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Extending the Last Planner System® to the Entire Project

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Abstract

Research Question: How to extend the Last Planner System® to planning the entire project?

Purpose: To provide one planning and control system for both project and production, and to improve project level planning.

Research Method: Design science research method

Findings: Project execution planning is the appropriate focus for extending the Last Planner System® because it responds to the question 'If this project can be delivered with acceptable risk' and provides a plan for project execution. Three primary weaknesses in current project planning were found: failure to involve the right people in planning, being overly deterministic in the face of uncertainty, and over reliance on the ability to predict probability of occurrence of risk events. This research report includes countermeasures for each of the three weaknesses.

Limitations: This research provides a proof of concept for building options into project schedules, but full validation requires implementation and refinement of the proposed planning process on projects.

Implications: Traditional project planning a) is overly deterministic, despite high levels of uncertainty faced by most projects, b) fails to involve the right people in planning, and c) is overly reliant on buffers as a means for mitigating risks, despite the fact that effective buffering requires the ability to calculate buffer size and that can be done only for risks that are statistically predictable.

Value for practitioners: Practitioners are provided a method for building options into project schedules and evaluating the impact of various options on project performance.

Keywords: Last Planner System®, project execution planning, stochastic planning, validation

Paper type: Full Paper

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Introduction

Since the Last Planner System® (LPS®) began to take shape in 1992, its use has been limited to production planning and control (Ballard 2000). Setting project objectives and monitoring progress toward them was left to 'project controls'; i.e. traditional project management. In the early 2000's LPS® took some territory from project controls; namely, in the application of pull planning to produce phase schedules, but responsibility for setting project objectives and monitoring progress toward them remained outside LPS®. The relationship between project controls (traditional project management) and production control (LPS®) has continued to be problematic. Despite the advice to limit project control schedules to milestones and long lead items, schedules continue to be overly detailed, overly deterministic and uninformed by those who do and direct the work. Such schedules make projects more difficult than they need to be. The research reported in this paper was undertaken to extend LPS® to planning and control of the entire project, to apply its principles to the management functions previously reserved for 'project controls'.

Thinking how to approach the task of extending LPS® to planning and controlling the entire project, our team chose to focus on project execution planning, which lies between development of a business case for a project and the decision whether to fund that project. Project execution planning is done to answer the question: *Can the project in question be delivered with acceptable risk?* As shown in Figure 1, answering that question is to be done by planning the project, taking into consideration risks and opportunities, and means for mitigating and exploiting them, respectively; then assessing the residual risk. Depending on the allocation of risk and reward, the client alone decides if the resultant project and its risk are acceptable, or the client decides together with those who share risk and reward.

Once prerequisites are satisfied (Understand what's wanted and conditions of satisfaction for its delivery and assure project definition readiness, as shown in Figure 1), the master schedule is pulled (see description in Pull Planning section) and risks are identified. Depending on the type of risk, mitigation can be achieved through avoidance, buffering or hedging. Buffering is applicable only for statistically predictable risk (as shown in the Literature Review section). Without the ability to calculate buffer sizes provided by frequency distributions, the provision of buffers is as likely to increase waste as to reduce it. Waste is not a kind of thing, but rather a potentiality for removing cost items without reducing value delivered (Ballard, 2016). Unfortunately, the ability to predict frequency of occurrence of risk events tends to be assumed even for risk events with indeterminate probability of occurrence, witness the common method of assessing risk events by guessing their probability of occurrence and multiplying that value by the expected impact should the risk event occur. The resulting values are assumed to indicate mitigation priorities. Such calculations can subordinate more substantive risks; e.g., those with high impact. For risk events that cannot be avoided and are indeterminate as regards probability of occurrence, hedging is the remaining type of mitigation.

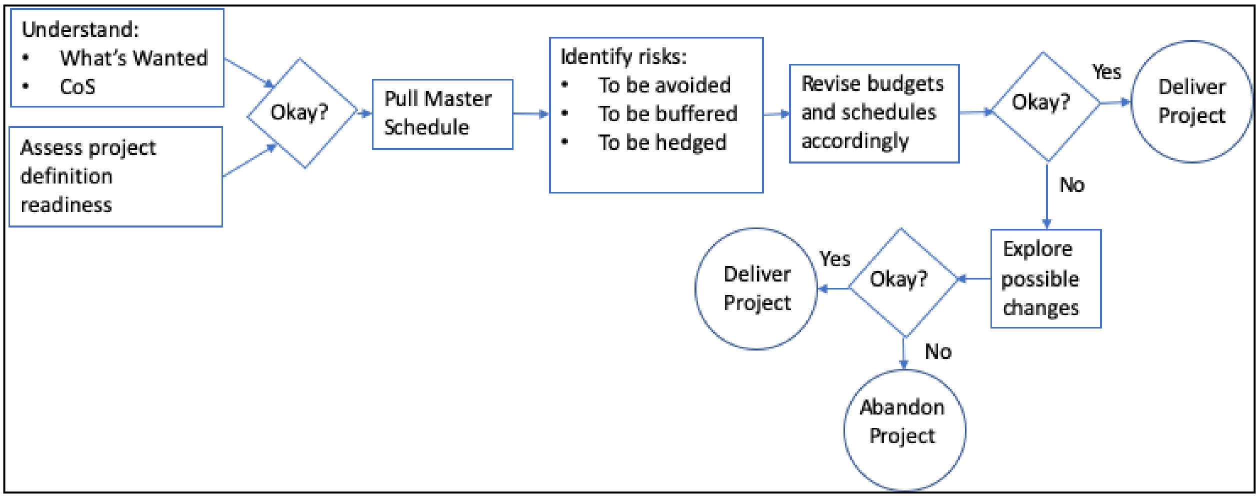

Figure 1: Project Execution Planning Process

Project execution planning will likely explore many alternatives, but the plan that is accepted is expressed in a program, schedule and budget as project targets to meet or beat for scope, schedule and budget. Project master control schedules are best expressed as logic networks connecting milestones, and include actions needed by later phases that must occur in earlier phases--both triggers for long-lead items and options chosen to mitigate or exploit uncertain events. That said, in the process of developing plans and schedules, more detailed planning may be needed to untie knots/to make sure that what is planned can be successfully executed. One of the challenges in planning is to reveal the assumptions behind the plans. That applies in LPS® as the planners tend to change over the life of the project; e.g., from general superintendents to foremen and craftworkers. Communicating the shared understanding developed at each level of planning and planners to the next level is vital. However, as has long been advocated regarding LPS®, don't confuse the work done to get to a project master control schedule with a project master control schedule. The latter should be clear and clean, unambiguously setting targets for collaborative action. A 'basis of plan' document describes the assumptions behind the control schedule and what was done to test those assumptions and the resultant control schedule.

Extending LPS® to project execution planning (aka "validation of the business case") and the project master schedule produced from the project execution plan if validated, is a further extension of LPS® in determining what SHOULD be done in order to achieve project objectives. Previously (see the Current Process Benchmark for the LPS®; Ballard and Tommelein, 2016), pull planning was recommended for use in developing phase schedules, assuming that the project master control schedule remained at milestone level. However, that assumption has been more often wrong than right. As a result, with a phase schedule already in place, it becomes more challenging to replace them. The methodology of CPM scheduling assumes that schedules should be detailed as early as possible, perhaps driven by the use of CPM schedules to support or contest claims involving project time delays.

The argument for extending the LPS® to managing the entire project is based on weaknesses in current project planning. Summarizing the literature section to follow, the gaps we propose to reduce by the LPS® extension are as follows: 1) failure to involve the right people in planning, 2) being overly deterministic in the face of uncertainty, and 3) over reliance on the ability to predict probability of occurrence of risk events.

Pull planning master schedules

We propose that the first gap, that of failure to involve the right people in planning, can be largely closed by a) engaging representatives of all project stakeholders in setting the target for net benefits in use (what's wanted and the constraints on acceptable delivery), and b) using pull planning to develop plans for project delivery because this method involves those with direct knowledge of and responsibility for the work in creating plans for doing that work. Pull planning has been successfully applied at the level of project phases, and also-although as yet less frequently-to the project milestone/control schedule. In this paper, we share cases where project milestone schedules were created using pull planning, and also provide one firm's standard process for pull planning.

The remaining two gaps, both of which concern uncertainty and its management, were addressed by developing a case study based on Robins & Morton's Cherokee Indian Hospital Project, completed in 2015, to illustrate how uncertain events with indeterminate probability of occurrence can be managed by building alternative pathways into master schedules.

Over-reliance on being able to determine the probability of risk events occurring

The dominant risk management method in current practice is to estimate the probability of occurrence of risk events, then multiply them times the expected impact in order to rank each risk as regards mitigation (In supply chains: Simchi-Levi et al. (2015); In projects: Hällgren & Maaninen-Olsson, 2005; Petit & Hobbs, 2010, Hazir & Ulusoy, 2019. There are two problems with that method: 1) only risk events that are statistically predictable can be buffered, and 2) risks that are not statistically predictable are disregarded. The Cherokee Indian Hospital Project case study illustrates how an uncertain event, that is not statistically predictable, can be managed to the benefit of the project and its client.

Overly deterministic project master schedules

As will be shown in the literature review, project master schedules tend to be overly deterministic, laying out only a single pathway to desired objectives, despite the high levels of uncertainty most projects encounter. The case study included in this report constitutes a proof of concept. It shows what <u>could have been done</u> on the project. Application of the concepts and methods for planning under uncertainty to new projects is still needed for full validation.

Structure of the Paper

After this Introduction, this paper consists of:

- A review of the relevant literature, intended to identify gaps in knowledge (know-that and/or know-how)
- An explanation of our research methodology; how we tried to reduce those gaps
- Input from subject matter experts

- Pull Planning: Haley & Aldrich's Standard Process
- Cherokee Indian Healthcare Project Case Study
- Conclusion and Recommendations for Future Research
- Acknowledgements
- References

Literature Review

In this section we review the traditions in conventional project risk management, the main focus of which is on handling uncertainty that is anticipated and described statistically. Further, we discuss the few proactive approaches that exist to flexibly handle project uncertainty that is not statistically predictable, and briefly review new initiatives towards more comprehensive management systems. Finally, we discuss lean construction and highlight LPS® practices of relevance from a risk management point of view.

Projects are increasingly characterized by very high, difficult to quantify, levels of uncertainty, where rational plan-oriented action and conventional risk management approaches are only practicable and successful to a limited degree, and where flexibility and tolerance of vagueness are necessary (Atkinson, Crawford, & Ward, 2006; Böhle, Heidling, & Schoper, 2016; Vaagen, Kaut, & Wallace, 2017). The aim of the planned LPS® extension, to also enhance project execution, is to proactively and flexibly handle such changes throughout the project delivery, and to develop a decision process that enables the team to prove early, *with limited knowledge*, whether the project can be delivered within allowable time, cost and risk limits. This is expected to lead to informed decisions and certainty in terms of expectations and risks to be taken.

Definition of project uncertainty

It was noted that in traditional project management the most studied uncertainty is that of *randomness in activity durations*; see Lambrechts et al., 2010 and Van de Vonder, Demeulemeester, Leus, and Herroelen (2006) for important reviews. This type of uncertainty is *anticipated and statistically described*, and often handled by buffering around critical path approaches. The potentials and shortcomings of these approaches are discussed in, e.g., Herroelen, Leus, and Demeulemeester (2002), where the authors conclude that the insertion of time buffers on critical chains may generate unnecessarily high project due dates, and may also fail to prevent the propagation of uncertainty throughout the schedule.

A different type of, potentially high impact, uncertainty facing building construction and engineer-to-order projects is that of change in the project scope, design and technical specifications (Ballard & Vaagen, 2017; Vaagen et al., 2017). This uncertainty is difficult to anticipate and quantify, and therefore, difficult to manage by conventional risk management approaches. In advanced shipbuilding, for example, frequent changes of this type are well known, but the exact change is difficult to predict (Emblemsvåg, 2014). See also Hansen et al. (2019) for an in-depth case. It may be everything from altering door and window positions to large scale scope outfitting changes. Such events differ from uncertainty in task duration, for a given set of activities, as it may change the project network itself, i.e. the activities to be performed and their sequencing, not only their durations (Ballard & Vaagen, 2017; Vaagen et al., 2017). From this follows that buffering has limited value, as we don't know where to put the buffers, what type of buffer to use, and how much buffer is needed.

High impact changes with limited predictability are acknowledged to be more or less a general feature of large and complex projects; see established definitions of project uncertainty in PMI 2008a p. 139 ["*An uncertain event, set of events or conditions that, if they occur, have one or more effects, either positive or negative, on at least one strategic business objective of the project or project portfolio*"], Knight (2006) ["…… *changes and developments in single projects, in the portfolio of projects, in the organisation itself, or its environment, in which the outcome or the probability of some changes is not fully known.*"], and in Korhonen, Laine, and Martinsuo (2014). That said, these are most often not addressed in advance, but *managed reactively after a change has materialized* (Hällgren & Maaninen-Olsson, 2005; Petit & Hobbs, 2010). This often brings *overreliance on deterministic plans* where all the important decisions are fixed early, and revenues are taken as constant. Such plans are necessarily updated in light of new information (in fact, the most common managerial practice (Jørgensen & Wallace, 2000)), but often with unreasonably large reaction costs (Vaagen et al., 2017). These late adaptation costs, while potentially substantially exceeding initial costs, are often ignored when uncertainty in client preferences is not captured and potential future changes are not addressed before they materialize.

One innovative approach to assess high impact changes that are difficult to anticipate is found in Simchi-Levi et al. (2015), in the context of an automotive supply chain. This optimization-based approach avoids the need to estimate change probabilities and directs attention to the impact of a potential change in a system perspective. This allows us to allocate buffers and develop flexibility strategies at the right places in the supply chains. We did not find similar methods for impact assessment in project contexts. One recent concept initiative is found in Vaagen and Masi (2019) for shipbuilding. Here, the authors apply the Design Structure Matrix (DSM) approach to the SFI system of coding for ships, which provides a functional subdivision of technical and financial ship information, to map relational dependencies and external influences between activities and systems. This enables us to better understand iteration, rework and information exchange loops. In a second step, lifecycle costing of these interdependent systems is suggested for impact assessment.

Finally, we highlight the consequence for plans and strategies of limited focus in the literature on the distinction between the negative and positive sides of uncertainty (Atkinson et al., 2006). In project-based constructions, net benefits in use is the result of subtracting whole life costs from whole life benefits (Ballard, 2016). In that framework, the fundamental meaning of a threat is risk of reducing net benefits in use, which can occur either from increasing costs or reducing benefits. Opportunities are possibilities to increase net benefits in use, which can occur either from reducing cost or increasing benefits. The knowledge needed is how to reduce costs without reducing benefits, and to increase benefits without increasing cost beyond the target ratio. In simple terms, we need to understand how to reduce costs, to increase benefits, and to regulate the interaction between the two.

In conditions of uncertainty, the norm in construction projects, what counts as net benefits in use to a client may change during the course of the project or events may occur that necessitate a change in pathway to targeted net benefits in use. A dominant share of established planning models does not capture this uncertainty, as modelling complex demand functions can be difficult. Revenues are often assumed fixed in models, and the costs of adapting late demand changes are not correctly captured (recall that these costs can occur multiple times exceed initial costs, unless the delivery process is designed to enable quick adaptation, i.e. flexibility). Consequently, the distinction between threats and opportunities (particularly the latter) is less understood.

Management of project uncertainty

Model based approaches

To enable adaptation to late changes with least disturbance and costs possible, models and planning processes that *handle information arrival and delayed decisions simultaneously* are needed; i.e. *flexibility*. Otherwise new information has no value, as it would not exploit the threats and opportunities that lie in e.g. allowing customers to make late changes. Delaying design information has provided substantial competitive advantage for Toyota (A. Ward, Liker, Cristiano, & Sobek, 1995; S. Ward & Chapman, 2011). Similarly, lean design principles (e.g. set-based design) from within the field of lean construction support generating alternative solutions, as an essential element of lean project delivery, but it is less clear how to flexibly implement multiple solutions throughout the project. In projects, research on how to operationalize alternatives in design and implementation paths is limited. One recent research direction is resource-constrained project scheduling to allow switching between multiple networks; see Servranckx and Vanhoucke (2019) for one example. For a comprehensive review on classification and methods for modeling project uncertainty see Hazir and Ulusoy (2019).

In the project planning literature, in general, there are few approaches dealing with information arrival and future decisions simultaneously (see the discussion in Vaagen et al. (2017)). In modelling terms, the problem at hand is a complex stochastic dynamic planning problem, with the difficulties involved in modeling and solving such problems described in Jørgensen & Wallace, 2000. These has led to simplifying assumptions on the central terms information arrival and delayed decisions, and to models that are not well suited to flexibly handle changes. That acknowledged, and while the general formulation of the problem is stated as unresolved (Jørgensen & Wallace, 2000 Vaagen et al. (2017), initiations to solve the problem exist. Deblaere et al. (2011) applies an optimized decision rule within a simulation model to estimate changes in parameter values. Like simulation models in general, it is suited for large real applications, but it cannot say anything about the optimality of the solution. It can only compare one solution to others. As such, it is less suited for conceptual analysis on how to develop flexibility. The stochastic model in Vaagen et al. (2017) handles optimality in the problem but is only suited for small problem instances. The authors include design planning into project scheduling, and show how design flexibility enabled by options (in this case, postponement and hedging strategies) adds value to the project and what, exactly, it is that produces this value. The reported cost improvements from such proactive approaches are up to 35%, as compared to reactive approaches. While difficult to be applied to large real-life problems, the findings provide valuable guidelines on how to extend the LPS® to include master planning with options.

For a recent review on classification and methods for modeling project uncertainty see Hazir and Ulusoy (2019).

Less tangible project management processes

Recognizing that model-based operational planning and control is only practicable and successful to a limited degree (Atkinson et al., 2006; Böhle et al., 2016), the focus is increasingly directed towards less tangible, but more generic, management processes associated with building trust, sensemaking, and organizational learning (Atkinson et al., 2006). Such initiatives often demonstrate innovative solutions, not visible within traditional approaches (Bendoly, Donohue, & Schultz, 2006). Cook (2001) argues for 'trust' being increased and uncertainty reduced by knowing the competence of other staff. Atkinson et al. (2006) point to trust as the most economic method of compensating for gaps in missing information, and emphasize that the link and dynamics between uncertainty, control and trust could be improved if the factor of 'trust' was included in uncertainty management processes. For more on these aspects in the context of a complex shipbuilding project see Hansen et al. (2019).

However, the problem is not less complex when replacing models and formal control systems with team coordination and judgmental processes. In fact, these processes open up for behavioral challenges, such as incentive misalignment (Bendoly et al., 2006), social motivations (Urda & Loch, 2013; Vaagen, Borgen, & Hansson, 2016), natural risk aversion (French, 1986), human limitations in working memory (Hogarth, 1987) and invisible and illusory correlations (Schuyler, 2001).

Models and formal management processes aim to eliminate or reduce the broad range of heuristics leading to bias in human centered decision processes, and to ensure a certain behavioral stability. Many argue, therefore, for a balance between formal management systems and informal mechanisms (Atkinson et al., 2006; Poppo & Zenger, 2002). Jørgensen and Messner (2009) states that formal management procedures that enable employees to deal more effectively with the work process and inevitable changes, are beneficial to overcome the challenges and risks of uncertainties.

Lean construction and the Last Planner System® of planning and control

An alternative literature stream to conventional project management is lean construction, with Lean Project Management (Ballard & Howell, 2003; Ballard & Tommelein, 2012), the Lean Project Delivery System (Ballard, 2008), and the Last Planner System® of planning and control at core (G. Ballard, 2000). This research stream acknowledges that well designed processes are both technical and social, with reliable commitment as the social glue (G. Ballard, 2000; H. G. Ballard, 2000), and that a balance between formal and less formal management and control processes is needed. The LPS® lean process fosters a collaborative planning environment to exchange progress and to continuously resolve constraints, which in turn increases project workflow efficiency and allows for better suited buffering strategies. It is a systematic reactive planning approach at the lowest possible level in the planning hierarchy, with decisions delegated to those with responsibility for the plan implementation. The LPS® differs from traditional project planning and control, following the rule to plan in greater detail as the time for execution approaches, which is an instance of the postponement strategy; i.e. a type of planning flexibility. Carefully designed buffering strategies *within* LPS® practices (following the rule of postponement) has been shown to better handle changes, particularly those anticipated and statistically describable (G. Ballard, 2000; G Ballard & Tommelein, 2016; O. AlSehaimi, Tzortzopoulos Fazenda, & Koskela, 2014). Practically speaking, the LPS® process implies adapting to new information from where the project is when new objectives or the need for new pathways to existing objectives is discovered. This may or may not cause substantial disturbance, according to the actions taken to prepare changes. That brings with it doing what can be done to generate new information beyond just letting time pass.

The problem to be solved is both to find or create new pathways to given objectives, and to figure out how to pursue ultimate or intermediate objectives that change during the course of the project. When creating new pathways, flexibility needs to be built in so that they can be taken with least disturbance. *What LPS® has not previously done is to build this flexibility into the master control schedule, to proactively handle changes within defined time and cost constraints*. In fact, LPS® has not addressed project execution strategy, master planning or master control scheduling at all, apart from advising that master control schedules be kept at the level of milestones between project phases and planning in greater detail as the time for execution approaches (Ballard & Tommelein, 2016).

As an example to the challenge to be solved, the lean design approaches within lean construction (e.g. set-based design) support generating alternative solutions (options), as an essential component of project delivery processes, but it is unclear how to operationalize these alternatives in master planning and delivery processes, i.e., how to enable delayed design decisions. This may explain why master plans are overly deterministic, and why projects struggle with lean customization to their uncertain context.

On the other hand, and despite the lack of planning flexibility, the LPS® practice enables people to deal more effectively with the work process and inevitable changes (in line with the claim of Jørgensen and Messner (2009)). The social LPS® skills, built on trust and reliable commitment, with knowledge on who has the relevant competence and responsibility to perform an activity, facilitate high performing responsive social networks (Priven & Sacks, 2013, 2015), although the norms and mechanisms behind this behaviour are not yet well understood (Ballard & Vaagen, 2017). One suggestion is that LPS® facilitates the development of an environment with psychological safety –i.e. a shared belief that the 'trust-based' team is safe for interpersonal risk-taking (Edmondson, 1999)–, and that teams operating under psychological safety become habituated and skilled in finding alternative ways to achieve goals in variable circumstances (Howell, Ballard, & Demirkesen, 2017).

Positioning our research in relation to existing literature

Summarizing the literature section, the source of uncertainty most often studied in planning is statistically describable variation in activity duration, with overreliance on buffers for risk mitigation (Hazir and Ulosoy, 2019). Potentially high impact changes that are difficult to predict are mostly treated reactively after the change has materialized (Hällgren & Maaninen-Olsson, 2005; Petit & Hobbs, 2010), often with high adaptation costs and time delays (Vaagen et al., 2017). In general, research on how to flexibly implement alternatives in planning models is limited and largely based on small case examples. These are less suited for large applications, but have been shown to be valuable for conceptual analysis on project flexibility; (e.g., the Vaagen et al. 2019 model).

Lean design strategies (set-based, modular) are an essential part of lean project delivery, but it is less clear how to flexibly operationalize these through the delivery of projects. Lean project delivery initially was limited to a project-based production system to support a new way to design and build capital facilities, with the LPS® at the core of its operational system. LPS® has not previously addressed flexibility to quickly and cost effectively handle changes, and not previously included master planning, apart from advising that master schedules be kept at milestone level and more detailed planning be postponed until more accurate information becomes available. That said, the social LPS® skills have been shown to enable people to deal more effectively with the work process and inevitable changes. This motivates exploration of planning flexibility within the framework of the Lean Construction and Last Planner System®, by also bringing in learning on planning flexibility from model-based research.

Research Methodology

Research in management is divided into two kinds: 1) Explanatory research looking for relationships between management actions and outcomes; e.g., what kind of leadership has produced best financial results, and 2) Constructive (design science) research that produces something useful for managing; a software program or a process such as mentoring (Rocha et al., 2012). Both produce knowledge, but of two different kinds: know-that vs know-how, respectively. Design science research is the best fit for our research. We have provided processes for better managing uncertainty in project planning. The relevant question about these processes is not "Are they true?", but rather "Are they effective?".

The origin of design science research can be traced to the paper by Kasanen et al. (1993). They follow Johnson and Kaplan's (1987) assertion that management accounting had become irrelevant to practice. Van Aken (2004) later argued that management research be regarded as a design science alongside medicine and engineering, as distinct from an exclusively explanatory science like physics and chemistry.

After Van Aken's generalization, others applied the design science methodology to specific fields of management—to the design of information systems (Peffers et al. 2007), to organizational development (Trullen and Bartunek 2007), to operations research (Manson 2007), to operations management (Holmstrom et al. 2009), and to construction management (da Rocha et al. 2012).

Steps in the Design Science Research Process

The basic steps in the design science research process are: 1) Find a problem that has practical relevance and also has research potential, 2) Understand the problem; e.g., through a review of the literature and data collection, 3) Develop a solution, 4) Demonstrate that the solution works, 5) Present its connection to theory and the research contribution, and 6) Assess the scope of application of the solution (Kasanen, et al. 1993).

Figure 2 shows a more developed process by Manson (2006), who notes that developing a solution is a design process that produces an artifact of some kind (construct, model, instantiation) and emphasizes learning through prototyping, which is characteristic of design. Initial prototypes tend to be deficient in some degree relative to their intended purpose. Remedies for these deficiencies are incorporated in new artifact designs until that point when design evaluation questions can be answered positively, or the researcher accepts defeat. The two design evaluation questions are (Manson 2006 quoting von Alan, et al. 2004): 1) What utility does the new artifact provide? and 2) What demonstrates this utility?

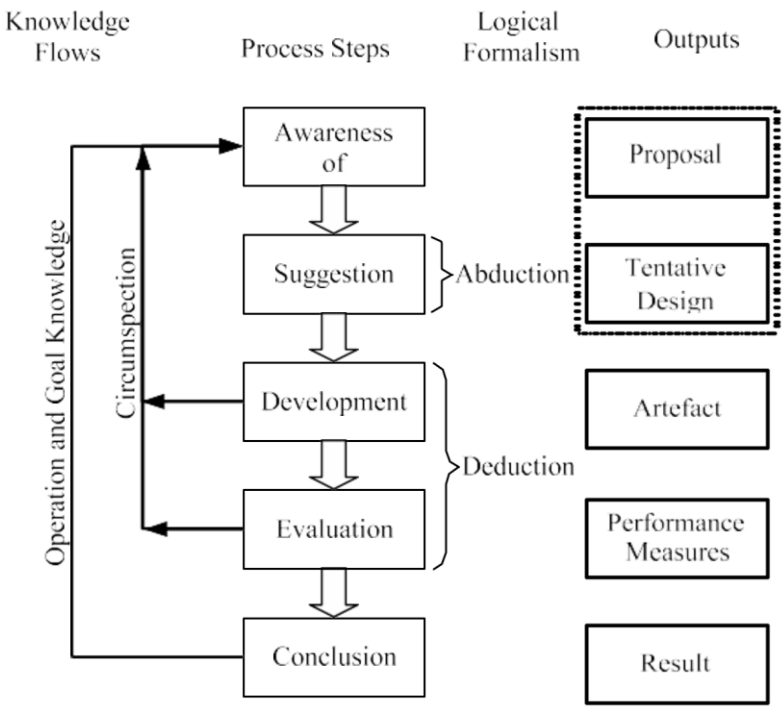

Figure 2: The general methodology of design research (Manson 2006)

Application of the Design Science Methodology in this Research

The selected problem is how to plan construction projects. Its practical relevance is to the challenge of improving the performance of projects executed in conditions of uncertainty. The research potential lies in answering the question how to manage uncertainty that cannot be statistically predicted regarding both occurrence and impact, and hence cannot be buffered with time, inventory or capacity because indeterminate impact would require an infinite buffer.

The artifact to be produced is a process for producing project execution plans. The process consists of component processes for pull planning, for risk assessment and mitigation, and for incorporating options into project milestone schedules. The artifact's intended utility is to increase flexibility in plans and in teams (Ballard and Vaagen 2017).

Please note: Portions of this section are based on Ballard and Elfving (publication pending), used with permission.

Input from Subject Matter Experts

The task team's approach to collecting information from subject matter experts was through having them join the team. Bill Kay and Dan Fauchier are experts in pull planning master schedules. Chris Maslyk and Seulkee Lee are experienced and competent construction project schedulers. Jeff Loeb, Bill Proctor, Bill Stevens and Steve Long are experienced construction project managers. Glenn Ballard and Hajnalka Vaagen are researchers with extensive experience in both construction and ship building projects. Input from these subject matter experts was first solicited to assure that the problems we proposed to solve were in fact problems and that they needed solving. Subsequently, the solutions developed for those problems were evaluated and refined by task team members.

Pull Planning: Haley & Aldrich's Standard Process with some modifications by research team members

Pull Planning is a method used in LPS® to develop a plan for doing work at any level of task breakdown: Project, Phase, Process, Operation or Step (Ballard and Tommelein 2016). Pull refers to developing a schedule or plan by starting at a selected output (milestone, plan for performing an operation, etc.) and working backwards defining the work that needs to be done to produce that output. 'Pulling' identifies the logic network of actions necessary to complete the work through a series of requests and commitments to those requests. This contrasts with "pushing" where the plan is developed starting from the beginning and working forward. Pull Planning is a collaborative process, involving those who have direct responsibility for the work being planned (Last Planners®) and with authority to make decisions, plus others who can provide needed information; e.g., owner, safety, quality, logistics, engineering specialists, etc. One of the keys to a successful Pull Plan is to have those subject matter experts and decision makers collaboratively working together to develop the sequence of activities that produces an acceptable workflow to meet project milestones and other objectives.

As was noted in Figure 1, Pull Planning of a project master schedule starts after assessing customer value and conditions of satisfaction (CoS), which include a milestone for project completion, which may in turn have been pulled from business needs such as the date school starts or a contractual commitment to deliver products or services produced in/with the asset to be constructed. Pull planning generates the milestones between planned start and finish of the project, thus defining project phases and their overlaps, plus actions needed in a phase to start chains of events that culminate in later phases, including both long-lead items and options to preserve the possibility of beneficial action should uncertain events occur in the future. Once the master schedule has been pulled, it is tested and refined to ensure that project milestones and CoS are met. Testing of phase durations can be done by planning individual phases to show handoffs between the organizations doing the work in each phase. That demonstrates that there is at least one logic network that fits within the available time for project delivery. We distinguish between the project schedule developed to assess feasibility of project execution and the master project control schedule that remains at the level of milestones between phases and includes only starting points for long-lead items and options. As previously recommended, detailing the phases between milestones is done sufficiently prior to scheduled start of a phase to allow time for removing constraints.

Figure 3 is a template for pull planning a master schedule for a project with multiple sites and project phases. The steps in the process may be performed with different 'tools', depending on context or preference. The first step in the process is to identify milestones, and then each function (swim lane) identifies the activities necessary to complete the milestone. Risks or constraints (red) and data needs (blue) are also identified. This is done as part of project execution planning to assess if the project can be delivered with acceptable risk. The project control schedule itself should be structured as a bar chart showing the phases between milestones and the overlaps of those phases, plus actions needed to initiate the work to acquire long lead items and actions needed to enable options (see case study following).

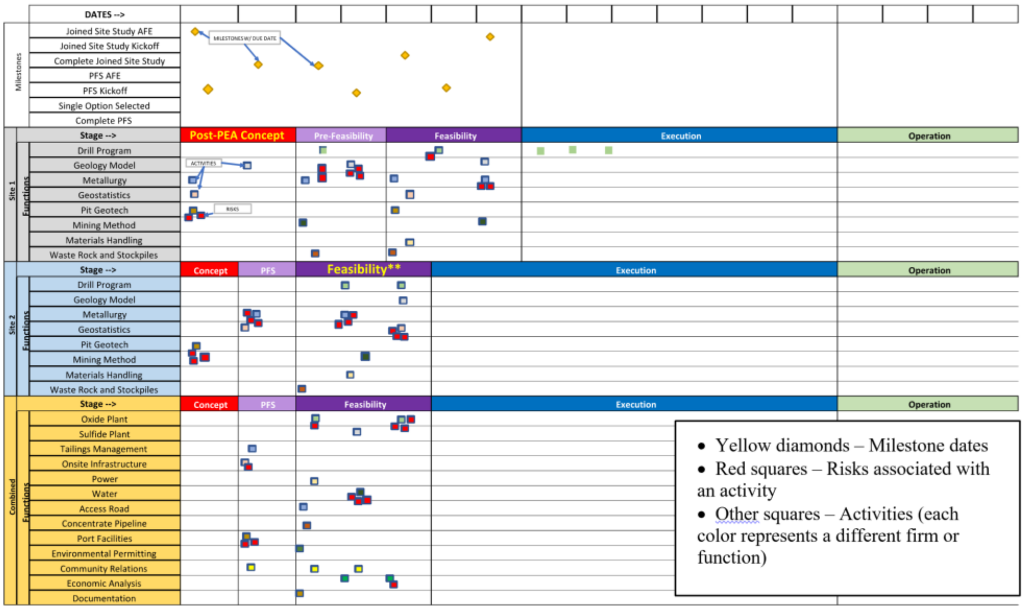

Figure 3: Template for Pulling a Master Plan

The process presented here is intended to apply to pull planning of the project master schedule and pull planning the phases within that master schedule. The differences between master and phase schedules involve:

- How plans are expressed: Project master schedules are expressed as annotated bar charts and project phase schedules are expressed as logic networks.
- Who participates in the planning: the front-line supervisors for design and construction may not have been identified, so someone higher in each organization will represent them.
- The level of detail in the plan: The level of detail in project execution plans is that level needed to assess feasibility of the plan. Once a project is funded and begun, the Last Planner System® rule 'to plan in greater detail as you get closer to doing the work' comes into play. Accordingly, project master control schedules do not show the handoffs between the different organizations involved in each phase, but phase schedules do show those handoffs.

Pull Plan Learning & Prework

Prior to the Pull Planning session, it is advisable to explain the process and tools that will be used to the session participants. This is typically done by teleconference. In addition, prework is assigned to the Last Planners® at this time to allow them to:

- identify activities they need to perform to accomplish the milestones, the durations of each activity, and
- predecessor task commitment(s) or data needed from others to start and/or complete each activity.

A Pre-meeting Worksheet for Pull Planning (Figure 4) is distributed to all Last Planners® to complete before the Pull Planning session.

Pre-meeting Worksheet for Pull Planning

Phase Pulled: Specify Milestone in this space...or intended duration
Discipline/Role (Last Planner): Enter Project Partner Type (e.g. Electrician)

1. For the phase we are pulling, you will need a high level understanding of the activities you will be performing and the needs you will have. This will help you build that understanding in advance.
2. Think through and list in the table below, the acitivities in your workflow and their approximate time durations. Don't concern yourself with actual dates yet. Try not to exceed 3-5 days of work to any one activity. Break longer duration activities into subactivities.
3. For each of your activities, list the things you need (if any) and from whom to complete your activity. List these needs in the boxes to the right of your workflow items, i.e., Z1-Z2-Z3.
4. List your activities and their needs backward from the final milestone, based on what you are required to deliver (conditions of satisfaction)
5. Be brief! Each activity and their needs must fit on a 4"x4" post-it note. The descriptions should only be detailed enough to remind you and the team of the negotiations you had on the subject.
6. Concentrate on your larger, higher level activities that are of interest to the other disciplines and have needs from other team members.
7. When the team meets, you will be asked to place notes in your commitment lane listing each of your activities (Give) and that activities needs (Get) on post-it notes.
8. After each member lays out their workflow, the team as a whole will work backward thru the entire board, negotiating and committing to additional workflow items that satisfy each activities needs.

Deliverables (Conditions of Satisfaction/ Milestone)	Your Workflow (What you will Deliver or Give) - this should include all high level activities associated with delivering a milestone			What you Need (Commitments for Others) - these are things that you need other to complete BEFORE you can complete your activity (Predesessor)								
	#	Activity Description (Give)	Duration	#	Who	Need 1 (Get)	#	Who	Need 2 (Get)	#	Who	Need 3 (Get)
	Z			Z1			Z2			Z3		
	Y			Y1			Y2			Y3		
	X			X1			X2			X3		
	W			W1			W2			W3		
Enter Description of Overall Work	V			V1			V2			V3		
	U			U1			U2			U3		
	T			T1			T2			T3		
	S			S1			S2			S3		
	R			R1			R2			R3		
	Q			Q1			Q2			Q3		
	P			P1			P2			P3		
	O			O1			O2			O3		
	N			N1			N2			N3		
	M			M1			M2			M3		
	L			L1			L2			L3		
	K			K1			K2			K3		
	J			J1			J2			J3		
	I			I1			I2			I3		
	H			H1			H2			H3		
	G			G1			G2			G3		
	F			F1			F2			F3		
	E			E1			E2			E3		
	D			D1			D2			D3		
	C			C1			C2			C3		
	B			B1			B2			B3		
	A			A1			A2			A3		

Figure 4: Pre-Meeting Worksheet for Pull Planning (Courtesy of Haley & Aldrich)

Pull Planning Session

Customer Value and Conditions of Satisfaction CoS

It is important for all participants to review and understand who the internal and external customers and key stakeholders are and what they value. Customers can be external (i.e. project owner) or internal (i.e. other team members). Key stakeholders are those that could have a significant impact on the success of the project (e.g., regulatory authorities). If a customer value assessment has not been completed for the project, then it is best to start the Pull Planning session with this exercise. Attention should be paid to whether the customers were involved in establishing the values – otherwise participants are only listing what they think the customer values. If the customers were not involved, then the resulting values need to be validated by a discussion with the customers. This customer value assessment helps to establish the CoS to meet project milestones that are critical to a successful Pull Plan.

While a project has cost and schedule goals which are important for project success, CoS are co-developed to keep the project team aligned on additional criteria important to the customers, key stakeholders and project team members that are critical for project success (e.g., safety, community interests, environment, etc.).

Milestones

Next is the identification and definition of the project milestones, including the milestone that the team will be pulling from. This includes an understanding of what work is included and excluded, as well as what work is released as each milestone is achieved; within a project, the completion of one milestone sets the stage for the beginning of another. For example, if project completion is the milestone, that releases the use phase in the life of the constructed asset. In some cases, phases may overlap in time, such that accomplishment of specific sub-milestones release later phases. An example is starting building skin when the structure has been erected a number of floors ahead.

Pull Plan Development

The team is now ready to build the Pull Plan. In the Haley & Aldrich process, this is done on a template on the wall listing milestones across the top in chronological order and including swim lanes for each of the Last Planners® (safety, logistics, engineering, legal, owner, each trade or other discipline involved).

At this point the milestone to which the plan is to be pulled is identified. This could be the end of the project or the end of a phase of the project. Again, it is important to stress the importance of understanding and agreeing on the definition of the milestone; what will have been completed and what will be released when the milestone is reached.

Next the Last Planners® fill out sticky notes (see Fig. 5 below) with the information from their prework. This information includes each of the activities they will perform (Give), the durations of each activity, and commitments needed from others (Get) to start and/or complete each activity. Sticky notes are posted by Last Planners® and requests are made of other Last Planners® for predecessor tasks. Last Planners® negotiate the requirements for the handoffs between the tasks posted. Participants must deeply understand their own work, including alternative ways of carrying it out, in order to be able to develop the best plan for all parties involved in the work being planned. The discussions between Last Planners® of the requirements for handoffs is critical to a successful Pull Plan and development of the subsequent master schedule. Last Planners® need to make sure that any predecessor activities they need completed to begin or complete their work is represented by the corresponding sticky note activity of the Last Planner® from whom they need that information or completed work. What someone really needs may not be stated and must be drawn out by others asking questions. Too often, we ask for everything when we only need one part of it in order to accomplish – or at least start – our task.

Sticky notes representing activities are initially put on the Pull Plan by swim lane (e.g., discipline) in chronological order between milestones. Some Last Planners® may find it easier to push and place activities from start to finish while others may be comfortable pulling activities back from a given milestone. Initially it is only important to get sticky notes representing activities on the plan in the correct sequence and aligned with the milestones above.

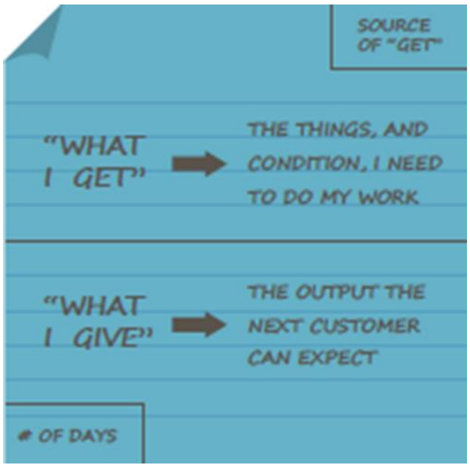

Figure 5: pull planning sticky note (Courtesy of Haley & Aldrich)

Once most of the activities have been put on the Pull Plan and participants have had some discussions on predecessor activities by others, it is time to "pull the plan". This is done by starting at the milestone you are pulling from, going through the activities in each swim lane one swim lane at a time, making sure the information is complete, predecessor needs are identified and represented by other activities on the Pull Plan by those responsible and that they will be completed when needed. If predecessor activities cannot be completed on time, then the participants will have to work out alternative workflows or consider adjusting milestones. The owner should be involved in any discussions related to moving milestones.

Participants are instructed to provide estimates of durations for their tasks—the time it normally takes, without buffers. If everyone buffers their tasks, the total amount of time buffer will exceed what's needed, so buffering is done for the entire logic network, not for the elements that compose that network. Buffering is explained further below.

Planning is subject to differences between assumptions about how the future will turn out and what actually happens. This reinforces why it is important that the Last Planners®, the actual work "doers", are included in the session to provide their insights from experience. This allows more realistic challenges to durations, establishes appropriate "buffers" or adjustments to schedules to build in flexibility without being too conservative, builds an understanding of and commitment to the plans and helps establish a team mentality in completing the work.

Risks and Opportunities

In addition to identifying the activities necessary to complete the work, the participants can take this opportunity to brainstorm and list the following information adjacent to specific activities:

- Risks (constraints, problems, waste)
- Opportunities
- Resource needs
- Ideas for improvement

Although uncertainties about future events may have been identified prior to initiating pull planning, at this point in time, uncertainties take center stage. Decisions will be made regarding which uncertainties can be buffered and which cannot, and then decisions made regarding mitigation of the former and management of the latter. Uncertainties, whether threats or opportunities, that are not statistically predictable may be managed through the use of options (as illustrated in the following case study section), and those options that are assessed as both feasible and effective will require actions to be taken in earlier project phases.

Replanning and Buffering

The Haley & Aldrich pull planning process produces a plan in the form shown in Figure 6 below, but is then expressed as a logic network (Figures 7, 8 and 9 below) that can be examined to determine if it fits within the available time. Routinely applied in the production of phase schedules, this approach can also be used to assess the feasibility of project master schedules. With appropriate information concerning project scope and time frame, experienced practitioners can produce what has been referred to as a 'proposal schedule'; i.e., a bar chart with lines representing the duration of each project phase, annotated to show actions needed to initiate procurement of long lead items and options, showing overlaps in time of the phases. The wild card is the level of uncertainty in the project. Assumptions must be identified and questioned, and If the client and team still have concerns about risk, more detailed pull planning of relevant phases can be done to provide greater confidence.

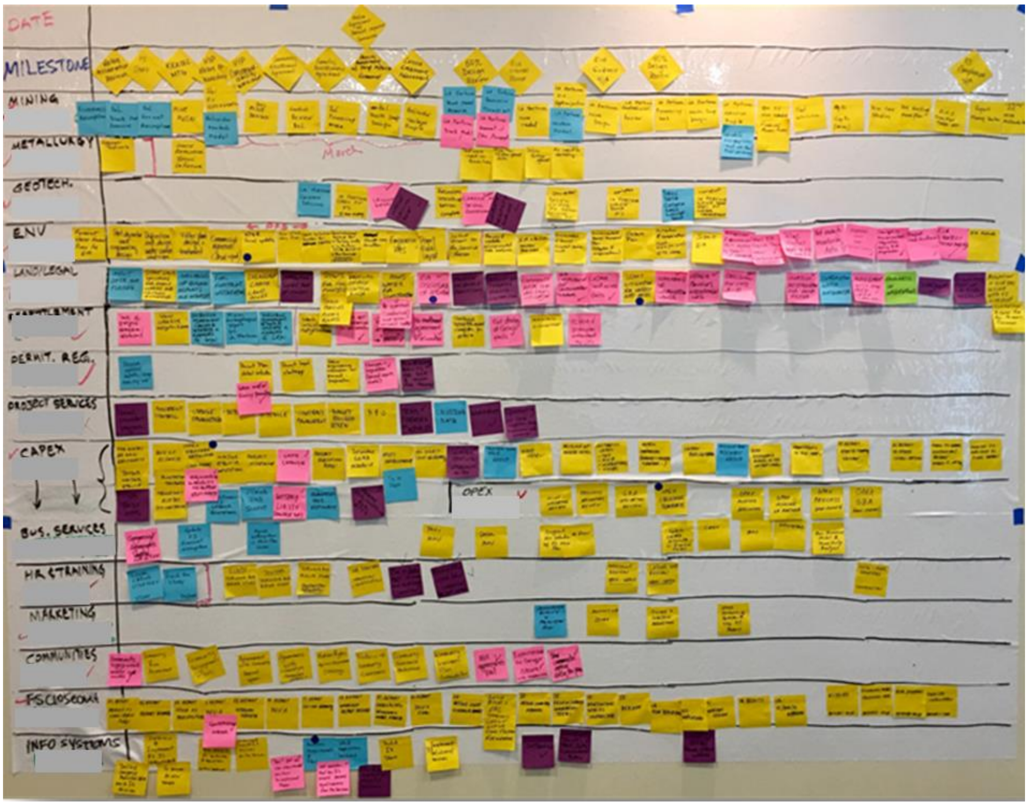

Figure 6: A plan in sticky notes

When the project master schedule is being pulled, the available time is between scheduled start and completion of the project. If an attempt at pulling is too long to fit within scheduled start and completion, replanning is launched to try to make it fit by identifying tasks that are not needed, can be reduced in duration, or can be divided into parts that overlap, increasing concurrency. This second attempt typically produces more intense conversations as participants try to better understand what their immediate customers really need, and what they themselves really need in order to serve their customers. To prepare them, participants are introduced to the reliable promising process in their orientation to pull planning.

The criterion for 'fitting within available time' is the longest path through the network plus a time buffer sized by the participants after identifying elements that are both critical and highly variable. Figure 7 shows a network that does not fit within the available time even before adding the time buffer.

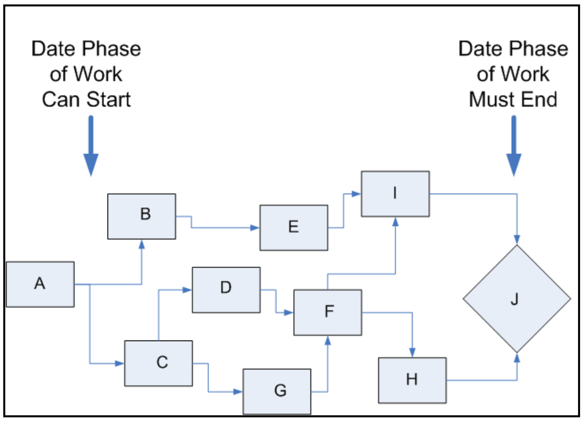

Figure 7: Logic network-does not fit within available time

Figure 8 shows the network produced after replanning, including provision for a schedule buffer, which in this example is approximately 10% of the scheduled duration of the network without buffer, but note that the buffer is to be calculated by the team suitable for each plan.

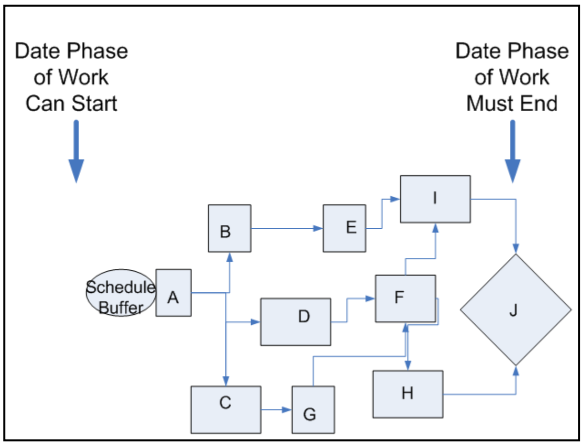

Figure 8: Logic network-with schedule buffer

On projects where the participants are paid collectively for performance, as in Integrated Project Delivery projects, the schedule buffer can be placed at the end of the project or phase and drawn down as needed. Where participants have separate commercial interests, the schedule buffer should be allocated to tasks that are both critical and uncertain (as shown in Figure 9), in order to avoid changing the start dates of activities every time the buffer is used.

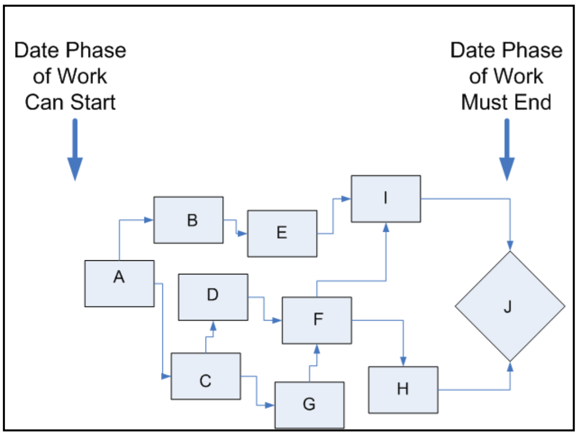

Figure 9: Logic Network-after buffer is distributed

Master Schedule

Pull planning a project master schedule typically involves consideration of alternatives that may be discarded before publishing a control schedule. In addition, plans may have been developed to higher levels of detail than appropriate for a project master control schedule in order to assess feasibility.

Standing advice regarding when to develop more detailed phase schedules is to provide a lead time for making tasks ready at least equal to the project's lookahead window. If the project is to start soon after acceptance of the project execution plan and the project control schedule, the plan for the first project phase should be developed and published at the same time.

The master schedule can be expressed in a variety of different scheduling software packages; e.g. MS Project, VisiLean or vPlanner software either during the Pull Planning session or after from the information provided on the Pull Plan. If created during the Pull Planning session the person developing the master schedule can list the predecessor links on the master schedule while the plan is being pulled. If the master schedule is to be created after the Pull Planning session it will be important to number all the activities (e.g. Safety 1, Safety 2, etc.) and each activity will have to list the activity number of the predecessor activities (e.g. Owner 14, Eng. 28.). Note: Pull plans can be created directly in vPlanner and perhaps other scheduling software.

Testing

Once a master schedule has been completed that fits within the available time and is buffered, it must be checked for meeting all project milestones. If the draft master schedule indicates all activities necessary to complete a milestone will not be completed before the date of that milestone, then the appropriate Last Planners® need to identify alternative workflow to meet the milestone. An advantage to having the scheduler create the master schedule during the Pull Planning session is that you have the opportunity to check that the resulting master schedule meets project milestones, and if not have the Last Planners® make the necessary adjustments to the Pull Plan and schedule to meet project milestones during the Pull Planning session.

When phases are head to tail, without overlaps in time, the critical path is easier to see. If phases are overlapped, which usually happens, it becomes more complicated because a given task may belong to both networks but be critical in one but not the other. Displaying master schedules as logic networks helps identify if a milestone is achievable, and also helps Last Planners® be better able to determine task criticality in execution.

Cherokee Indian Healthcare Project Case Study – Master planning with options

The case presented in this section is a study of Assessment and Management of Project Uncertainty in Construction using a Master Pull Plan (See Figure 10) from a Hospital Project for the Cherokee Indian Hospital Authority (CIHA) in Cherokee, NC. Key project information is as follows: ILPD project under a Howard Ashcraft multi-party agreement contract, 150,000 SF Acute Care Hospital Project, with a total program budget of $75M.

The case is structured as follows: First, key project and planning information is provided. Second, major uncertainties affecting project goals are identified, and options for how one of those uncertainties could have been handled are suggested. Third, different planning approaches, with and without options, are analyzed. The master planning with options proposed here makes use of a real master plan developed through pull planning. What we illustrate here is the potential additional gain by planning with options when uncertainty is a major element of the planning problem.

Brief description of the Pull Planning Process

Bill Stevens, Robin & Mortons' General Superintendent:

> *"We had enabling work in this project. We did pull planning, but it didn't become a primary driver of the job. In Cherokee hospital project we had to literally move a mountain (700,000CY of earth) before we could start construction. This was considered as an enabling project so it gave the designers ample time to get the project developed so design would not impact our construction schedule. However, our schedule process was as follows: We developed a Master Schedule or what we called a Validated Target Schedule (VTS) at the initial alignment meeting when Howard Ashcraft conducted our offsite Business Case validation meeting. Next, we developed a Pull Schedule from the major milestones off the Master schedule with the major trade contractors. Then we refined the schedule as the design developed and conducted weekly work plans with the people or leaders of the teams that actually performed the work. We only tracked PPC, but we did our learning from our weekly analysis of our PPC and discussions stemming from that data at our weekly work plan meetings."*

Figure 10 illustrates the project schedule developed in part through pulling the master schedule.

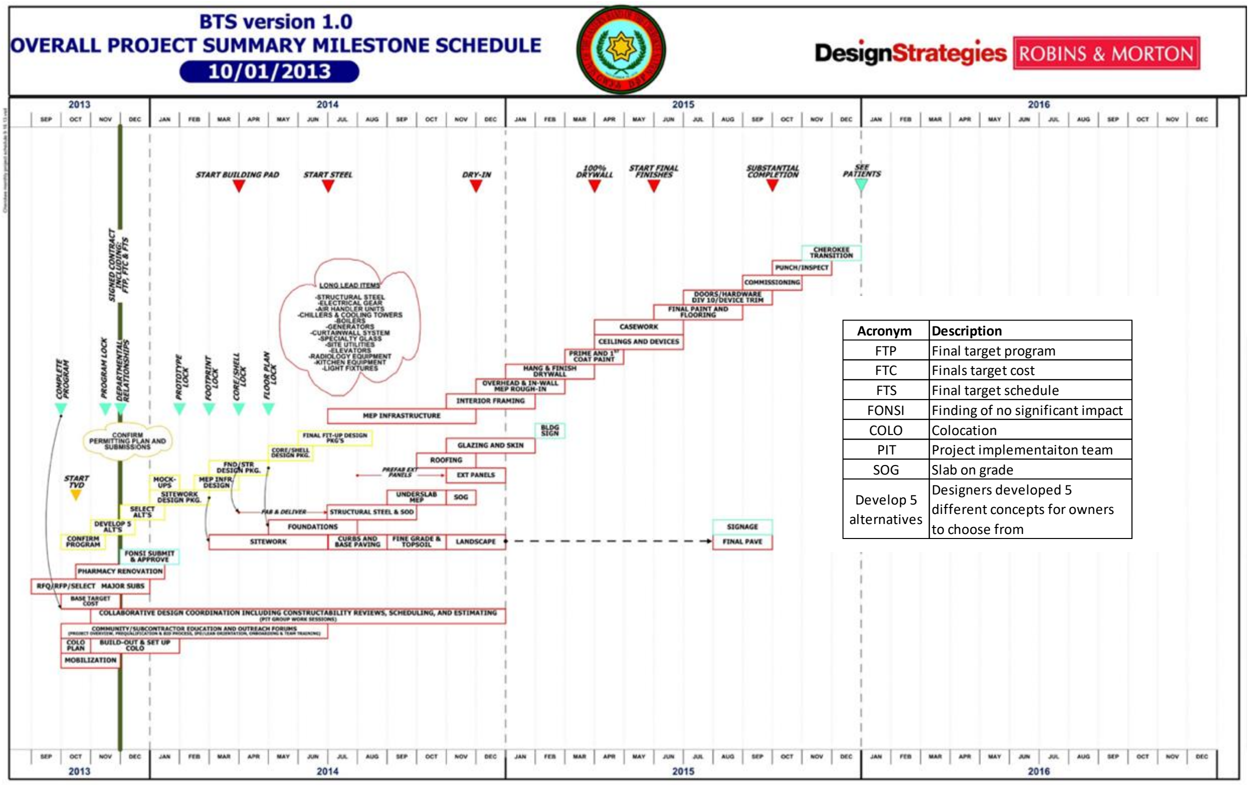

Figure 10: Master Pull Plan (Provided by Bill Stevens, Robins & Morton on 7/26/2019)

Other Notes:

- Medical equipment (including dental chairs) was a long lead item.
- Red Triangles– major pulling milestones for construction.
- Turquoise Triangles– major pulling milestones (decision points) for owners.
- Yellow Triangle – major pulling milestone for designers.
- The plan shown is how the project was executed. The option to delay selection of dental chairs was not considered in initial planning, and delaying dental chair selection was an idea that emerged after the project.

Table 1 lists the Milestones and Activities as indicated by Figure 1. They are listed in chronological order to the extent possible—some overlap in time. Summary Activities are included in the table to identify the phase of the project to which the Milestones and Activities belong. As an example, Milestones and Activities with ID 3-10 belong to Summary Activity ID 2. Since the target date for new information is Dry-In (Activity 47), it is apparent from the table that postponement of dental equipment decisions will impact construction.

Table 1: Work Breakdown Structure of Master Pull Plan

ID	Task Name	Duration
1	Start Project	0 days
2	**Team Selection and Alignment Process**	**349 days**
3	Complete Program	0 days
4	Mobilization	44 days
5	Colo Plan	23 days
6	Build-Out & Set Up Colo	66 days
7	Community/Subcontractor Education and Outreach Forums	195 days
8	Collaborative Design Coordination Including Constructability Reviews, Scheduling, and Estimating	304 days
9	Base Target Cost	45 days
10	RFQ / RFP / Select Major Subs	87 days
11	**Design**	**229 days**
12	Start TVD	0 days
13	Confirm Program	34 days
14	Program Lock	0 days
15	Departmental Relationships	0 days
16	Develop 5 Alt's	32 days
17	Fonsi Submit & Approve	46 days
18	Select Alt's	34 days
19	Sitework Design Pkg.	43 days
20	Mock-Ups	23 days
21	Prototype Lock	0 days
22	MEP Infr. Design	32 days
23	Footprint Lock	0 days
24	FND / STR. Design Pkg.	43 days
25	Core / Shell Lock	0 days
26	Floor Plan Lock	0 days
27	Core / Shell Design Pkg.	33 days
28	Final Fit-Up Design Pkg.	55 days
29	**Construction and Prefabrication**	**413 days**
30	Start Building Pad	0 days
31	Sitework	86 days
32	Fab & Deliver Structural Steel & SOD	65 days
33	Foundations	66 days
34	Start Steel	0 days
35	Curbs and Base Paving	44 days
36	Structural Steel & SOD	66 days
37	MEP Infrastructure	109 days
38	Prefab Ext. Panels	66 days
39	Fine Grade & Topsoil	45 days
40	Underslab MEP	45 days
41	Roofing	43 days
42	Landscape	43 days
43	SOG	20 days
44	Ext Panels	43 days
45	Glazing and Skin	65 days
46	Interior Framing	65 days
47	Dry-in	0 days
48	Overhead & In-Wall MEP Rough-In	65 days
49	Bldg. Sign	20 days
50	Hang & Finish Drywall	64 days
51	Prime and 1st Coat Paint	44 days
52	100% Drywall	0 days
53	Ceilings and Devices	65 days
54	Casework	65 days
55	Start Final Finishes	0 days
56	Final Paint and Flooring	66 days
57	Doors / Hardware DIV 10 / Device Trim	66 days
58	Final Pave	43 days
59	Signage	43 days
60	**Commission and Inspect**	**88 days**
61	Substantial Completion	0 days
62	Commissioning	44 days
63	Punch / Inspect	43 days
64	Cherokee Transition	44 days
65	See Patients	0 days

*Red – Milestones *White – Activities *Grey – Summary Activities (or Phases)

Customer value and the main uncertainties that affect the objectives of the hospital

The Cherokee Indian Hospital Authority finds value in extending their service to the entire tribe to proactively focus on preventing disease, to maximizing service (the number of patients treated) while minimizing the costs. The project objective is to deliver as great a net benefit in use as possible to the customer, over the entire life of the product. Net benefit in use equals gross benefits less costs (to design and build, to maintain, use and decommission). In this hypothesized case, it is assumed that there are uncertainties about the demand for services of different kinds. Consequently, managing those uncertainties is needed to better deliver customer value. Benefit and cost driver changes may require different actions and strategies. Cost driver changes ought to be reduced or eliminated to the extent this is possible. Benefit drivers may require flexibility in the design and delivery processes.

The main uncertainties that could have impacted the Cherokee Project (ref. to Bill Stevens, General Superintendent for Robins & Morton) are as follows: change in site location, change in dental equipment type and quantity of chairs, change in surgery suite design, and change in pharmacy pick system design.

The uncertainty chosen to be assessed in this case is **uncertainty in demand for dental services**, this leading to **uncertainty in dental equipment type and quantity of chairs**. The authors recognize that uncertainty in site location poses more difficult challenges than uncertainty in dental equipment, but the latter is sufficient to accomplish our purpose; namely, to provide a method for incorporating options into project execution plans and master schedules and for assessing the cost in time and money of those options relative to potential benefits.

Options to consider to handle uncertainty in demand for dental equipment type and quantity of chairs.

An option is the possibility to observe the outcome of a random event, and then do something (if you so wish). An option provides flexibility, and flexibility has value. An option usually comes at a cost. Before choosing and implementing an option, the trade-off between the value of flexibility and costs of creating flexibility through the chosen option must be calculated.

Option to delay the decision on the dental equipment type and quantity until relevant information on demand can be made available

It is assumed that insufficient study had been made of demand for dental services, and that conducting such a study could be completed by the Dry-In milestone in the project master schedule. The question then is if the project should be delayed until that later start date, if the project should continue with the current estimate for dental equipment, or if options should be integrated into the project plan to enable full utilization of more accurate estimates of demand for dental services.

This last alternative above includes the following new options.

- **O1**: Shell Option: Prepare the foundation/ floor plan to enable quick installation of different types and number of chairs, increase space, specify easily removed flooring to install equipment support, etc.
- **O2**: Contract with Key Suppliers Option: Contract to deliver more chairs and other dental equipment at a given time, if needed.
- **O3**: Initiate a study of demand for dental services, to be completed at Dry-In milestone.

Alternative planning approaches, with and without options

To assess whether the project can satisfy unified objectives (time, costs, risks), the following planning approaches are applied for the case at hand. Note that all planning approaches listed below build on a PULL-driven lean milestone plan. As such, they differ from traditional PUSH-driven milestone plans.

- Deterministic approach under the assumption that customer demand on dental services is known. This approach provides the best possible solution under the given assumption.
- Reactive approach, by replanning a deterministic solution with new and relevant information throughout the project delivery, or after a change has materialized. This may involve substantial rework.
- Proactive strategy, making use of options identified above, to create flexibility to enable adaptation to change with least costs and time possible and least disturbance on the system.

In the **Deterministic** approach the project team assumes demand for dental chairs Type A to be 10 and plans for this demand without concern for potential future changes or new information. Setting low numbers as is done in this example is quite common in situations where the choice of a project is mainly driven by costs.

Assume further that *demand information on dental chairs becomes available at Activity 47* "Dry-In"; which is, 20 Type B dental chairs. This means that the original deterministic plan for 10 chairs Type A chairs is necessarily updated with this information. In this hypothetical case, the uncertainty regards the demand for dental equipment and how much that will differ from what is assumed prior to a detailed study. Since the study is contracted for delivery at the Dry-In milestone, uncertainty regarding time of arrival is reduced and hopefully eliminated.

This **Reactive** approach requires revising the Planning, Design and Construction phases and has collateral impacts (Time, Money and project momentum) on surrounding construction. Reactive approaches typically are most costly in time and money and hurt team chemistry/project momentum. Recall the literature (Vaagen et al., 2017) regarding the adaptation costs/rework of such approaches can be much higher than the initial estimated costs.

In the **Proactive** strategy the project team takes demand uncertainty into consideration and uses options to enable the late selection of alternatives, at the last responsible moment, which is identified as Activity 47. It is apparent from Table 1 that postponement of dental equipment decisions will impact construction.

As shown below, the design and construction changes required under the proactive approach are substantially less than changes required under the reactive approach.

However, options usually have some early development costs, as compared to the deterministic approach, while their benefits are uncertain, as we don't know if the option will be needed or not. On the other hand, the reaction time and costs of the proactive strategy are far less than in the reactive approach.

Activities, iterations and rework loops for the three solution approaches

In the **Deterministic** approach, no iteration or rework loops are involved, since the dental equipment type, and quantity of chairs is assumed known from the start of the project.

In the **Reactive** approach, iterations and rework loops are created as a result of new and unexpected information at activity 47 "Dry-In", see Figure 11. These loops affect the project in 3 out of its 4 phases: Team Selection & Alignment, Design and Construction. All looped activities (e.g. the loop 3, 8 and 13) are defined in Table 2.

- Rework loop in Team Selection & Alignment: 8 → 13, 13 → 3, 3 → 8
- Rework loop in Design: 28 → 27, 27 → 26, 28 → 27, 27 → 26
- Rework loop in Construction: 47 → 48, 48 → 46, 46 →37

Table 2: List of tasks from Table 1 that are significantly affected by 'Change in dental equipment type and quantity of chairs

ID	Task
1	Start Project
3	Complete Program
8	Collaborative Design Coordination Including Constructability Reviews, Scheduling, and Estimating
13	Confirm Program
26	Floor Plan Lock
27	Core / Shell Design Package
28	Final Fit-Up
37	MEP Infrastructure
46	Interior Framing
47	Dry-In
48	Overhead & In-Wall MEP Rough-In

Proactive Strategy: Iteration / rework loops are created as a result of demand information arrival at activity 47 – "Dry In", see Figure 12. However, since this case includes options (implemented in Phase I of the plan) to enable accommodating this change, the amount of disturbance and rework is reduced.

On Figure 12 only Stage 2 activities are shown. Stage 1 activities in Team Alignment and Selection are shown in Table 3 (0.25 for tasks #8 and #13).

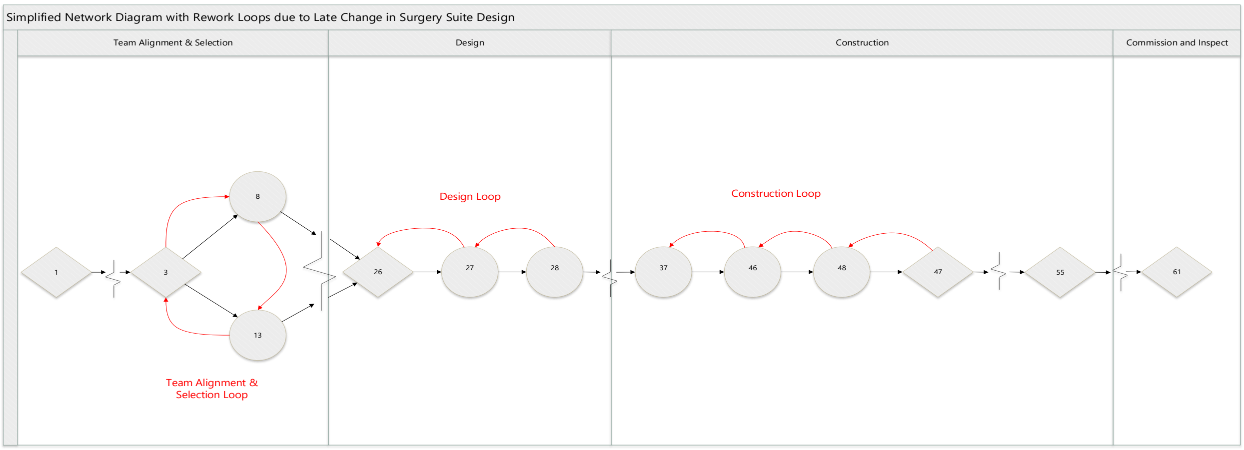

Figure 11: Reactive approach Case ii - Simplified subnetwork diagram with rework loops due to late change in dental clinic design

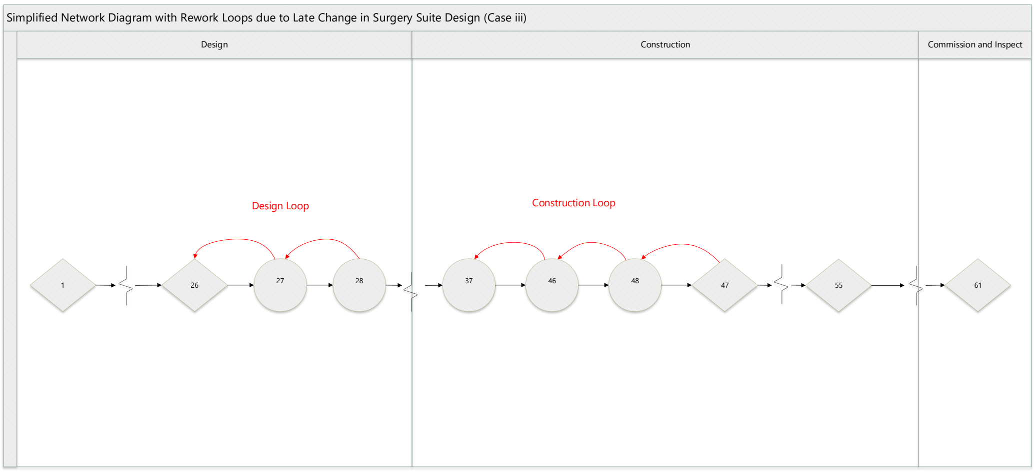

Figure 12: Proactive strategy Case iii - Simplified network diagram with rework loops due to arrival of new information for dental clinic design

Evaluation of the alternative planning approaches

The costs of the subproject activities (see Tables 6 and 7) were calculated by Bill Stevens through a rough analysis of their individual sizes in terms of square footage and cost when compared to the size of the overall project activities. For example, if the dental clinic subproject has a size of 10,000 square feet compared to the overall project size of 150,000 square feet, then the dental clinic is 1/15 of the overall project. If the overall project costs $75M, then the dental clinic has a cost of $5M.

Case i (deterministic approach): Activities included in this approach are those listed in Table 3, and their durations and cost were factored to only represent the subproject of the dental clinic.

Case ii (reactive approach): Activities included in this approach are those listed in Table 2, and their durations and cost were factored to only represent the subproject of the dental clinic.

Case iii (proactive approach with Option O1, O2 and O3): activities included in this approach are listed in Tables 4 and 5.

Table 3: Duration of activities for Deterministic, Reactive and Proactive (cases i, ii and iii) for the Dental Clinic Subproject.

		Case i	Case ii			Case iii	
		Do	Do	Undo	Redo	Do (First Stage)	Do (Second Stage)
Phase	Subproject Activity	Duration	Duration	Duration	Duration	Duration	Duration
Team Alignment & Selection	8	0.25	0.25	0.25	0.25	0.25	0.00
	13	0.25	0.25	0.25	0.25	0.25	0.00
Design	27	0.25	0.25	0.25	0.25	0.15	0.15
	28	0.5	0.5	0.25	0.25	0.25	0.15
Construction	37	0.5	0.5	0.5	0.5	0.3	0.4
	46	0.25	0.25	0.5	0.35	0.15	0.35
	48	0.25	0.25	0.5	0.35	0.15	0.35
		2.25	2.25	2.5	2.2	1.5	1.4

* 1 unit of duration is equal to 33 days.

In the proactive approach with options we do something in light of uncertainty (prepare) and postpone certain decisions until relevant information becomes available. In our case, the foundation/ floor plan is prepared first (call it *first stage*) to enable quick installation of different types and different number of chairs in the future (call it *second stage*). The date for arrival of demand information on dental equipment was determined as the last responsible moment, and arrangements with suppliers were made to ensure their adaptability to different type/quantity of dental equipment.

For clarity, while both stages and periods are time related entities in planning, they are essentially different. A *period* is a time step in a model, predefined at the beginning of the time horizon, disregarding the arrival of information (information flow). *Stages* are defined by information arrival, by a point in time where it is possible and makes sense to make decisions, as we have learned something new since the last decision. The stage structure is built on the recognition that new and relevant information is needed to make new decisions, and new information is only interesting if new decisions can be made (feasibility). The activities associated with proactive and reactive approaches are, therefore, usually different.

See Table 4 for durations of activities impacted by postponement of decisions regarding dental equipment. For simplicity, we assume one unit of time equals 33 days. The durations of the subproject activities are experience-based estimates by Bill Steven, Robins & Morton General Superintendent. Stevens provided the following gross estimate: *"within a week's time (~0.25 units of time) we can put some structural engineers together with the concrete contractor and we can collaborate to begin developing a design. The structural design for the dental clinic subproject refers to the overhead light support, below slab structural support for the chair, not the overall core and shell".*

Table 4: First stage tasks for Proactive Strategy with option O1, O2 and O3 (Case iii). First-stage refers to the time before arrival of dental equipment information.

First Stage		
Task ID (i = First Stage)	**Task Description**	**Duration**
1i	Start first stage activities of planning with options	0
3i	Include potential options O1, O2 and O3 in Complete Program	0
8i	Collaborative Design Coordination to enable option O1	0.25
13i	Confirm Program with option O1	0.25
26i	Preliminary Floor Plan Lock to enable option O1	0
27i	Preliminary Core / Shell Design Package to enable option O1	0.15
28i	Preliminary Fit-Up Design Package to enable option O1	0.25
37i	Installation of MEP Infrastructure to enable option O1	0.3
46i	Installation of Interior Framing to enable option O1	0.15
47i	Information about dental equipment type and quantity of chairs arrives-O3	0
48i	Installation of Overhead & In-Wall MEP Rough-In to enable option O1	0.15
		1.5

Table 5: Second stage tasks for Proactive Strategy (Case iii), after arrival of dental equipment information.

Second Stage		
Task ID (ii = Second Stage)	**Task Description**	**Duration**
1ii	Start second stage activities of planning with options	0
3ii	Include dental equipment type and quantity of chairs in Complete Program	0
8ii	Collaborative design coordination for dental equipment type and quantity of chairs	0
13ii	Confirm program with dental equipment type and quantity of chairs	0
26ii	Floor plan lock for dental equipment type and quantity of chairs	0
27ii	Core / Shell design package for dental equipment type and quantity of chairs	0.15
28ii	Fit-Up design package for dental equipment type and quantity of chairs	0.15
37ii	Installation of MEP Infrastructure for dental equipment type and quantity of chairs	0.4
46ii	Installation of Interior Framing for dental equipment type and quantity of chairs	0.35
47ii	Dry-In for Dental Clinic begins	0
48ii	Installation of Overhead & In-Wall MEP Rough-In for dental equipment type and quantity of chairs	0.35
		1.4

Table 6: Durations and costs for cases i, ii and iii for the Dental Clinic Subproject

	Case i	Case ii	Case iii
Total Subproject Duration (1 unit = 33 days)	2.25	6.95	2.9
Total Subproject Cost (1 unit = $1M)	5.6	17.3	7.2

Table 7: Durations and costs for cases i, ii and iii for the Overall Project

	Case i	Case ii	Case iii
Total Project Duration (1 unit = 33 days)	20.8	25.5	21.45
Total Project Cost (1 unit = $1M)	75	86.7	76.6

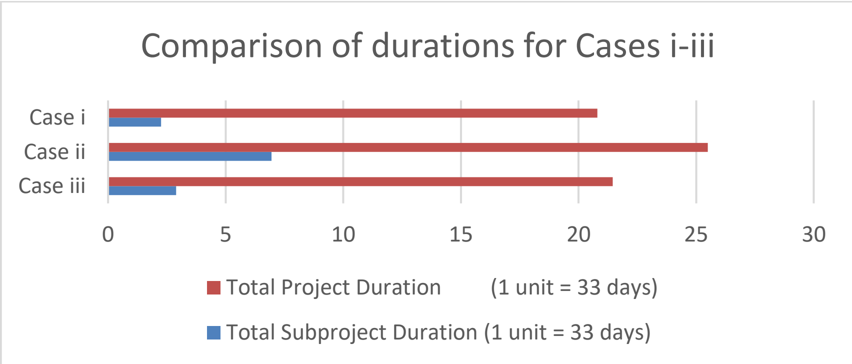

Figure 13: Comparison of subproject durations to overall project durations for cases i-iii.

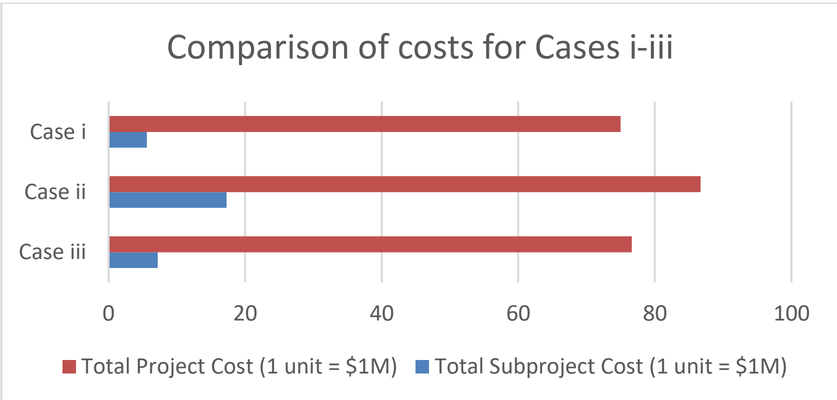

Figure 14: Comparison of subproject costs to overall project costs for cases i-iii.

Differences in plans

One major aspect of planning for flexibility is that this approach is different from the very beginning. When we assume everything is known, with a reactive approach to changes, postponement has no value, and activities start as soon as possible (PUSH), without regard to information arrival. In the flexibility strategy with options, we evaluate the point in time when useful information for the activity subject to missing information becomes available and plan this activity from this point (PULL), i.e. we postpone it to the last responsible moment. Before this point in time, activities with complete information and/or low impact activities can be scheduled (PUSH); i.e. fill in the 'waiting time' with low impact and certain activities.

When not feasible to postpone the entire activity, because of time limitations, the activity is to be broken into sub-activities, where the first step can be standardized and scheduled before the timing of relevant information, and the customer specific second step is scheduled when relevant information becomes available.

Concluding remarks on the case study

As noted in the Research Methodology section previously, a design science research project must successfully answer two questions: 1) What utility does your artifact provide? and 2) What demonstrates that utility? We have proposed two artifacts: 1) a process for pull planning project master schedules, and 2) a process for shaping and evaluating options to preserve the possibility of beneficial action on uncertain future events. Haley & Aldrich's pull planning process has been successfully used to construct project master schedules, but some specific tools may differ as a result of context or preference.

The process for shaping and evaluating options was described using a hypothetical case study, the objective of which was to provide countermeasures for two weaknesses in current project planning: 1) over-reliance on buffers as means for mitigating risks, and 2) deterministic planning in conditions of uncertainty.

The countermeasure for over-reliance on buffers as means for mitigating risk is to recognize risks and opportunities whose probability of occurrence cannot be statistically predicted and to include those risks and opportunities in project planning. In the case, the demand for dental equipment was uncertain, as was the relationship between measured demand and the demand assumed at the outset of the project.

The countermeasure to deterministic planning in conditions of uncertainty is to include options in project plans that enable beneficial action on future uncertain events, however they turn out to be. In the case, we demonstrated how to develop master plans with options to enable late selection of design alternatives (in our case, selection of dental equipment type and size), and how to validate a project with limited (design) information. We demonstrated that the proactive strategy, the one with options, enables quick adaptation to real-time demand information, and leads to reduced time and cost estimates, as compared to the reactive planning approach. A caution is in order here: All options have costs, and there is no guarantee that the cost of a specific set of options will be less than the cost of doing nothing. Calculation is needed. Hence the focus on providing a method for that calculation. The cost and time estimates of the three planning approaches (deterministic, reactive and proactive) are given in Figures 13 and 14. The static deterministic approach, while the one with lowest time and costs, is an overly optimistic situation that rarely happens.

The value gained by the Cherokee Nation from investing in the option to better match capacity with demand for dental services was considered to be sufficient benefit relative to the additional cost and time—that's why, in this hypothetical case, the project chose to invest in the Proactive strategy. The impact on duration and cost of the project when options are not considered is shown in the Reactive approach (case ii).

The authors hope to have explained how some project uncertainties cannot be buffered, but rather require actions that increase flexibility in plans, and also hope to have provided persuasive evidence in support of planning with options in conditions of uncertainty to provide that flexibility, and sufficient explanation of the methodology for those who want to try it on their own projects and further refine and improve the process.

Conclusion

In the Introduction to this research report, the following gaps were proposed to be reduced by extending LPS® to planning the entire project, replacing traditional project management: 1) Neglect of the social process for producing project execution plans and the schedules developed from them; 2) Over-reliance on buffers for risk mitigation, and 3) Deterministic planning when uncertainty is a major element of the problem, as it is in most projects. The existence and importance of these gaps were argued in our review of the literature.

We have offered pull planning as a method that actuates the social process of reliable promising. Making requests of ‘providers’ initiates the reliable promising cycle, by clarifying what’s wanted and conditions of satisfaction. To help practitioners apply pull planning, Haley & Aldrich’s standard process is provided. The successful applications of the process also serve to demonstrate its utility.

The feasibility and potential benefits of incorporating options into plans and schedules (2 above) was shown in the case study, which demonstrated how to evaluate options, and how they can increase net benefits in use over the life of the constructed asset. The case also showed that the probability of occurrence of some risks cannot be statistically predicted, and hence that buffers cannot be sized to provide a desired level of protection, and that the alternative, to increase flexibility in plans, is feasible. Note also that engaging those directly responsible for doing the work being planned has been shown to increase team flexibility to changes in pathways and even changes in objectives.

Limitations of the Research

Design science research requires validation that the artifacts produced are fit for purpose. That can be provided over a range, from having expert practitioners agree to try using the artifacts, to the trials having been carried out successfully. The validation of our proposed process for embedding options in schedules sits somewhere between these two extremes, and experimentation by practitioners is needed for further refinement and validation. The same holds for pull planning project execution plans and project milestone schedules. Members of our task force with the needed capabilities have committed to do the needed experimentation, and we hope others will join them.

Recommendations for Future Research

In addition to experimentation with embedding options in Lean project milestone schedules (master project control schedules) and pull planning project milestone schedules, just mentioned above, future research is also needed to explore the feasibility of applying methods of risk assessment and mitigation that try to strengthen project networks against low probability/high impact events (in the spirit of Simchi-Levi, et al. 2015), as distinct from weighting specific risks and selecting only those with highest weights for mitigation. The SFI system of coding for ships (ref. Literature section) for a functional division of technical and financial ship information, progressively detailed through subdivisions, appears to be applicable to build environment projects, but that needs to be demonstrated through research, and developed into a method/tool for use in practice.

In addition to the three criticisms of previous project planning addressed in this report, another criticism is the relative neglect of opportunities as opposed to risk events (threats). The Cherokee Indian Hospital Project case study is structured to illustrate both the feasibility and benefit of incorporating options into project master schedules, and by focusing on an opportunity to increase benefits to the customer, to also illustrate the feasibility and benefit of incorporating options into project master schedules to increase net benefits in use. However, more research is needed to develop, test and refine methods for identifying and exploiting opportunities, as well as for increasing project team flexibility to exploit those opportunities.

The research reported in this paper is focused on planning; i.e., project execution planning and the project master control schedules that are derived from the project execution plan. The control function also needs to be researched. How would project control; i.e., monitoring and correcting deviations from pathways to project objectives, be performed consistently with Last Planner System® principles? A contribution to that research is made in the research report titled "LPS® Metrics", which proposes to measure the extent to which capacity is allocated to required (critical) tasks, but the use of those metrics and the expectations of supervisors at every level need to be made more explicit.

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