) and project processes (i.e., initiating, planning, executing, controlling, and closing) as indicated by the Project Management Institute at the time the model was developed (Kwak and Ibbs, 2002). PM2 uses a series of predefined statements to evaluate PM processes, organizational characteristics, and focus areas for each maturity level. Kwak and Ibbs (2002), when referring to their five-level PM2 model, indicate that the level of maturity achieved does not imply that an organization uses all practices associated with that level. Instead, the organization might achieve a specific maturity level by using a combination of practices that place it at higher levels of maturity.

While assessments made using MMs rely on self-reporting statements, they provide a simple way for teams to start conversations using a common language, become aware of the practices they use, and achieve consensus regarding the status of their processes (Boughzala and de Vreede, 2015). The models are used as part of a continuous improvement cycle, where the cycle starts with the use of the model and progresses as the organization assesses their practices, identifies recommendations to improve, defines improvement plans, and starts the cycle once again (Rosenstock *et al*., 2000).

Considering the existing reviewed MMs and how they are structured, the authors developed a method, described in the next section, to elicit areas of interest concerning CS, define statements to categorize distinct levels of CS maturity, and build a model to reflect maturity in CS. The authors were tasked as part of a larger study, via a request for proposal process from a funding organization, with identifying barriers and drivers to promote and implement CS. In this context, the development of an MM was viewed as a solution to identify actionable steps to improve collaboration and implementation while addressing a practical need. The model is grounded in the literature but also vetted by practitioners. By tying foundational questions to industry concerns, this study addresses literature and practice needs at the same time. Furthermore, from a theoretical standpoint, this study contributes to the CEM body of knowledge by identifying and organizing constructs that support collaborative scheduling (CS). These constructs then form a model that can serve as a benchmarking tool to guide practitioners toward the development and implementation of collaborative schedules.

RESEARCH METHOD

The overall contribution of this work is to provide a usable model that extends the literature, identifies inconsistencies related to collaborative schedule development, and improves collaboration in the construction industry. To accomplish these goals and illustrate the key components of the MMCS, as referenced in the review, this section describes the model development via focus groups, affinity diagrams, and structured maturity modeling. A survey was then used to support the validation of the model. The larger study, of which this research is a part, addresses limitations, practices, and guidelines to support increased collaboration in scheduling practice (CII, 2021a). Results from that study feed into and influence the development of the MM (Table 1).

Insert Table 1 here

Focus Groups and Affinity Diagrams

The MMCS was designed via an iterative process driven by subject matter expert (SME) input. Multiple rounds of focus group elicitation, model design, feedback, and revisions occurred, with the four steps repeated until the model was complete. Rounds one to three involved a focus group elicitation session, compilation and synthesis of responses by the authors, circulation of a draft to the focus group, collection of feedback via emails and a virtual meeting, and then revisions based on that feedback. Round four only involved a focus group meeting, as consensus was obtained, and the model was considered complete. This process aligns with best practices for elicitation from focus groups and aggregation by consensus, as defined by Parnell *et al.* (2013). The focus group comprised 15 construction industry SMEs that represented companies from multiple sectors (e.g., oil and gas, pharmaceutical, energy, commercial, manufacturing, facilities, etc.) and multiple roles (e.g., owners, contractors, and designers). Each focus group participant was an employee of a member company of the Construction Industry Institute (CII), an organization based in the United States whose membership comprises about 140 owners (public and private), engineering contractors, and suppliers (CII, 2021b). The group of practitioners was formed based on an open call by the CII to support and encompass a variety of views. The participants were asked to provide their professional opinions, and the inputs given were not necessarily the views of their employer, the CII, or corporate sponsors. All focus group members identified as male. The group had a combined 355 years of experience, ranging from 6 to 43 years in the industry. Two of the participants had up to 10 years of experience, six had between 11 and 20 years, and the remaining seven had more than 21 years of experience each.

The focus group met nearly bimonthly during the study, and there were four in-person meeting dates, from January to August 2019, that supported the model development presented in this paper. Two of the focus group meetings were 1.5 days in duration, and the other two were 1 day each. Three principal investigators from academia led the discussion and interviews during the focus group sessions, while a group of graduate students took notes and documented the discussions. The multiple iterative meetings enabled the model to be developed in phases, with a feedback loop included at each session. The diversity of views and experiences captured over time within the focus group supported multiple forms of validity: (1) face validity, i.e., industry-backed views of what happens in reality; (2) content validity, i.e., accurate representation of the reality studied; and (3) construct validity, i.e., measuring what matters to describe the phenomenon under study (Lucko and Rojas, 2010). The model is grounded on industry-based knowledge, including what this group of practitioners elicited as relevant for their work, but is also supported by the literature on socio-technical aspects on the development and implementation of collaborative schedules, as reviewed in this study (i.e., criterion validity).

Focus Group Session One

To begin the development of the model, data on current industry practices and limitations were elicited from the focus group team. To facilitate this initial discussion, the following questions, adapted from CII (2021a), were asked to define the basis of the inputs into CS:

1. Has the schedule become a deliverable for contracting and litigation rather than a tool for collaboration (among owners, designers, contractors, and trade partners), commitment, and accountability?
2. Is the scheduling effort focused on justifying the baseline schedule because of contract requirements, or is it put toward better solutions?
3. Are schedulers now merely computer technicians, or do they facilitate team planning and subsequent re-scheduling?
4. Is it understood that planning and scheduling are two different skill sets?
5. How significant are the differences between levels of detail throughout the life cycle of the project?
6. Do project teams perform life cycle planning and scheduling from the owner's perspective, integrating and aligning schedules with important owner milestones?

Each member of the focus group was asked to consider each question thoroughly and one at a time, writing down each response and thought on separate sticky notes. The responses were then read aloud without attribution and arranged on the wall by themes in order from least collaborative to most collaborative. The themes that emerged during this non-attribution discussion were then arranged into an affinity diagram, which, by definition, arranges responses into a hierarchy, with duplicate statements consolidated (Parnell *et al*., 2013). The hierarchy of the affinity diagram is logical, mutually exclusive, collectively exhaustive, and can depict competing objectives to the decision problem (Parnell *et al*., 2011). During this process, a major theme emerged for each posed question, and an additional thread in the hierarchy was reserved for variables, inputs, and responses outside of the six-question structure.

The affinity diagram built from the first focus group session in January 2019 was analyzed for recurring themes and phrases. The following themes and phrases were defined and considered as inputs to the MM's first iteration: collaborative vs. noncooperative, proactive vs. reactive, precise vs. imprecise, accurate vs. inaccurate, progressive vs. underdeveloped, strategic vs.

shortsighted, detailed vs. ambiguous, and the differentiation between planning and scheduling. These generally opposite descriptive traits were initially used to define metrics that could be measured and differentiated across levels in an MM. When organizing responses from the least to the most collaborative, a natural pattern of three tiers or levels of collaboration emerged: bronze (least collaborative), silver (moderately collaborative), and gold (most collaborative), aligned with statements, methods, and techniques.

Then, pillars were directly built from responses to the initial six questions and subsequent affinity diagram, but the phrasing of themes was revised to: *scheduling significance*, *scheduling effort*, *role of scheduler*, *scheduling/planning differentiation*, *scheduling detail*, and *goal alignment with owner*. Within each of the six pillars, statements were aligned horizontally across bronze, silver, and gold to provide the focus group with a spectrum of keywords and phrases that could classify project teams and schedules. This task organized the statements as best as possible when considering the extent of collaboration in a project schedule. Examples of how the pillars and the associated keywords/phrases are organized are shown in Appendix 1.

Focus Group Session Two

The initial analysis of pillars was then presented to the focus group at the second meeting in March 2019. The goal of this focus group meeting was to gather feedback, refine, and confirm the model foundation. The focus group was asked to review the model as well as each individual pillar for idea representation, accuracy, alignment, and thoroughness. Additionally, the group would decide if certain pillars should be combined or deleted, or if new pillars should be added. The goal was to define MM pillars that encapsulate the themes that make a schedule truly collaborative and how project teams could advance their level of understanding and techniques of CS.

From the feedback session, some changes were made to the MM as a result. Scheduling effort was combined with scheduling detail to create the new pillar *scheduling representation*. The difference between scheduling and planning was eliminated, and that pillar was combined with the role of the scheduler into a new *planners and schedulers* pillar. Finally, a new fifth pillar was added for *communication*. The affinity diagram (sticky note) activity from the first meeting was repeated for this fifth pillar to generate phrases and keywords that depict the least collaborative to the most collaborative activities and techniques when considering communication. Discussions on the second day of the focus group meeting identified that keywords under the pillars should also be vertically aligned and utilize similar language horizontally across pillars. After the meeting, draft models were circulated in three separate iterations to the focus group, upon which feedback was given and incorporated.

Focus Group Session Three

The third focus group was held in May 2019. During this session, metrics, or swim lanes, were defined for each pillar. The metrics contain some similar descriptors that were used in the creation of the model, especially considering the list of opposite traits from session one, as well as terms that were agreed upon and continued to be discussed by the focus group. Swim lanes are additional influences on collaboration and decompose the pillar into metrics that can measure the extent of collaboration while also defining the scope of each pillar. Figure 1, presented later in this paper, depicts, as an influence diagram, the five pillars and the horizontal swim lanes as defined by the focus group (CII, 2021a). Elaborating on the need for consistent language, the swim lane metrics use horizontal alignment to depict levels of collaboration within each pillar, as presented later in Appendix 1.

Focus Group Session Four

The final MMCS draft was presented to the focus group in August 2019. The focus group affirmed consensus, and no major revisions to the model were made. After the meeting, the model was finalized and presented with each swim lane and a narrative for each pillar.

Survey Development and Deployment

To validate the pillars and swim lanes and extend the results of the MMCS beyond the small focus group of SMEs, a survey was created to assess the level of collaboration against project performance, as perceived by practitioners, and assess the level of collaboration (gold, silver, and bronze) existing in current projects. The goal was to map current projects to the MMCS and statistically determine if the swim lanes of the model were distinct, unique, and non-overlapping. The survey was reviewed by the IRB at (removed for peer review) and distributed via Qualtrics from August 2019 through October 2019. Promotion for the survey included contacts of the principal investigators and focus group SMEs, professional networks and groups via LinkedIn and emails, and two face-to-face industry events.

Survey Design

The survey contained four main sections: background, demographics, performance metrics, and pillar evaluation, which were directly related to the structure of the MMCS. The survey mimicked the process of practitioners evaluating their projects by using the MMCS and aimed to provide an overview of the use of practices related to CS across the population sample. The survey asked the respondent to recall a reference project and answer questions to reflect that project's performance as well as the respondent's experiences working on that project and with that project team. As this is part of a broader study, this paper focuses on the pillar evaluation questions only. The survey questions are available in CII (2021a).

The pillar evaluation section contained most of the survey questions; the entire survey was over 60 questions. Each question also had three responses from which a participant could choose, relating to the gold/silver/bronze narrative and matched horizontally across each swim lane to track and evaluate all coded survey responses simply and effectively. For example, the question related to the *culture* swim lane in the *scheduling significance* pillar states: *The schedule used within the project supported strong project culture associated with accountability, timeliness, and collaboration.* Just as the other pillar evaluation questions, respondents were asked to choose *yes, no,* or *partially* as their multiple-choice response, with *yes* representing the gold level of collaboration, *partially* representing the silver level, and *no* representing the bronze level of collaboration. For four select questions, *yes* represented bronze collaboration while *no* represented the gold level of collaboration, due to how the questions were worded. Specifically, those questions focused on static vs. dynamic schedules, the scheduler's role as a recorder, quality checks, and sharing project feedback. Survey participants were not aware of the gold/silver/bronze levels while taking the survey and were asked to anonymously reflect on their project's characteristics and experience. Some swim lanes were assessed by multiple questions in the survey to fully capture the complexity of the practice. Overall, each swim lane was assessed by at least one question.

In total, the survey received 413 responses, of which 241 were usable. Responses were removed from the sample if any pillar evaluation questions were left blank or if a respondent completed the online survey in less than five minutes (speeding). The survey also included an attention check question, where a question about BIM was asked twice, about one-third and again two-thirds through the survey. If a respondent did not answer those two questions with the same response, potential straight lining or inattention was assumed, and that response was removed from the sample. The final data set of 241 respondents included 64 project managers, 18 assistant project managers, 24 project engineers, 51 schedulers, 10 superintendents, and 74 respondents with other job titles (architect, project controller, construction manager, Lean coach, consultant, estimator, etc.). The final population had an average of 16.5 years of experience in the construction field.

MATURITY MODEL FOR COLLABORATIVE SCHEDULING (MMCS)

The final complete MMCS of five pillars and corresponding swim lanes is presented in Appendix 1. In the tiered model of bronze, silver, and gold project teams, bronze project teams do not show much collaboration, silver project teams offer some collaboration with room for improvement, and gold project teams are the epitome of CS. Gold teams set the industry standard to which all other project teams should strive. Each swim lane has a narrative lead that applies to each bronze, silver, and gold level, with the levels identifying the degree of project collaboration within each lane. Additionally, each swim lane is an influence or component of the pillar and, as a metric, allows the pillar to be measured and rated (CII, 2021a). The pillars are defined as follows:

- *Scheduling significance*: the value the project team and stakeholders place on creation, use, and management of the project schedule
- *Planners and schedulers*: the roles, responsibilities, and interactions between collaborative planners and schedulers
- *Scheduling representation*: the ability to grade a project based on appropriate schedule detail, proper tools and methods used during schedule creation, and proper control metrics and quality checks to effectively maintain the schedule
- *Goal alignment with owner*: goal alignment with the owner's expectations with respect to the schedule
- *Communication*: focuses on the need for defined communication plans regarding who is expected to participate in different meetings, communication channels, and frequency of updates

Figure 1 presents each pillar, the swim lanes, and a definition of each swim lane. The bronze, silver, and gold categorization for each swim lane and pillar can be found in Appendix 1 and are discussed in additional detail in CII (2021a).

Insert Figure 1 here.

Comparing and Contrasting the MMCS with Literature Recommendations

In general terms, MMs usually have 3–6 levels, with labels that allude to the level of maturity described, and are accompanied by specific characteristics associated with each level of dimensions or process areas (Fraser *et al*., 2002) or, in the case of the MMCS, as pillars and swim lanes. Even though Fraser *et al*. (2002) suggest that details about each evaluated area are not usually provided in proposed MMs, which tend to use generic statements in Likert-scale format, the details in the MMCS are provided to highlight differences across swim lanes in each level. The MMCS uses a similar rationale to Crosby's (1979) grid by providing statements that characterize processes and attitudes toward CS at different levels. Additionally, in line with the rationale used in the CMM

(Paulk *et al*., 1993), the MMCS provides statements representative of practices for each key area of interest (pillar) across specific processes, characteristics, and attitudes supporting CS (swim lanes). Compared to the PM2 (Kwak and Ibbs, 2002), the MMCS also allows for a combination of practices to define a level of maturity. That is, a project does not need to use all practices assigned to a specific level to attain that level of maturity; this is explained using the bronze, silver, and gold cut-offs defined for each maturity level, which is supported by survey data.

The literature about MMs lacks empirical details supporting the development of the models and their validation and follows a more prescriptive approach, which supports assessment but does not support improvement, as practices are not prescribed to progress from less mature to more mature levels (Tarhan *et al*., 2016). The MMCS development addresses these gaps identified in the literature by relying on data gathered from focus groups of industry subject matter experts and a survey, used for statistical analysis, to identify key areas of interest and associated practices that support higher levels of maturity. Moreover, the MMCS can be extended so that practitioners can assess their level of CS and provide relevant information about guiding practices that can be used to move toward higher levels of CS maturity (CII, 2021a). As future work, the MMCS can also provide recommendations to achieve higher levels of maturity based on a combination of data from the focus groups and the survey analysis.

SURVEY RESULTS—ANALYSIS, DISCUSSION, AND MODEL VALIDATION

To provide further validation of the MMCS and insights into the current industry practice in collaboration in project scheduling, statistical analysis was conducted on the survey data. Table 2 presents this analysis via STATA; pairwise comparisons of survey questions representing each swim lane within a pillar were examined. The pairwise comparisons were built in contingency tables, which counted the number of *yes, no,* and *partially* responses across two pairwise questions at a time; the table arranges those responses into a matrix, with one survey question in rows and the other in columns. Chi-squared tests were predominately used for this analysis unless any bin in the contingency table had a count of five or fewer responses. In those cases, Fisher's exact tests were used, as the Fisher's test is a substitute test for the potentially unreliable chi-square under the conditions of small sample size. The chi-square test examines differences in frequencies in a contingency table, and its null hypothesis assumes no differences or that the data are independent. For swim lanes that had more than one question assigned in the survey, a composite score was calculated to determine gold/silver/bronze collaboration in that project for that swim lane.

The analysis discovered that collaboration in practice, as implied by practitioners through the survey responses, is not consistent. Most of the tests in Table 2 are significant, implying a rejection of the null hypothesis and differences in the data. Within each pillar, industry projects do not have the same level of collaboration within each swim lane, and room for improvement exists in the current industry standard. This result aligns with Kwak and Ibbs (2002), which indicated that projects in a certain maturity level might not use all practices pertaining to that level in a consistent fashion.

Insert Table 2 here.

The MMCS can differentiate projects as gold/silver/bronze in general, and additional classifications can be made by drilling down into specific pillars and swim lanes. With that, the model can be used to evaluate CS at the macro level (overall project) or micro (swim lane) level to promote incremental, continuous improvement in schedule collaboration within a project. The prevalence of significant tests provides support that the model can discriminate between levels of collaboration and swim lanes within the pillars. These findings shed light on practices that are not implemented consistently in projects, despite recommendations proposed in benchmark documents discussed in the literature review (e.g., Ballard and Tommelein, 2016; HE, 2018; CII, 2019).

Within pillar 1, *scheduling significance, accuracy,* and *adaptability* were significant when compared to every other swim lane within the pillar. This addresses the importance of schedules accurately representing the project's reality but also having room for flexibility to adapt to changing environments. In addition, *visibility, stakeholders,* and *culture* were significant to all other swim lanes within pillar 1, except for *creation.* This implies that the existing culture on how schedules support accountability, timeliness, and collaboration goes hand in hand with the stakeholders' access to information available to the team and their involvement throughout the project. This also reinforces the notion that the development of plans and schedules is part of a socio technical system which supports not only the technical needs of the project but also the needs of those in charge of designing and building it (Ballard and Tommelein, 2016). The least significant swim lane across pillar 1 is *creation,* which is related to how schedules are treated from a contractual standpoint. Results reflect the current environment of the industry, which might still treat schedules as contractual documents to monitor progress rather than as a tool to promote project collaboration and support production management (Olivieri *et al*., 2019; Alves *et al*., 2021).

Within pillar 2, *planners and schedulers, cross-discipline interaction* and *understanding* of one's role in a schedule are not significant when facilitating or promoting CS. However, significance exists between one's own personal *job role* within the schedule and approaching the project schedule with a *planning mindset*. This finding underscores the importance of schedulers approaching the scheduling task with a planning mindset and having the team recognize the scheduler's role as an active participant in schedule development, alongside the rest of the team and not in an isolated fashion (Alves *et al*. 2020). Surprisingly, despite the importance of *cross-discipline interaction* to support CS and team alignment as discussed in the literature (CII, 2009, 2019), this swim lane was not as significant in promoting CS. This finding also underscores the importance of fully engaging a planning mindset with the team versus simply following prescriptive contractual requirements of just meeting with other project participants.

For pillar 3, *scheduling representation,* the significance of *agility, level of detail,* and *quality checks* could be due to how quickly a schedule can be updated, how tasks are defined, and how the overall work can be checked and evaluated. These three significant swim lanes in pillar 3 also align with the significance of *accuracy* and *adaptability* in pillar 1, as these lanes affect the schedule overall, how it can change, and work defined for promoting collaboration. These findings also find support in the literature regarding the importance of visual displays of information to promote open and shared understanding (Ballard and Tommelein, 2016; Castillo *et al*., 2018).

Each swim lane within pillar 4, *goal alignment with owner,* was significant when compared with others in the pillar. This finding underscores practitioners' perceptions about the need for alignment in their projects and how that is captured and represented in schedules. For teams to deliver projects aligned with the owner's goals, interactions between the owner and project teams must follow the owner's directives (usually spelled out in the project documents) and ultimately support the owner's expectations for the project from the early days of schedule development and continuing throughout the project (CII, 2009; 2015). While data suggest that interaction among team members supports *goal alignment with the owner* and CS, the same could not be said about *cross-discipline interaction* for *schedule representation*. Additional research might be needed to explain the impact cross-disciplinary teams have on how schedules are represented and ultimately what might help or hinder their efforts towards CS.

Pillar 5, *communication,* was significant across all swim lanes when pairwise compared except for the pairing of *psychological safety* and *coordination.* However, *psychological safety* was significant when paired with *communication plan, channels,* and *engagement.* Such results likely stem from the fact that although most people want to feel safe in sharing opinions during the project, it may not be the most important indicator of successful collaboration. Moreover, psychological safety depends on other environmental factors related to team structure and team leader coaching (Edmondson, 1999), which are not explicitly considered in the MMCS, and might deserve additional analyses in terms of how these impact coordination and ultimately CS efforts. Conversely, the swim lanes of *engagement, coordination, channels,* and *communication plan* were all significant when paired with one another. This supports the collaboration results of the model, as each of the four listed swim lanes facilitates strong communication and collaboration among project members as they know how, what, and when to communicate while also being evaluated on their level and frequency of engagement. This supports and augments findings and recommendations discussed in other publications (e.g., Ballard and Tommelein, 2016; Daniel *et al*., 2017; CII, 2019). The significance of the *engagement* and *coordination* swim lanes with other *communication* swim lanes implies that collaboration and communication are not consistently implemented within current projects. This highlights the need to improve performance in these practices to support collaborative schedules.

CONCLUSIONS AND FUTURE WORK

This study contributes to the body of knowledge by identifying and organizing constructs that support CS. Over a series of four focus groups comprised of construction industry SMEs, five pillars of CS were defined and established: *scheduling significance, planners and schedulers, scheduling representation, goal alignment with owner,* and *communication.* Each pillar was then decomposed into swim lanes, which are metrics that reflect influences on collaboration within the context of each pillar. These concepts, such as *culture, understanding, agility, expectations,* and *engagement,* provide fidelity into the scope of each pillar. The swim lanes also assist in measuring the extent of collaboration in current industry projects. The MMCS can then be applied to define and measure the current level of collaboration in a project. The MMCS also provides a targeted and usable maturity model for scheduling collaboration, which had been lacking in the CEM literature. Then the metrics, or swim lanes, were examined via an industry survey, which empirically showed collaboration is currently not consistent within industry projects, with respect to the five pillars of CS. Furthermore, the statistically significant tests provided support for the uniqueness and discriminatory nature of each swim lane within the pillars and the need to consider collaboration amongst multiple pillars and metrics. Statistical analyses plus a comparison and contrast with the existing literature provide validity support to the model, providing empirical support that the pillars of the MMCS can differentiate projects in terms of the extent of development and implementation of collaborative schedules.

The study further augments the literature on schedules and the scheduling process by focusing on social aspects and processes that support the development of schedules beyond the use of processes, software, and algorithms to crunch and make sense of hard data. The MMCS focuses on the mechanics of how schedules are generated and by whom, aligning itself with the existing literature on construction projects as socio-technical systems. Considering the existing literature on MMs, the MMCS draws from knowledge by industry practitioners and the extant literature and addresses limitations identified by previous models, which lacked specificity and actionable recommendations. Constructs related to the development of collaborative schedules were identified and represented by the pillars and lanes of the MMCS and can support future research on the topic. However, this study is limited by the extent of the focus group and survey responses.

The MMCS elicits specific attributes and actions that are part of the road toward CS, allowing practitioners to work on different elements at a micro level (swim lanes) and macro level (pillars) toward increasing collaboration as schedules are developed. The study also illustrates how the identified practices are inter-related within the model and how they represent the status quo of schedule development in the industry. Just as a medical doctor needs supporting data to make a diagnosis and provide a course of treatment, the analysis presented attempts to point the industry to "pain points" that prevent the full development and implementation of collaborative schedules. Future work entails developing implementation recommendations for each pillar and swim lane, demonstrating actionable steps that industry professionals can undertake to improve a project's level of collaboration. Those actions can improve the macro and micro collaboration levels of a project and have shown preliminary promise in productivity in industry practice. Other work includes linking performance indicators with CS practices and standardizing a benchmarking assessment so that practitioners can understand the current level of collaboration in their projects before maturity improvements.

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Figure 1. Affinity diagram illustrating the relationship between the MMCS pillars and lanes and their definitions.

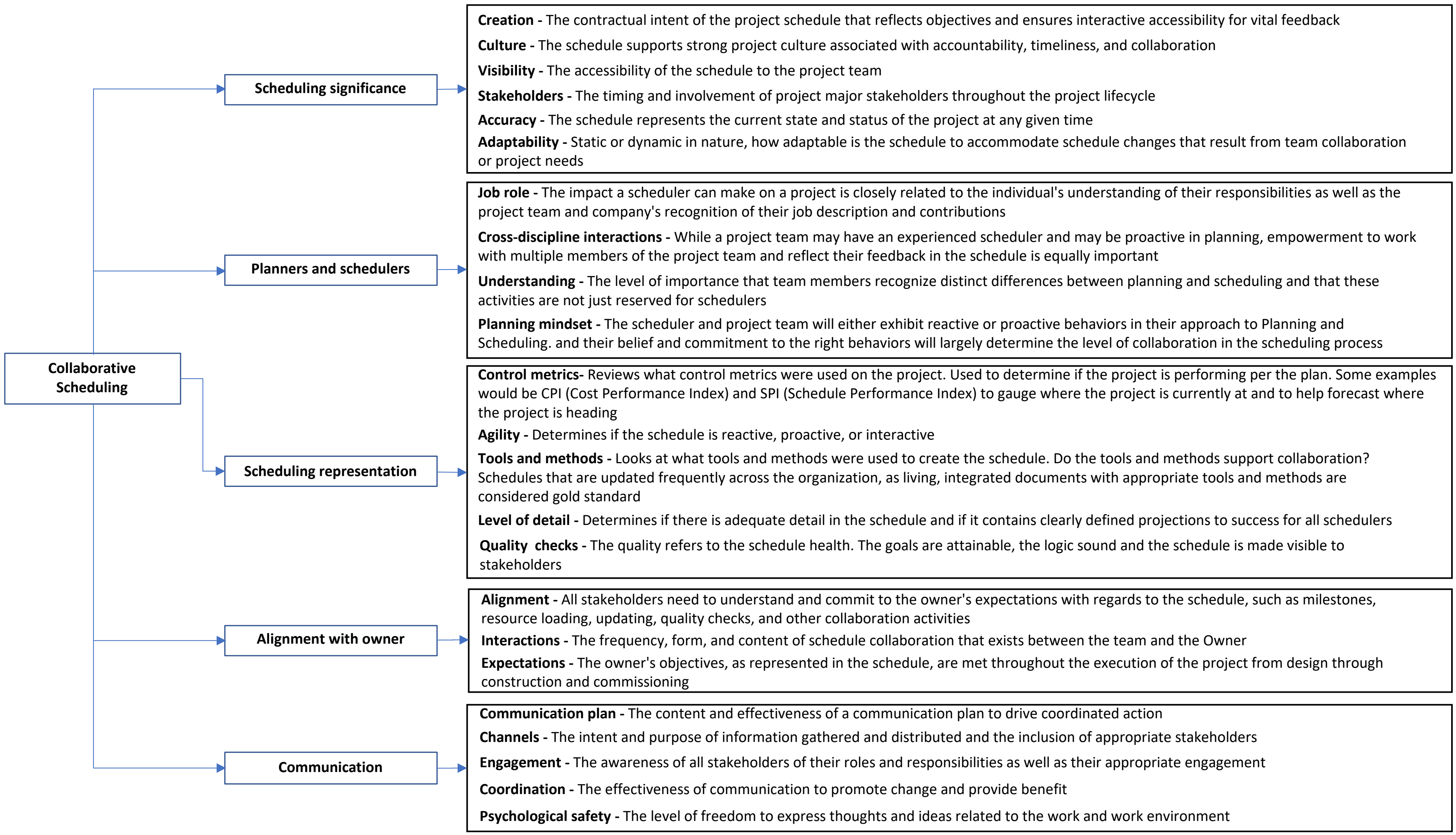

Table 1. Research method scope.

Research Stages	Goals	Results
Focus group 1	• Use of CII (2021a) questions to elicit current collaborative scheduling (CS) standards and practices. (January 2019)	• Affinity diagrams with recurring themes, e.g., proactive vs. reactive practices; differentiation between planning and scheduling. • Major themes organized into seven pillars: scheduling significance, scheduling effort, role of scheduler, scheduling/planning differentiation, scheduling detail, and alignment with owner. • Stated practices organized in levels from least to most collaborative. • Conceptual model organized into pillars with statements defined from least collaborative to most collaborative into three levels (bronze, silver, and gold)
Focus group 2	• Gather feedback about results from the first focus group, refine the initial model, and confirm the model foundation. (March 2019) • Develop a maturity model for collaborative scheduling (MMCS) that is capable of differentiating projects' CS maturity levels.	• Major themes re-organized into five pillars: ○ *Scheduling Significance; Scheduling Representation* (combination of previous pillars: scheduling effort + scheduling detail) ○ *Planners and Schedulers* (combination of previous pillars: role of scheduler + scheduling/planning differentiation) ○ *Goal Alignment with Owner* ○ *Communication* was added as a pillar. • Identification of keywords to serve as basis for "lanes" or metrics under each pillar, e.g., under *Scheduling Significance*, the keywords *visibility* and *stakeholders* were identified to categorize statements about scheduling visibility and stakeholders involved in the process, respectively.
Focus group 3	• Refine each lane. • Define bronze, silver, and gold statements for the lanes under each pillar. (May 2019)	• Explanations (narratives) defined for each lane, e.g., *visibility*: the accessibility of the schedule to the project team.
Focus group 4	• Continued discussion and refinement of the MM. (August 2019)	• Review and refinement of definitions and statements for each component of the MMCS, i.e., pillars, lanes, narratives for each gold/silver/bronze collaboration level. **Final version of MMCS.**
Survey development and refinement	• Use the MMCS to develop a survey to assess the level of CS against project performance as perceived by practitioners.	• Survey to gauge practitioners' perceptions of the level of collaboration along each pillar or lane for a current industry project.
Survey deployment	• Deploy the survey to reach a diverse group of practitioners considering a broad range of projects.	• Survey responses: 413 responses, of which 241 were usable. • Demographics: The final population of 241 respondents included 64 project managers, 18 assistant project managers, 24 project engineers, 51 schedulers, 10 superintendents, and 74 respondents with other job titles (architect, project controller, estimator, etc.).
Survey analysis	• Verify the model's ability to assess a project's CS efforts.	• The model can be used to evaluate CS at the macro (overall project) or micro (swim lane) level to promote incremental, continuous improvement in schedule collaboration within a project. • **Validation of MMCS design (along with literature support).**

Table 2. Chi-square results

Pillar	Question #	Swimlane	Question #	Swimlane	Chi-Square *p*-value	Fisher's Exact *p*-value
Scheduling Significance	26	Culture	25	Creation	0.412	
	27	Visibility	25	Creation	0.283	
	28	Stakeholders	25	Creation	0.082	
	31	Accuracy	25	Creation		0.008**
	32	Adaptability	25	Creation		0.025*
	27	Visibility	26	Culture		0.000***
	28	Stakeholders	26	Culture	0.000***	
	31	Accuracy	26	Culture	0.000***	
	32	Adaptability	26	Culture		0.000***
	28	Stakeholders	27	Visibility	0.000***	
	31	Accuracy	27	Visibility		0.000***
	32	Adaptability	27	Visibility		0.000***
	31	Accuracy	28	Stakeholders	0.000***	
	32	Adaptability	28	Stakeholders	0.002**	
	31	Accuracy	32	Adaptability	0.000***	
Planners and Schedulers	34	Cross-Discipline Interactions	33	Job Role		0.000***
	35	Understanding	33	Job Role	0.427	
	36	Planning Mindset	33	Job Role	0.000***	
	35	Understanding	34	Cross-Discipline Interactions		0.669
	36	Planning Mindset	34	Cross-Discipline Interactions		0.000***
	36	Planning Mindset	35	Understanding	0.130	
Scheduling Representation	29	Control Metrics	30	Agility	0.530	
	37-39-41	Tools & Methods	30	Agility	0.221	
	43-47	Level of Detail	30	Agility		0.000***
	44	Quality Checks	30	Agility		0.002**
	37-39-41	Tools & Methods	29	Control Metrics	0.533	
	43-47	Level of Detail	29	Control Metrics		0.000***
	44	Quality Checks	29	Control Metrics		0.039*
	43-47	Level of Detail	37-39-41	Tools & Methods		0.070
	44	Quality Checks	37-39-41	Tools & Methods		0.210
	44	Quality Checks	43-47	Level of Detail		0.000***
Goal Alignment with Owner	49	Interactions	48	Alignment		0.000***
	52	Expectations	48	Alignment		0.000***
	52	Expectations	49	Interactions		0.000***
Communication	54	Channels	53	Communication Plan		0.000***
	61	Psychological Safety	53	Communication Plan		0.025*
	45-59	Coordination	53	Communication Plan	0.000***	
	Q60-Q55-Q46-Q56-Q57-Q58	Engagement	53	Communication Plan		0.000***
	61	Psychological Safety	54	Channels		0.018*
	45-59	Coordination	54	Channels	0.000***	
	Q60-Q55-Q46-Q56-Q57-Q58	Engagement	54	Channels		0.000***
	45-59	Coordination	61	Psychological Safety		0.361
	Q60-Q55-Q46-Q56-Q57-Q58	Engagement	61	Psychological Safety		0.004**
	Q60-Q55-Q46-Q56-Q57-Q58	Engagement	45-59	Coordination		0.000***

	Swimlane	Narrative…	Bronze (Level 1)	Silver (Level 2)	Gold (Level 3)
Pillar 1 - Scheduling significance	Creation (Q25)	Schedule created primarily….	To define contractual expectations & responsibilities but not used	To define contractual expectations & responsibilities but was not used by entire project team	To enable strong project management communication and collaboration throughout project team
	Culture (Q26)	Project scheduling culture…	Does not support accountability, timeliness and collaboration	Somewhat supports accountability, timeliness and collaboration	Supports accountability, timeliness and collaboration
	Visibility (Q27)	Visibility…	Was poor across the project team	Was moderate across the project team	Was high into the schedule and its creation for project team
	Stakeholders (Q28)	Stakeholders…	Were not involved early enough or considered in schedule creation	Were involved early enough but not all appropriate and necessary	Were appropriate and involved early enough in creating the schedule
	Accuracy (Q31)	There were….	Substantial schedule inaccuracies	Few schedule inaccuracies	No schedule inaccuracies that adversely impacted performance
	Adaptability (Q32)	The project schedule was….	Static, solely defined by contract expectations	Mixed, responsibilities were defined but not widely shared	Dynamic, a living document
Pillar 2 - Planners and schedulers	Job Role (Q33)	The schedule creator job role was…	A creator/recorder, scheduler single-handedly creates the schedule	An Organizer, Scheduler seeks inputs from trades before creating the schedule	A Facilitator, scheduler facilitates the creation of the schedule via interactions with trades
	Cross-Discipline Interactions (Q34)	Schedulers…	are siloed and only have the technical ability to create	have partial access to other disciplines and are not fully empowered	have clear access across disciplines and are empowered to have input into both planning and scheduling
	Understanding (Q35)	There was…	No understanding of differences between planning and scheduling	Partial understanding of planning and scheduling differences	Superior understanding of the difference between planning and scheduling difference
	Planning Mindset (Q36)	Schedulers and project team…	exhibit poor planning mindset and are reactive	partially exhibit a planning mindset	exhibit a planning mindset meaning they were actively engaged, timely and forward-looking
Pillar 3 – Scheduling representation	Control Metrics (Q29)	There were…	No control metrics were used to monitor and control the schedule	Some appropriate and sufficient control metrics were used to monitor and control the schedule	Appropriate and sufficient control metrics were used such as CPI and SPI to monitor and control schedule
	Agility (Q30)	Schedule was…	Static and could not be changed easily	Flexible to accommodate changes	Interactive and represented an accurate and obtainable projection that could be easily updated
	Tools and Methods (Q37 - Q42)	There were…	Little to no use of scheduling tools and methods utilized company wide (beyond scheduling software ex. P6)	Use of additional tools/methods to support collaboration during schedule development	Frequently updates of the schedule across the project; living, integrated document with appropriate tools and methods used (ex. LPS, BIM, 4D, AWP Takt Planning)
	Level of Detail (Q43, Q47)	Schedules…	Did not contain sufficient detail to be useful for team or individual	Contained adequate detail to a reasonable work plan for team and individual	Were appropriately detailed to successfully complete the project
	Quality Checks (Q44)	Quality Checks were….	Minimal to none conducted	Somewhat conducted	Regularly and appropriately conducted
Pillar 4 – Goal align. w. owner	Alignment (Q48)	Major owner-defined milestones were…	Communicated with infrequent check ups	Were communicated with moderate frequency of check ups	Were clearly communicated with frequent check ups
	Interactions (Q49 – Q50)	There was…	Poor interaction between contractor and owner	Some interaction between owner and contractor	Sufficient interaction between owners and contractors
	Expectations (Q52)	Owner's expectations were…	Poorly represented in the schedule	Partially represented in the schedule	Fully identified and represented in the schedule
Pillar 5 – Communication	Communication Plan (Q53)	There was…	No clearly defined communication plan in place	A communication plan but it was inaccurate or not followed by all	A communication plan that clearly defined and effective
	Channels (Q54)	Communication was…	Disorganized with no clear channels defined	Clear with defined channels but not fully utilized	Organized with clearly defined channels
	Engagement (Q55 – Q58, Q60, Q46)	Communication was…	Not productive and only considered few direct stakeholders, with no other feedback gathered	Somewhat productive with limited stakeholders and was not very flexible	Productive, openminded, and inclusive of all stakeholders with frequent feedback
	Coordination (Q59, Q45)	Schedule related information was…	ineffective and did not drive coordinated action	Somewhat clear but failed to drive coordinated action	Clear and concise for driving coordinated action
	Psychological Safety (Q61)	Stakeholders did…	Not feel safe enough to share ideas and their opinions	Share their thoughts/ideas but held back in certain situations	feel comfortable and were open and honest with all thoughts/ideas throughout the project in any circumstance