Managing Project Complexity Using a Matrix-Based Approach

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Abstract: This paper introduces a methodology to enhance project knowledge when managing complex projects to support more strategic project management decision-making. The methodology leverages the use of a layered DSM to identify key dependencies between critical knowledge areas, as traditionally defined by the Project Management Institute (PMI). Identifying and understanding such dependencies between critical knowledge areas specific to the project in question enables increased scrutiny of how those dependencies may be better managed to enable a more optimal and likely successful project result. Two unique applications are examined and presented to demonstrate the methodology being proposed. Initial results suggest a heightened awareness of the detailed project knowledge that is more easily overlooked when considered from a macro-level project perspective. As such, it suggests that this increased and more strategic project knowledge successfully informs better project management decision making thus increasing the likelihood of optimal project success.

Keywords: Project Complexity, Project Knowledge, Project Management, Layered DSM

1 Introduction

The Project Management Institute (PMI) defines a project as "a temporary endeavor undertaken to create a unique product, service, or result" (PMBOK, 2017) While accurate, this fairly simply definition of a project does not do justice to the complexity that many projects often entail. For example, from a product design and development perspective a typical project is often large involving significant complexity. In describing the importance of the project planning activity De Lessio et. al. (2009a p. 285) suggests that "along with the often-large size and multiple teams working on the same project, most projects are inevitably characterized by uncertainty, design iteration and product change". While this example is specific to product design and development, the notion of complexity resulting from uncertainty, iteration and change is not atypical and can be applied to most projects individuals and organizations are confronted with. In examining project complexity, Bakhshi et. al., (2016 p. 1200) categorizes projects as a hierarchy of simple, complicated, complex, and chaotic. They suggest that "in complicated projects, there are cause-and-effect relationships between tasks and elements" while "complex projects consist of ambiguity and uncertainty, interdependency, non-linearity, unique local conditions, autonomy, emergent behaviors and unfixed boundaries.

Maneuvering such project complication and complexity typically requires experience and knowledge about the project in question and its desired objective and result. Knowledge and expertise are essential for understanding complicated projects eventually requiring proper practices in order to overcome problems (Snowden and Boone, 2007). PMI describes project management as "the application of knowledge, skills, tools, and techniques to project activities to meet project requirements" (PMBOK, 2021 p. 245). They further describe project management body of knowledge as "a term that describes the knowledge within the profession of project management" and elaborate that it "includes proven traditional practices that are widely applied as well as innovative practices that are emerging in the profession." However, given the complexity and uniqueness of any given project it can be reasonably concluded that any one individual or even project team will not inhabit all of the knowledge required to successfully execute a project at its launch. Highly trained and well-educated experts must be coordinated so that their technical inputs integrate well into the human system in which they are operating (Pinto and Slevin, 1987). History is rife with examples of projects that have failed or have been restructured for a less than desired result from that which was originally proposed. Returning to the example of new product design and development and considering such an endeavor as a complex project, authors in literature have suggested failure rates as high as 90%. Gourville (2006) suggests that studies show that new products fail at a rate of between 40% – 90%, depending on the category. In rebuking such claims, Castellion and Markham (2013) cite many authors who claim similarly high new product failure rates but suggest the actual failure rate is only 40%. However, even if accurate, 40% is still quite significant.

Each project whether somewhat routine or a completely new and unique endeavor is subject to being compromised by unexpected events. Simply depending on the past experience and expert judgement of the project manager and supporting project actors, often intuitive at best, is not always enough to avoid such complications. As a result, this paper proposes a methodology to draw on the expert judgement and experience of the project team in a systematic way in order to consider and optimize project knowledge to enhance the reality of successfully completing a project to the optimum desired value. PMI often specifically cites "expert judgement" as a tool and/or technique for managing project knowledge. The methodology being proposed enables that expert judgement to be better scrutinized in a reflective and/or instructive manner. It leverages the concept of applying a layered Design Structure Matrix tool to inherent knowledge areas, as traditionally defined by PMI, to consider their dependencies and how such dependencies may enable more focused project insight and inform better strategic decision making to enhance a more likely scenario of an optimal and successful project result. While DSM methodology is a commonly used tool in assessing critical dependencies in complex systems, our methodology is the first to specifically focus on the PMI proposed knowledge areas of the complex project system.

2 Project Failure and Project Knowledge

Much has been written in literature about the causes of project failure. Most authors agree that there are a multitude of contributing factors for such failure depending on the nature and complexity of the project. Pinto and Mantel, Jr. (1990) suggest that understanding the causes of project failure has been difficult for both academic researchers and practitioners. They further suggest several difficulties contributing to this lack of understanding including; the concept of project failure is “nebulous” with little agreement on how it is defined, much research on project failure is “conceptually or anecdotally based” and that the causes of project failure may vary by the type of project in question. In analyzing the commonalities between many authors who have written about project success factors, Pinto and Slevin (1987) compiled the following list of what they deem “critical success factors”:

1. Clearly defined goals: including the general project philosophy or general mission of the project, as well as commitment to those goals on the part of project team members.
2. Competent project manager: the importance of initial selection of a skilled (interpersonally, technically, and administratively) project leader.
3. Top management support: top or divisional management support for the project that has been conveyed to all concerned parties.
4. Competent project team members: the importance of selecting and, if necessary, training project team members.
5. Sufficient resource allocation: resources, in the form of money, personnel, logistics, etc., are available for the project.
6. Adequate communication channels: sufficient information is available on project objectives, status, changes, organizational coordination, clients' needs, etc.
7. Control mechanisms: (including planning, schedules, etc.)—programs are in place to deal with initial plans and schedules.
8. Feedback capabilities: all parties concerned with the project are able to review project status, make suggestions, and corrections through formal feedback channels or review meetings.
9. Responsiveness to clients: all potential users of the project are consulted with and kept up to date on project status. Further, clients receive assistance after the project has been successfully implemented.

While the specific value of project knowledge in enhancing the achievement of each critical success factor suggested may be debated, it can be reasonably acknowledged that project knowledge does, in fact, offer enhancement to each critical success factor identified. In addition, project knowledge includes both explicit knowledge (documented information like lessons learned, reports, and best practices) and tacit knowledge (unwritten insights and skills gained through experience). Sanchez (2008) describes two fundamental approaches to knowledge management including the tacit knowledge approach that emphasizes understanding the kinds of knowledge that individuals in an organization have and the explicit knowledge approach which emphasizes processes for articulating knowledge held by individuals. PMI defines a “Project Management Knowledge Area” as “an identified area of project management defined by its knowledge requirements and described in terms of its component processes, practices, inputs, outputs, tools, and techniques” (PMBOK, 2017 p. 14). As such, it can be discerned that in order to optimize project success, project knowledge must leverage the inherent and learned knowledge of each project team member as the project progresses through its life cycle. Gasik (2011 p. 23) references Desouza and Evaristo, (2004), when he states that “project knowledge management, especially in complex projects, is one of the main success factors in project management; lack of project knowledge management is one of the main reasons for project failure”. To this extent, this paper leverages the traditional knowledge areas as described by the PMBOK to introduce a methodology to enable and enhance project knowledge and the management of that knowledge.

The Project Management Institute (PMI) has traditionally proposed the concept of process groups, which correlate to the phases of a typical project lifecycle, and ten unique knowledge areas as represented in Figure 1 (PMBOK, 2017). As can be deciphered from Figure 1, each knowledge area can invoke some level of activity that must be considered as the project progresses through the specific process groups.

Knowledge Areas	Project Management Process Groups				
	Initiating Process Group	Planning Process Group	Executing Process Group	Monitoring and Controlling Process Group	Closing Process Group
4. Project Integration Management	4.1 Develop Project Charter	4.2 Develop Project Management Plan	4.3 Direct and Manage Project Work 4.4 Manage Project Knowledge	4.5 Monitor and Control Project Work 4.6 Perform Integrated Change Control	4.7 Close Project or Phase
5. Project Scope Management		5.1 Plan Scope Management 5.2 Collect Requirements 5.3 Define Scope 5.4 Create WBS		5.5 Validate Scope 5.6 Control Scope	
6. Project Schedule Management		6.1 Plan Schedule Management 6.2 Define Activities 6.3 Sequence Activities 6.4 Estimate Activity Durations 6.5 Develop Schedule		6.6 Control Schedule	
7. Project Cost Management		7.1 Plan Cost Management 7.2 Estimate Costs 7.3 Determine Budget		7.4 Control Costs	
8. Project Quality Management		8.1 Plan Quality Management	8.2 Manage Quality	8.3 Control Quality	
9. Project Resource Management		9.1 Plan Resource Management 9.2 Estimate Activity Resources	9.3 Acquire Resources 9.4 Develop Team 9.5 Manage Team	9.6 Control Resources	
10. Project Communications Management		10.1 Plan Communications Management	10.2 Manage Communications	10.3 Monitor Communications	
11. Project Risk Management		11.1 Plan Risk Management 11.2 Identify Risks 11.3 Perform Qualitative Risk Analysis 11.4 Perform Quantitative Risk Analysis 11.5 Plan Risk Responses	11.6 Implement Risk Responses	11.7 Monitor Risks	
12. Project Procurement Management		12.1 Plan Procurement Management	12.2 Conduct Procurements	12.3 Control Procurements	
13. Project Stakeholder Management	13.1 Identify Stakeholders	13.2 Plan Stakeholder Engagement	13.3 Manage Stakeholder Engagement	13.4 Monitor Stakeholder Engagement	

Figure 1. Project Management Process Group Knowledge Area Mapping (PMBOK, 2017)

In an effort to adopt a more systems view of Project Management in PMBOK Edition 7 (2021) the Project Management Institute has shifted from the "knowledge areas" of past editions to what they have defined as "project performance domains". However, while the specific knowledge area is not always independently identified and perhaps even renamed (i.e. Integration Management is now called Governance Management) each of the traditional knowledge areas identified in past editions is still embodied in one of the project performance domains. Additionally, PMI still describes the Project Management Body of Knowledge (PMBOK) as "the knowledge within the profession of project management" (PMBOK, 21 p. 245). In explaining the changes in PMBOK Edition 7 (2021) they suggest that previous editions of the PMBOK® Guide emphasized the importance of tailoring the project management approach to the unique characteristics of each project and its context and state that Edition 6 specifically incorporated considerations to help project teams think about how to tailor their approach to project management with content that was included in the front matter of each of the Knowledge Areas to provide considerations for all types of project environments. They emphasize that edition 7 further expands upon that work with a dedicated section on Tailoring in the PMBOK® Guide and conclude by saying that "it recognizes that there is continued value for some stakeholders in the structure and content of previous editions and enhances the content in this edition without negating that value" (PMBOK 2021, p. XIV). As such it is proposed here that considering the dependencies between different project knowledge areas as traditionally defined by the PMBOK and defined below, is still a relevant methodology for understanding and enhancing project knowledge specific to a particular project. The knowledge areas are each defined in Table 1 as they were defined in the PMBOK, edition 6 release (PMBOK, 2017).

Table 1. PMBOK Knowledge Areas (PMBOK, 2017)

Project Integration Management	Includes the processes and activities to identify, define, combine, unify, and coordinate the various processes and project management activities within the Project Management Process Groups.
Project Scope Management	Includes the processes required to ensure that the project includes all the work required, and only the work required, to complete the project successfully.
Project Schedule Management	Includes the processes required to manage the timely completion of the project.
Project Cost Management	Includes the processes involved in planning, estimating, budgeting, financing, funding, managing, and controlling costs so that the project can be completed within the approved budget.
Project Quality Management	Includes the processes for incorporating the organization's quality policy regarding planning, managing, and controlling project and product quality requirements in order to meet stakeholders' objectives.
Project Resource Management	Includes the processes to identify, acquire, and manage the resources needed for the successful completion of the project.
Project Communications Management	Includes the processes necessary to ensure that the information needs of the project and its stakeholders are met through development of artefacts and implementation of activities designed to achieve effective information exchange.
Project Risk Management	Includes the processes of conducting risk management planning, identification, analysis, response planning, response implementation, and monitoring risk on a project.
Project Procurement Management	Includes the processes necessary to purchase or acquire products, services, or results needed from outside the project team.
Project Stakeholder Management	Includes the processes required to identify the people, groups, or organizations that could impact or be impacted by the project, to analyze stakeholder expectations and their impact on the project, and to develop appropriate management strategies for effectively engaging stakeholders in project decisions and execution.

3 Project Knowledge and Dependencies

The concept of the "triple constraint" and how their interdependencies and project implications has been widely discussed in literature. Sometimes referred to as the "iron triangle" or the "project management triangle", and typically, referencing the dependencies between that of "time", "cost" and "scope", their conflicting effect on a successful project result has been widely discussed and debated. In discussing the conflicting relationship of the triple constraint variables, many authors also elaborate on how changes to one not only affect the others but ultimately impact the overall quality of the project result. van Wyngaard et. al. (2012 p. 1991) reference multiple authors when they state "although the triple constraint theme has various interpretations, the literature shows a general agreement that project scope, time and cost comprise the three key triple constraint variables". The inherent relationship of the triple constraint variables is often shown as a "project management triangle" as represented in Figure 2. The triangle configuration suggests that their individual impact is equally disruptive and the double-sided arrows suggest that the dependency is not unilateral or one directional between any two of the triple constraint variables. Finally, the figure suggests that each and/or all can impact the quality of the overall project result. "The project management triangle is a useful model to illustrate the consequences of change on the triple constraint to key project stakeholders. The triangle reflects the fact that the three constraints are interrelated and involve trade-offs – one side of the triangle cannot be changed without impacting the others. Project quality takes root in all three variables of the triple constraint and is affected by balancing the three factors" (van Wyngard et. al. 2012 p. 1991).

While the dependencies between each knowledge area acknowledged and represented by the triple constraint variables is often critical to any given project we argue that too frequently project management focus is limited to these three knowledge areas often at the peril of the other knowledge areas that can be equally impactful to the successful execution of the project. As such, it is proposed here that any of the ten knowledge areas, as traditionally proposed by PMI, and relevant to a particular project can be critical, to the project being considered, and thus also deserving of additional scrutiny. In discussing the failure of IT projects, Hughes et. al. (2016 p. 3) suggests that "the historical and somewhat traditional measure of project success, namely, time, cost, and quality, does not provide for a firm basis to define whether a project is a success or a failure, as it measures the project management or so-called technical elements only". While it is agreed that the type and level of scrutiny is dependent on the complexity and type of project, in question, it is suggested that each knowledge area of project knowledge should be considered. More importantly, the disruption that changes to one knowledge area may have on other knowledge areas should be scrutinized in detail to inform better project knowledge insight and decision making. To this effect, a layered DSM matrix is proposed to consider focused scrutiny on the relevant knowledge areas in question to consider their dependencies and potential impact to the overall success of the project.

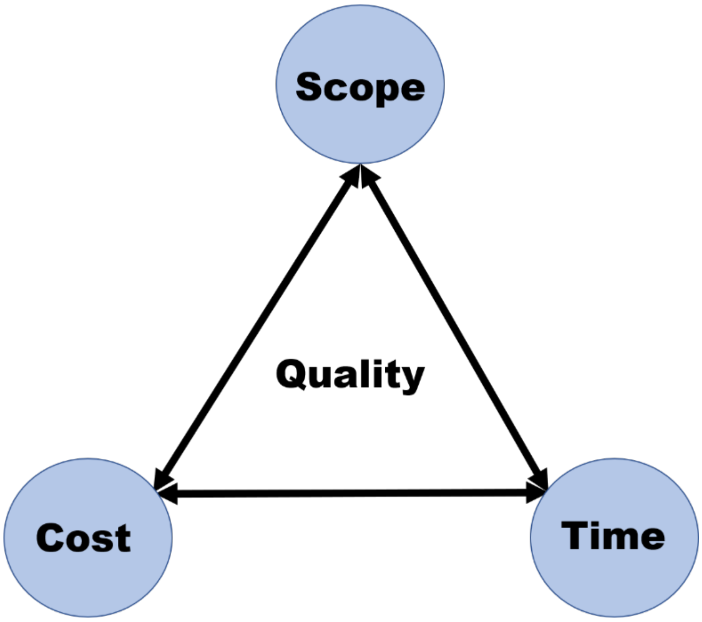

Figure 2. Triple Constraint Representation

4 Modelling Project Knowledge Interdependencies

Browning (2001) writes that products, processes and organizations are each a kind of "complex system" and further suggests that the classic approach to understanding complex systems is to model them. INCOSE (2015 p. 5) defines a system as "an integrated set of elements, sub-systems, or assemblies that accomplish a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services and other support elements". In this vain, considering specific knowledge areas as unique knowledge elements of any given project that must be integrated to achieve a defined product result, it is suggested that a project can be viewed as a complex system.

In complex product design and development projects, matrix-based tools have evolved, at least in part, because of the inability of existing project management tools to handle such project complexity. Yassine (2004) states that existing tools often fail to address the interdependency common to complex product development projects. Considering any complex project as a system, and correlating this sentiment it is suggested that a layered DSM analysis of the dependencies between knowledge areas of a particular project will enhance project knowledge understanding and more likely lead to heightened project success. Browning (2001) identifies four areas of application for DSM methodology including component-based or architecture, team-based or organization, activity-based or schedule and parameter-based DSM's. He further describes Component-Based or Architecture DSM as focusing on modelling system architectures based on components and/or subsystems and their relationships, aiding in architectural decomposition strategies.

It is proposed here that as knowledge areas are an integral part of the complex project system, they can thus be considered components of that system and modelled to infuse more knowledge of how that system should function going forward. As such, this paper proposes that the layered DSM approach can be applied to enhance intimate insight of the intricacies and dependencies of complex project knowledge to invoke the likelihood of a more optimal understanding and decision-making capability. A layered DSM leverages the DSM methodology originally proposed by Stewart (1981) and decomposes it into increasingly defined but equally scoped layers of detail so the relationship between subsequent layers can be more easily and thoroughly scrutinized. Since the DSM tool was originally proposed by Stewart (1981) the general consensus amongst most authors is that the components suggested along the top of the matrix impact the components listed along the left of the matrix or similarly, the components listed down the left side of the matrix are impacted by those populating the top of the matrix. However, when applied at the highest or macro level of project knowledge areas the value is seemingly generalized with limited value. When considering the dependencies between knowledge areas at this macro level the result is rather superficial particularly as the project becomes increasingly complex. While application at this level can indicate general dependency between project knowledge areas it is limited in scrutinizing the detail and actual impact of those dependencies on the overall project. As demonstrated in Figure 3, when analyzing the dependencies between project knowledge areas at this macro level it is conceivable to conclude that every knowledge area has impact on or is affected by the other specific knowledge areas, at least in some part.

	Integration Management	Scope Management	Time Management	Cost Management	Quality Management	Human Resource Management	Communications Management	Risk Management	Procurement Management	Stakeholder Management
Integration Management		X	X	X	X	X	X	X	X	X
Scope Management	X		X	X	X	X	X	X	X	X
Time Management	X	X		X	X	X	X	X	X	X
Cost Management	X	X	X		X	X	X	X	X	X
Quality Management	X	X	X	X		X	X	X	X	X
Human Resource Management	X	X	X	X	X		X	X	X	X
Communications Management	X	X	X	X	X	X		X	X	X
Risk Management	X	X	X	X	X	X	X		X	X
Procurement Management	X	X	X	X	X	X	X	X		X
Stakeholder Management	X	X	X	X	X	X	X	X	X	

Figure 3. Macro-level DSM Analysis

To address this limited ability of focus, De Lessio et al. (2013) introduced a layered approach to a DSM model which offers an increasingly detailed view of the system being modelled, thus enabling the understanding of the more intricate relationship between system components. The layered approach suggests an iterative process by which the DSM methodology is applied to increasingly detailed views of the project, starting from a high-level, low-resolution view of the project knowledge areas. By implementing such a modelling technique to understand the relationship between critical knowledge areas of a complex project it is proposed that the increasingly focused and informed understanding will lead to greater knowledge identification thus enabling a more likely optimal project execution and result. In applying this methodology, the goal is to focus on particular knowledge areas of the project where more focused understanding of their dependencies is desired. Using the layered DSM approach and considering the more detailed second layer or even third layer enables specific focus on the knowledge areas that may have significant dependency and thus inform more specific project understanding and relevant impact. Limiting the modelling to the key knowledge areas of interest is suggested as trying to model all ten knowledge areas in one application of the layered DSM would likely become unmanageable. It is thus proposed that invoking such focus and understanding of key knowledge areas of a project at this level of detail will inform and enhance project knowledge and lead to a greater likelihood of project success.

What follows are examples of the application of our proposed Project - Layered DSM. The objective is to demonstrate that this proposal is applicable no matter the nature or level of complexity of the project. In both instances, the project manager drew from their expert judgement and current level of experience regarding the project in question to analyze the dependencies between the knowledge areas where it was felt additional scrutiny would be beneficial and informative. Essentially, the methodology enabled the intuitive and qualitative nature of "expert judgement" to be scrutinized in a more quantitative manner based on the relationships that were identified. While these are two fairly simple applications considering the relationship of a subset of key knowledge areas, they successfully demonstrate the application of the methodology at different phases of the project lifecycle. It is safe to say that further application considering the specific relationships to even more relevant project knowledge areas will provide a much more comprehensive analysis and understanding of the overall project needs. In addition, we argue that this methodology coupled with other quantitative tools depending on the desired understanding of the project will complement and enhance its value even more.

The first is a reflective analyzation applying the methodology to an ongoing complex product design and development project involving the design, development and launch of a satellite while the second is more instructive applying the methodology to an early stage PhD project to consider what actions might be taken to enhance the project launch and initiation. Both demonstrate the informative nature of the proposed methodology in guiding how the project may progress going forward. Additionally, while quite different in project objective, both embody the definition of a complex project. Baccarini (1996 p. 202) proposes “that project complexity be defined as 'consisting of many varied interrelated parts' and can be operationalized in terms of differentiation and interdependency”. He elaborates that “this definition can be applied to any project dimension relevant to the project management process, such as organization, technology, environment, information, decision making and systems”. As such, these examples clearly demonstrate the application of our proposed layered DSM methodology to gain better perspective of intricacies between key project knowledge areas to enhance overall project understanding.

4.1 Applying Layered DSM to a satellite Launch Project

		Integration Management	Scope Management	Schedule Management			Cost Management	Quality Management	Resource Management		Communications Management	Risk Management			Procurement Management	Stakeholder Management		
				Payload Technical Development	Development Schedule with	Satellite Launch Schedule			Student availability during vacation	Student technical competencies		Technical Risk	Programatic Risk	Financial Risk		Scheduled Milestone Deliverables	Desirable Technological	Student Learning
Integration Management		■																
Scope Management			■															
Scedule Management	Payload Technical Development			■												X	X	X
	Development Schedule with				■											X	X	X
	Satellite Launch Schedule					■											X	
Cost Management							■											
Quality Management								■										
Resource Management	Student availability during								■			X	X			X		
	Student technical competencies									■		X		X		X	X	X
Communications Management											■							
Risk Management	Technical Risk								X	X		■						
	Programatic Risk								X				■					
	Financial Risk									X				■				
Procurement Management															■			
Stakeholder Management	Scheduled Milestone			X	X				X	X						■		
	Desirable Technological			X	X	X				X							■	
	Student Learning			X	X					X								■

Figure 4. Layered DSM Satellite Launch Project Model

Figure 4 demonstrates the application of the proposed layered DSM methodology to a CubeSat program. Through the program, many batches of undergraduate students were able to participate in the building of CubeSats that have been successfully launched and operated in Low Earth Orbit. In this example the layered DSM is being used to examine dependencies between following key knowledge areas to better understand project value expectation from the perspective of the project team in order to revise how project management may be revised to better realize that value as the project progresses:

The dependencies between project resources (human) and project risk considering the fact that it is a space program that is run primarily by students with just a few faculty support staff. The layered DSM, demonstrates that technical risks are the greatest in the program and that other risks such as programmatic and financial risks can be/have been mitigated through some institutional knowledge.

The dependencies between project time management requirements and stakeholder expectations. From the DSM, we note that the project stakeholders are expecting the project to be delivered on time as per the agreed schedule. However, the expanded DSM allows us to observe that our stakeholders value the student learning outcomes of the project and are open to being flexible with the schedule should more time be needed for students to develop something from the ground up. This could be due to the nature of satellite launches, which often tend to be delayed, and launch providers having more flexibility due to the increase in the number of launch opportunities in recent years.

The dependencies of project resources (human) with stakeholder expectations. The layered DSM shows that our project stakeholders place higher value towards training and expanding our student's technical competencies. This is likely related to their interest in wanting us to help build up a pipeline of talent that would eventually be hired by companies in the local space industry.

4.2 Applying Layered DSM to a Research Project Planning Phase

The second application examines a PhD research project and focuses on the planning phase for experimental setup in the NUS Multiphase Oil-Water-Air Flow Loop Facility (Loh, n.d., 2025) to consider how the experiment may be optimized. The experiment aims to validate numerical results from Computational Fluid Dynamics (CFD) with empirical experiments. This doctoral research examines slug-flow dynamics in a horizontal pipeline through high-fidelity CFD simulations, controlled flow-loop experiments, and extensions of classical slug-flow equations. The interdisciplinary workflow, encompassing numerical modelling, laboratory commissioning, and uncertainty management, presents coordination challenges ideally addressed by a layered DSM analysis. A macro-level DSM analysis of project knowledge areas revealed the following critical causal pathways:

- Scope vs. Schedule which was selected due to high anticipated dependency strength and its identification as a primary driver of delays in similar past projects.
- Scope vs. Risk which was selected as the highest-strength dependency and a common feature in research projects where scope evolution continuously generates new risks.
- Quality vs. Risk which was selected due to its expected bidirectional nature and the known relationship between simulation fidelity and experimental uncertainty in fluid dynamics research.

Leveraging the results of the macro-level DSM, an expanded, layered DSM that decomposes the three high-coupling interfaces was introduced as shown in Figure 5. This expanded layered DSM matrix captures more granular interactions and feedback loops that drive coordination complexity in the slug-flow research project. Further analysis of the dependencies between the targeted knowledge areas informed the following:

- Scope vs. Schedule: New or revised simulation/experiment cases must be slotted into both High-Performance Computing (HPC) and laboratory calendars, and any scope change mandates formal timeline revision.
- Scope vs. Risk: Additions or revisions to flow regimes and measurement requirements introduce uncertainties that must be logged, quantified for probability and impact, and addressed through updated contingency strategies.
- Quality vs. Risk: Increases in CFD fidelity or lapses in laboratory equipment quality expose latent failure modes, necessitating their incorporation into the risk register, root-cause investigation, and refinement of fallback procedures.

Further analysis of the layered DSM results also enabled identification of three potential feedback loops that informs the project management strategy:

- Feedback loops: Project planning workshops have highlighted potential feedback loops, particularly between Change Control and Risk Analysis. Formal change-management protocols will be established at project initiation to streamline these interactions.
- Critical paths: The identified critical path between Scenario Definition and HPC Scheduling suggests incorporating automated queue management and strict scenario governance from the outset.
- Buffer opportunities: The early engagement of technicians and equipment providers in scope planning discussions is planned to provide buffers against potential cascading delays.

		Integration Management	Scope Management			Schedule Management			Cost Management	Quality Management			Resource Management	Communications Management	Risk Management						Procurement Management	Stakeholder Management
			Scenario Definition	Parameter & Instrument Spec.	Change Control	HPC Run Scheduling	Lab Test Scheduling	Schedule Baseline Update		Mesh/Model Refinement	Equipment Calibration	Validation Testing			Risk Identification	Risk Analysis	Mitigation Planning	Risk Logging	Contingency Planning	Failure-Mode Analysis		
Integration Management																						
Scope Management	Scenario Definition					X	X								X	X						
	Parameter & Instrument Spec.						X	X							X	X	X					
	Change Control					X	X	X								X	X					
Schedule Management	HPC Run Scheduling		X		X																	
	Lab Test Scheduling		X	X	X																	
	Schedule Baseline Update			X	X																	
Cost Management																						
Quality Management	Mesh/Model Refinement																	X	X			
	Equipment Calibration																	X	X	X		
	Validation Testing																		X	X		
Human Resource Management																						
Communications Management																						
Risk Management	Risk Identification		X	X																		
	Risk Analysis		X	X	X																	
	Mitigation Planning			X	X																	
	Risk Logging									X	X											
	Contingency Planning									X	X	X										
	Failure-Mode Analysis										X	X										
Procurement Management																						
Stakeholder Management																						

Figure 5. Layered DSM – Research Project Planning Phase Model

While the DSM presented is based on expert judgment rather than empirical data, it provides a structured approach to proactively identify and manage anticipated complexities. As the project moves into execution, regular DSM updates incorporating actual performance data will ensure continued alignment and effective management of project complexities.

5 Summary and Future Work

Project management is typically an integral part of most individual's day to day life but particularly highlighted in an individual's work responsibility. In most instances, individuals are thrust into a complex project with insufficient inherent knowledge required to embark on and successfully complete a project to its targeted and optimum objective. As a result, project success is often elusive or compromised from its targeted goal. While DSM has been specifically applied to enhance success, particularly in the field of product design and development it has rarely been applied to understanding and communicating the objectives of the project itself. This paper proposes the use of a layered DSM methodology as a tool to assist in better understanding the intricacies and relationships between critical knowledge areas within the complex project itself no matter what the nature of the project. De Lessio et al. (2009b) argued that the relationship between planning and communication is often implied but not discussed in detail in the literature. In that vein, it is suggested that incorporating more specific knowledge while managing and planning a complex project would enhance the project outcome. As such, this paper proposes that a layered matrix-based approach could be used to identify and communicate the dependencies of critical project knowledge areas to inform and enhance project understanding and enable better decision making and project execution. While the examples presented in this paper consider the dependencies between knowledge areas from a synchronous perspective more exploration of how asynchronous dependencies (i.e. one knowledge area has greater impact or is more greatly impacted by that of which it is being compared to) would add even more detailed understanding of the project knowledge areas being considered. Further development and use of this method in managing complex projects no matter what their nature can be used to support critical project understanding and communication between project actors that will ultimately result in a more likely and optimal project success.

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