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Project Complexity Mapping in Five Dimensions for Complex Transportation Projects

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Abstract: Traditional three-dimensional project management theory is based on optimizing the cost-schedule-technical dimensions. Recent studies in the United Kingdom, Canada, and Australia have shown that the current project management body of knowledge may not be adequate to address interrelated and dependent variables encountered on complex projects. This paper reports the findings of an international research team's detailed study of 18 complex projects, which confirms the findings of the previous research and proposes a framework upon which a complex transportation project's scope of work can be better conceptualized and a methodology to graphically display a project's complexity in order to better understand and prioritize the available resources. The result is a "complexity footprint" that helps the complex transportation project manager identify the sources of complexity so that appropriate resources can be allocated to address those factors before they create a crisis. **DOI:** **10.1061/(ASCE)ME.1943-5479.0000163.**

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Introduction

The past two decades have fundamentally changed transportation project management (PM). Project scope has increased; the project delivery period has shrunk; and the impact of external factors such as environmental policy and the source of construction financing drive the design solutions to most transportation projects [Federal Highway Administration (FHWA) 2006]. Understanding the factors that lead to the successful delivery of transportation projects is evolving from a purely technical, short-term focus based on design loads/requirements, to a broad, holistic, longer-term focus that includes both subjective (e.g., public acceptance and political support) and objective (e.g., capacity, budget, schedule) measures of project performance (Jugdev and Muller 2005). The College of Complex Project Management (CCPM) maintains that managing the project delivery process is a "continuum: at one node is traditional PM, with its philosophy, organizational [sic] architecture, methodology, tool set and contracts all firmly based upon certainty; at the other node is complex PM, with its philosophy, organizational [sic] architecture, methodology, tool set and contracts all firmly based upon uncertainty and complexity" (CCPM 2008). This evolution in PM theory is being termed "complex project management" (Whitty and Maylor 2009), "an emerging natural extension of traditional PM to create a specialist profession . . . " (CCPM 2008). Thus, the objective of this study is to extend the CCPM's "continuum" theory to a framework that permits the project manager to employ a holistic approach using proactive tools to deliver complex transportation projects.

Defining Complex Project Management

The CCPM differentiates between routine projects and complex projects by "the degree of disorder, instability, emergence, nonlinearity, recursiveness, uncertainty, irregularity and randomness, including a high uncertainty about objectives" (CCPM 2008). Williams (1999) argues that uncertainty must also be considered when defining a complex project. The U.S. FHWA uses a more specific definition, which keys on a monetary value and projects that "have a high-level of public or congressional interest; are unusually complex; have extraordinary implications for the national transportation system; or are likely to exceed $500 million in total cost." (FHWA 2010). The two definitions of a complex project are very similar. The CCPM speaks in theoretical terms that essentially describe the ability of the complex PM to control the various factors that impact project delivery (e.g., disorder, instability, emergence, nonlinearity, recursiveness, uncertainty, irregularity, and randomness), whereas the FHWA's stated concerns are monetary value, social/political impacts, and national-level transportation goals. Similarly, both definitions recognize that these projects have factors whose control lie outside the ability of the PM and as such must be identified, evaluated, and recognized in the PM plan.

It is worth noting that neither the CCPM nor the FHWA approach mentions technical factors such as the actual engineering design of the complex project. Therefore, a project can have a complicated technical design without becoming complex. Routine PM is fundamentally based on the technical design. In essence, the

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dimensions of the scope, schedule, and cost are predicated on the assumption that the technical design requirements will subsequently define both the project's cost and the time required to deliver it. Marshall and Rousey (2009) define successful PM as "the scope, schedule and budget are in balance." As such, routine PM can be defined as a three-dimensional system. Once the fundamental relationship is optimized, a PM plan can be developed to successfully execute the project.

However, complex transportation projects often have their technical design driven not by traditional design loads and capacities, but by external factors such as changing environmental legislation, unfavorable public opinion, political influence, and the need to attract private financing over a multiyear period (Jugdev and Muller 2005; Little 2006; FHWA 2006; Whitty and Maylor 2009). As a result, it becomes important to identify a transportation project as complex at its conception and provide the PM the maximum amount of time to develop project control plans that recognize the uncertainties, ambiguities and interrelationships and keep project execution from slipping over the edge of chaos (Williams 1999). Therefore, the paper will propose a framework from which the sources of transportation project complexity can be conceptualized and a tool for measuring and visualizing the various dimensions of project complexity.

Defining Complex Project Management for Transportation Projects

Simon (1962) proposed an "architecture of complexity" that was based on the concept that "complexity frequently takes the form of hierarchy and that hierarchic systems have some common properties that are independent of their specific content." Simon went on to define a complex system as one "in which each of the subsystems is subordinated by an authority relation to the system" and opines that "all complex systems [are] analyzable into successive sets of subsystems." He also concluded that complex systems are dynamic and that the interrelations between subsystems are subject to constant change as time elapses. Simon's paper serves as the foundation for defining complexity in the context of transportation PM. A typical highway project (analogous to Simon's system) is composed of a set of severable features of work (analogous to Simon's subsystems) that are often constructed by different trade subcontractors, such drainage, paving, bridges, etc., which are interrelated through technical relationships and the sequence in which they must be constructed. A cost overrun in one early feature of work can impact the ability to afford the construction of a later feature and generate unplanned changes to its design to accommodate the project's authorized budget. Additionally, a transportation project is typically a public work, constrained by the regulations applied to public funding and as a result, susceptible to influence by public opinion, political motivations, and a variety of other external factors that are outside the direct control of the PM. There are significant, dynamic interrelations between hierarchical subsystems. Thus, Simon's complexity model is satisfied for this industry sector.

Complexity Theory

In a book entitled *Tools for Complex Projects*, Remington and Pollack (2007) extend Simon's complexity theory to the management of complex infrastructure projects. These authors attribute project complexity to the "interrelationships and feedback between increasing numbers of areas of uncertainty and ambiguity." A project's level of complexity reaches a point where it "exhibits emergent properties which could not be predicted from looking at the individual parts [i.e., subprojects]" and will "show nonlinear behavior [due to] the number of different elements in the project and their interconnectedness." In a nutshell, the PM's ability to control all aspects of the project decreases as complexity increases to a point where the PM can no longer control the impact of external factors.

The point where the transition takes place is termed the "edge of chaos" (Thomas and Mengel 2008). This is the "point between order and chaos where the system gets the benefit of some level of chaos and the resulting creativity whilst the system still has enough order to survive, maintain coherence, and specialization in some functions" (Remington and Pollack 2007). Thus, it becomes important to

- Identify all the subsets of internal and external factors and their potential interactions at an early stage in the project so that the manager of a complex project can clarify ambiguities before they impact the project, and
- Make plans to deal with external factors that introduce chaos and assign resources to influence the interrelationships to at very least mitigate the impact of those external influences.

In other words, the objective is to manage the project at the edge of chaos and to achieve the benefit of the creativity that comes from chaos. This leads to the conclusion that part of the definition of complex project success is the PM's ability to anticipate uncertainty in a manner that keeps the project under control.

Complexity Theory Applied to Transportation

As part of the redefinition of transportation project success, the roles and responsibilities of PMs are expanding beyond the traditional cost—schedule—technical triangle (Atkinson 1999) to include management of relational, cultural, and stakeholder issues (Clelland and Ireland 2002). The weight of evidence suggests a broad recognition that the nature of PM is changing. The U.K. developed a conceptual framework in 2003 called "Rethinking Project Management" (Winter and Smith 2006) and applied a rigorous approach to the problem of complex PM. The result was a framework called "Five New Directions of Thought" to define the difference between routine PM and the management of complex projects in the 21st century.

With the five directions framework, the study sought to move PM theory from a linear process where all the variables are controlled, termed by the authors as "life cycle theory," to a nonlinear process where some or all of the variables are not controllable, "complexity theory." The study concluded that the challenge to complex PM is "poor understanding and handling of uncertainties, handling chaos and complexity" that is derived from the "future tense trap"—fixing requirements before sorting out what the project team is trying to accomplish (Winter and Smith 2006). The so-called trap is the conceptualizing of a project as a purely technical solution to a given requirement without regard to the potential impact of external factors. In essence, the Rethinking Project Management study sought to change the very definition of a project from a collection of constructed products designed and built to perform a given function (the "future tense trap") to a vital element of societal progress that adds value not only to the specific location in which it is built but also creates value for a broader set of interrelated functions that exist within and without the constructed project's boundaries.

To accomplish the transformation of the PM body of knowledge requires a fundamental change in the way complex PMs are prepared. A complex project requires more than the ability to complete engineering design, estimate cost, and develop schedules (i.e., a trained technician). Complex PMs must be "reflective practitioners who can operate effectively in complex project environments

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through experience, intuition and the pragmatic application of theory" (Winter and Smith 2006). The CCPM standard for complex PMs outlines the body of knowledge necessary for competency in this new specialization. Table 1 shows the relationship between the literature on complexity and the Rethinking Project Management study. One can see that all three documents intersect when organized by Winter and Smith's five new directions of thought. This permits the researchers to use these works as the foundation for defining and measuring complexity for transportation projects as discussed in subsequent sections of this paper.

Whitty and Maylor (2009) frame the definition of complex PM in the form of two questions that synthesize the issue of transition from routine PM theory to complex PM theory:

- "Under what conditions of complexity are the current toolsets and approaches to managing projects effective?
- How should the approach to a high complexity project differ from that of a noncomplex project?"

The answers to these questions describe the transition from routine PM to complex PM. The upshot is that complex PM includes a skill set that goes beyond mere technical competence and requires skills that permit the complex PM to work successfully in conditions of uncertainty to deliver projects with significant factors beyond the PM's control (CCPM 2008). Some of those skills involve teambuilding; the capacity to creatively develop solutions that transcend traditional engineering and routine PM approaches; and the ability to tolerate a much higher level of risk because the complex PM can comprehend the ramifications inherent to uncontrollable external factors, using the chaos to create innovative PM plans that addresses them (Clelland and Ireland 2002; Winter and Smith 2006; Remington and Pollack 2007; Thomas and Mengel 2008).

In summary, a complex transportation PM must conceptualize the project in a different light than the routine project. This issue was recognized in a recent study and articulated as follows:

> An important and difficult part of project management is the conceptualization stage. How well a project is conceptualized affects how well the project is defined and appropriately scoped. As the project scope is acknowledged as the basis upon which subsequent project management processes and activities are planned and delivered, the conceptualization stage can be seen as central to project management processes . . . particularly when dealing with multiple powerful stakeholders and "messy" situations (Joham et al. 2009).

These authors use the term "project scope" to cover the totality of project requirements and specifically recognizes complexity in the PM process brought by factors that are outside Marshall and Rousey's (2009) traditional three dimensions of transportation PM (cost, schedule, and technical) when they cite multiple powerful stakeholders and 'messy' situations. Furnishing a framework from which to conceptualize a complex transportation project and possibly furnish one answer to Whitty and Maylor's (2009) questions is the objective of this paper. To do so require an in-depth exploration of complex projects and since most complex transportation projects tend to be very large in cost, delivery period,

Table 1. Intersection of Complexity Literature with "Rethinking Project Management" Directions

"Rethinking Project Management" (Winter and Smith 2006)	*Competency Standard for Complex Project Managers* (CCPM 2008)	*Tools for Complex Projects* (Remington and Pollack 2007)
"Direction 1: from the Life Cycle Theory of Project Management towards Complexity Theory of Project Management."	"Complex projects are characterised [sic] by a degree of disorder, instability, emergence, nonlinearity, recursiveness, uncertainty, irregularity and randomness"	"Analyzing and anticipating the types and levels of complexity which are likely to be encountered in the life cycle of the project/programme [sic]"
"Direction 2: from Projects as Instrumental Processes towards Projects as Social Processes"	"There is dynamic complexity where the parts in a system can react/interact with each other in different ways"	"Analyzing complex relationships between subprojects; managing inter-dependencies between sub-projects"
"Direction 3: from Product Creation towards Value Creation."	"This standard lays the foundation for project management to effectively deal with complex projects, and in doing so, to add real value to our world."	". . . utilizing Earned Value Management Performance Measurement. . . . integrates a partnering approach to the management of large . . . projects . . . "
"Direction 4: from Narrow Conceptualization towards Broad Conceptualization."	". . . high uncertainty about the objectives, and/or high uncertainty in how to implement the objectives."	"Meaning-making activities, including those who have set goal to clarify goals as much as possible."
"Direction 5: from Trained Technicians towards Reflective Practitioners."		
Characteristics of a reflective practitioner	Characteristics of a complex project manager	Characteristics of a complex project manager
Can learn, operate, and adapt effectively in complex project environments	"Makes own behavioural [sic] choices with knowledge of a range of alternatives and their situational consequences	"Ability to develop creative ways forward
Through experience, intuition, and the pragmatic application of theory in practice	Puts in the effort necessary for thinking	High-level communication abilities.
	Budgets their time with the focus on strategy	Comfortable with ambiguity and ability to communicate ambiguity to other levels [by] simplifying the issues
	Does not fill their calendar, allows contemplation time	Ability to take multiperspective viewpoints
	Is inquisitive and investigative	Opportunistic to take advantage of [unexpected] ideas
	Has a dialectic within themselves of confidence and doubt"	Treating the project as many interrelated projects . . . "

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and scale, a case study research methodology was deemed appropriate (Yin 2002).

Case Studies of Complex Transportation Projects

Since the recognition that complex PM is a field that requires its own body of knowledge is recent, there has been little formal research on the topic directly related to transportation projects. The material in this paper comes from a study funded by the U.S. National Academies of Science's Strategic Highway Research Program-2 (SHRP2) entitled: "Project Management Strategies for Complex Projects." Because differentiating between routine and complex project characteristics requires in-depth examination, the study's methodology was based on case studies of 18 complex projects in Canada, New Zealand, the United States, and the U.K. Case studies can be utilized to look in-depth at a case to focus on attitudes, behaviors, meanings, and experiences by obtaining information from a number of different sources related to a project (Yin 2002). The sources include archival project documents, public records, news and trade publication, journal articles, and personal interviews with project participants. The research aimed to identify the critical dimensions of complex PM in transportation and to supplement the existing body of knowledge with tools used successfully in managing complex projects.

Research Methodology

The U.S. case study projects were selected from the major projects list maintained by the FHWA (2010). The primary selection criterion was the availability of the major PM for interview. Secondarily, the FHWA Innovative Program Delivery Office maintains a set of case study synopses for major projects which furnished the researchers a means of identifying those major projects that would fit the definitions for complexity found in the literature. The international projects were selected using the same prime criterion with the researchers needing to make contact with the PM to ensure that the project was also complex. The principal research tool was the structured interview of the primary agency participants in each case study project using the U.S. Government Accounting Office's protocol (1991) for case study methodology. The interviews were conducted and answers were recorded to a standard interview questionnaire developed using the principles for questionnaire design by Oppenheim (1992). Information was recorded, collected, and coded following standard research methods and ultimately merged with similar information derived from the literature review. The methodology is provided in Fig. 1.

Once the interviews were complete and recorded, the output was examined and analyzed for its meaning as well as its relationship to the issues of interest in the research. A set of standard data coding categories was developed into which words or phrases that appear in the text of an interview form, a case study project solicitation document, or a document from the literature on complex projects were placed. The frequency of specific category appearance was used as proposed by Weber (1985) to infer the content of a given document and to identify intersections of independent converging lines of information between case study projects. The result was an inference regarding the given agency's approach to complex PM and trends across the population that can be identified and reported. Finally, each interview concluded with the interviewees rating the relative complexity of cost, financing, schedule, technical design and external factors that materially impacted the final project delivery plan. The case study interviews were structured to allow the researchers to assign a specific complex management tool to at least one of the sources of complexity. The number of times a specific tool was mentioned as a means of managing one of the five-dimensional sources of complexity is listed in the respective column of Table 2 below.

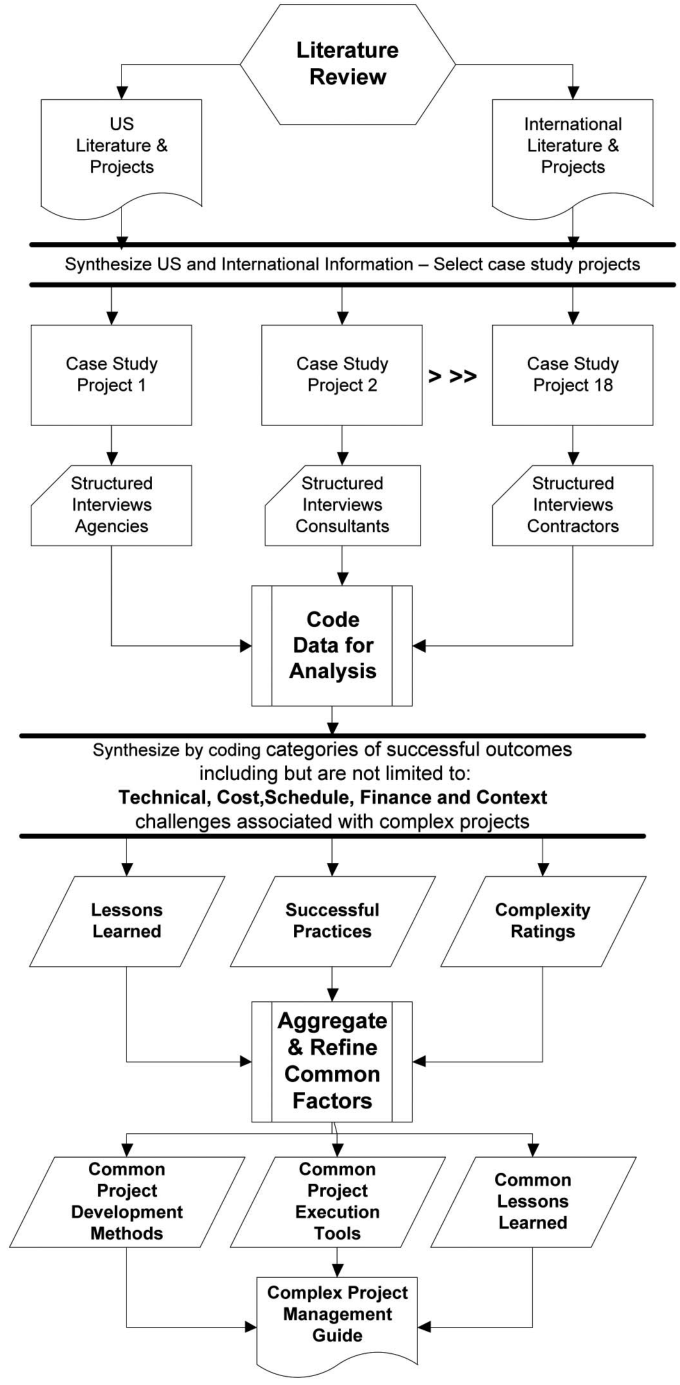

Fig. 1. Research methodology

The concept of the "dimensions of complexity" was defined by Remington et al. (2009) as the "source characteristics of complexity." Therefore the content analysis was organized to identify appropriate complexity dimensions for transportation projects by building on the three dimensions cited by Marshall and Rousey (2009) for transportation. One of the major topics sought in the interviews were project development methods and project execution tools used to surmount issues found on complex transportation projects; and the content analysis revealed that the methods and tools (see Table 2) used to deliver the 18 complex projects could

Table 2. Complex Project Development Methods and Case Study Project Execution Tools

	Number of projects	Dimension
Project development method (executive level)[a]		
Define project success factors by each dimension as required	15	All
Select contracting and delivery methods based on outcomes	13	Technical, financing, schedule
Assemble owner-driven project team	15	Context, technical
Prepare early cost model and finance plan	11	Financing, cost
Define political action plan	12	Context
Project execution tool (project team)[a]		
Incentivize critical project outcomes	12	All
Develop dispute resolution plan	10	All
Perform comprehensive risk analysis	17	All
Identify critical permit issues	15	All
Evaluate applications of off-site fabrication	5	Technical, schedule, cost
Determine required level of involvement in row/utilities	15	Technical, context, cost
Determine work package/sequence	10	Technical, schedule
Design to budget	3	Technical, cost
Co-locate project team	6	Technical
Establish flexible design criteria	13	Technical
Evaluate flexible financing	11	Financing
Develop finance expenditure model	8	Financing
Establish public involvement plan	16	Context

[a]See the appendix for a brief description of each. Refer to Shane et al. (2011) for a detailed explanation of each.

be categorized at the highest level into the five dimensions shown in Table 3:

1. Technical: all the typical engineering requirements including scope of design and construction, quality, and need for integrated delivery;
2. Schedule: the calendar-driven aspects of the project;
3. Cost: quantifying the scope of work in monetary terms;
4. Context: external influences impacting project development and progress; and
5. Financing: not cost but the sources of the project's funding.

Table 3 shows that Table 2 methods and tools were most frequently needed to deal with complexity in the technical and context dimensions. Examples are setting flexible design criteria and developing a political action plan at the early project concept stage. The observations of the other three dimensions were roughly equal. However, the fact that financing was found to equate to cost validated the creation of that as a separate category from cost. A similar observation can be made for context and technical. In routine projects, the contextual issues are usually addressed during planning and design as an integral part to the design developmental process. The fact that complex PMs needed to specifically address contextual influences and the fact that often those influences were ultimately reflected in the final project also validated the creation of context as a separate dimension of complexity.

The final content analysis revealed that PMs of both large and small complex projects must ultimately optimize the available

Table 3. Complex Project Case Study Summary and Transportation Project Dimensional Complexity

Case study project	Location	Project delivery method	Budget	Number of observations of methods and tools applied to complex project management issues by dimension: Technical	Schedule	Cost	Context	Financing
Doyle drive	California	DBB& PPP	$1.05 B	9	7	7	9	8
T-REXSE I-25/I-225	Colorado	DB	$1.67 B	12	8	9	9	8
I-95 New Haven harbor crossing	Connecticut	DBB	$416 M	6	3	4	5	3
I-595 corridor	Florida	PPP	$1.8 B	11	7	7	9	8
New Mississippi river bridges	Illinois/Missouri	DBB-BV	$667 M	11	6	7	8	7
Louisville Southern Indiana Ohio river bridges	Indiana/Kentucky	DBB	$4.1 B	4	3	3	5	2
Intercounty connector	Maryland	DB	$2.7 B	10	6	7	8	7
Hudson-Bergen light rail	New Jersey	DBOM	$1.2 B	1	1	1	1	2
Detroit River international crossing	Michigan/Ontario, Canada	PPP	$2.2 B	7	4	4	7	5
Northern Gateway toll road	New Zealand	Alliance	$275 M	12	7	8	9	8
North Carolina tollway	North Carolina	DB	$583 M	10	6	6	8	7
I-40 crosstown	Oklahoma	DBB	$600 M	7	5	6	7	4
Lewis and Clark bridge	Oregon/Washington	DBB-BV	$29.8 M	9	7	6	6	5
Green street	Canada	DSB	$10 M	8	6	5	4	5
Texas SH161	Texas	DBB&DB	$1.0 B	8	5	5	8	6
Heathrow T5	UK	DB	$5.8 B	7	5	4	6	5
Capital beltway	Virginia	PPP	$2.2 B	9	6	7	9	8
James river bridge	Virginia	DBB-BV	$49 M	11	8	7	9	6
		Total	$27.2B	152	100	103	127	104

Note: BV = best value; DB = design-build; DBB = design-bid-build; PPP = public-private partnership; PDM = project delivery method.

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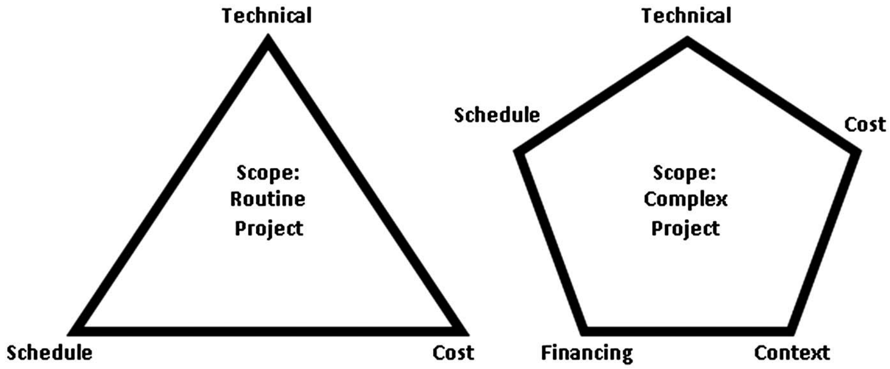

Fig. 2. Conceptual dimensional difference between routine and complex project management (reprinted from Marshall and Rousey 2009, with permission of the Transportation Research Board)

resources (time and money) with the technical performance needs of the project (design) while operating under both known and unknown constraints (context), all the while accommodating the requirements of new financing partners and funding models (financing). Generally speaking, this requires the owner to think continuously about budgeting, scheduling, designing, allocating, and pricing the inherent risk of a given project (Touran 2006).

The external factors identified in the interviews that significantly impact complex projects can be grouped in two major categories: project context and project financing. Thus, complex PM involves an increase in the PM's skill set from the traditional three dimensions to encompass five dimensions. Fig. 2 shows the five-dimensional model that is proposed for a complex transportation PM framework.

Table 3 shows the relative complexity on a dimension by dimension comparison. The first conclusion that can be derived from the analysis of the dimensional comparison in Table 3 is that in spite of the agency's contrary view, the Green Street project was not a complex project since its PM rated the three traditional dimensions as more complex than either context or financial. The agency PM's reasoning was that the complexity came from using mechanistic pavement design for the first time and an untried project delivery method. Thus, the technical dimension was rated highly complex and the uncertainty about the costs associated with the new project delivery method drove that dimension's rating. Therefore, the complexity in the Green Streets project is transient and will decrease as the agency gains experience with the two newly adopted procedures. Table 4 also shows that in the remaining seventeen case studies at least one of the new dimensions was rated as more complex than the three traditional ones. This leads to a conclusion that given the five-dimensional model, a complex project can be defined as one where the PM must manage at least four of the five possible dimensions.

The notion portrayed in Fig. 2 is that by elevating the impact of context and financing on the transportation project delivery plan, the complex PM will then have a framework within which to conceptualize the complex scope of work and develop proactive remedies for factors that are not controllable, such as possible political interference during project execution (context) or the need to develop the construction schedule around the availability of private

Table 4. Comparison of Case Study Project Complexity by Dimension

Project	Technical versus context	Schedule versus context	Cost versus context	Technical versus financing	Schedule versus financing	Cost versus financing	Context versus financing
Doyle Drive	Technical	**Context**	Cost	**Financing**	**Financing**	**Financing**	**Financing**
T-REX	**Context**	**Context**	Cost	**Financing**	**Financing**	Cost	**Context**
I-95 New Haven	**Context**	Schedule	**Context**	**Financing**	Schedule	**Financing**	**Context**
I-595 corridor	Technical	Schedule	**Context**	**Financing**	**Financing**	**Financing**	**Financing**
New Mississippi Bridge	**Context**	**Context**	**Context**	Technical	Schedule	Cost	Context
Ohio River Bridge	**Context**	**Context**	Cost	**Financing**	**Financing**	Cost	**Financing**
Intercounty connect	**Context**	**Context**	**Context**	**Financing**	**Financing**	**Financing**	**Financing**
Detroit River International	**Context**	**Context**	**Context**	**Financing**	**Financing**	**Financing**	**Financing**
Hudson-Bergen rail	Technical	Schedule	Cost	Technical	**Financing**	**Financing**	**Financing**
Northern gateway	**Context**	**Context**	**Context**	**Financing**	**Financing**	**Financing**	**Financing**
North Carolina toll	Technical	Schedule	Cost	**Financing**	**Financing**	**Financing**	**Financing**
I-40 crosstown	**Context**	**Context**	**Context**	**Financing**	Schedule	**Financing**	**Context**
Lewis-Clark Bridge	**Context**	**Context**	**Context**	Technical	Schedule	Cost	**Context**
Green Street	Technical	Schedule	Cost	Technical	Schedule	Cost	**Context**
Texas SH161	**Context**	**Context**	**Context**	**Financing**	**Financing**	**Financing**	**Financing**
Heathrow T5	**Context**	**Context**	**Context**	**Financing**	**Financing**	**Financing**	**Context**
Capital beltway	**Technical**	**Context**	**Context**	**Financing**	**Financing**	**Financing**	**Financing**
James River Bridge	**Context**	**Context**	**Context**	Technical	Schedule	Cost	**Context**

Note: Bold font indicates the context and financing dimensions to communicate the overall impact that the newly proposed dimensions were found to have with respect to the three current dimensions.

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and/or public funding (financing). In the routine project, the context factor is addressed as a part of project planning and design (termed "context sensitive design") and the project financial plan is a unidirectional process flowing from the cost estimate. In both cases, the technical requirements of the project are preeminent over the constraints imposed by context and financing, making the result of the entire process a "go-no go" decision; i.e., the final design either results in an environmental permit or not and the construction funding is either available as required or the project is delayed until it does become available. In both examples, the PM reacts to the external influences over which there is no control. In the five-dimensional PM model shown in Fig. 2, the complex PM considers context and financing as equal to the traditional three dimensions of cost, schedule, and technical. Thus, a complex PM must balance the interrelationships between the cost, schedule, and technical dimensions with those of the context and financing dimensions rather than merely considering context and/or financing as a constraint that may become a roadblock to project delivery.

The external validity of the five-dimensional framework was substantiated through subsequent application on two holdout cases from the original sample. After development of the five-dimensional framework from the original 18 cases, the framework was tested on the I-74 corridor project in the Quad Cities of Iowa/Illinois (a design-bid-build project) and on the I-15 South project in Las Vegas, Nevada (a design-build project). In both of the validation cases, the case study questionnaire, glossary, and assessment tool was sent to the project team leaders along with a short background narrative on how to use the framework. In both cases the five-dimensional framework was validated, as financing (I-74) and context (I-15) were rated highly compared to the traditional three dimensions.

Results of the Analysis

A detailed discussion of all the results obtained from the research project described above is not possible within the constraints of this paper and thus, the reader is referred to the original research report for those details (Shane et al. 2011). Remington et al. (2009) differentiated between complexity dimension and severity. That work was based on "qualitative thematic factors." This project sought to measure the relative impact of each dimension on the given project, which may in fact be quite similar to Remington's definition that complex projects "demonstrate a number of characteristics to a degree, or level of severity, that makes it extremely difficult to predict project outcomes, to control or manage the project."

The ranking system utilized a two-step forced choice procedure. The first step was for the project team leaders to rank each of the five dimensions on a one to five scale from least complex (1) to most complex (5), with no two dimensions carrying the same ranking. The team members had to discuss the nature of project complexity until agreement was reached on the rankings. After the team reached agreement on rankings, the team then had to assign a dimensional impact ratings indexed on a scale of 10 to 100 against a baseline standard of 55 for an agency's typical routine project. Thus, index numbers greater than 55 indicate that the rated factor was more complex than a typical project. The results were then graphed in the form of a radar diagram that displays the "complexity footprint" for each project. Fig. 3 illustrates the radar diagrams for four case study projects' rated complexity. By visual inspection, one can see that the Doyle Drive project was rated as having an above average complexity in all five dimensions; whereas the Hudson-Bergen Light Rail project only exceeded average complexity in the technical dimensions.

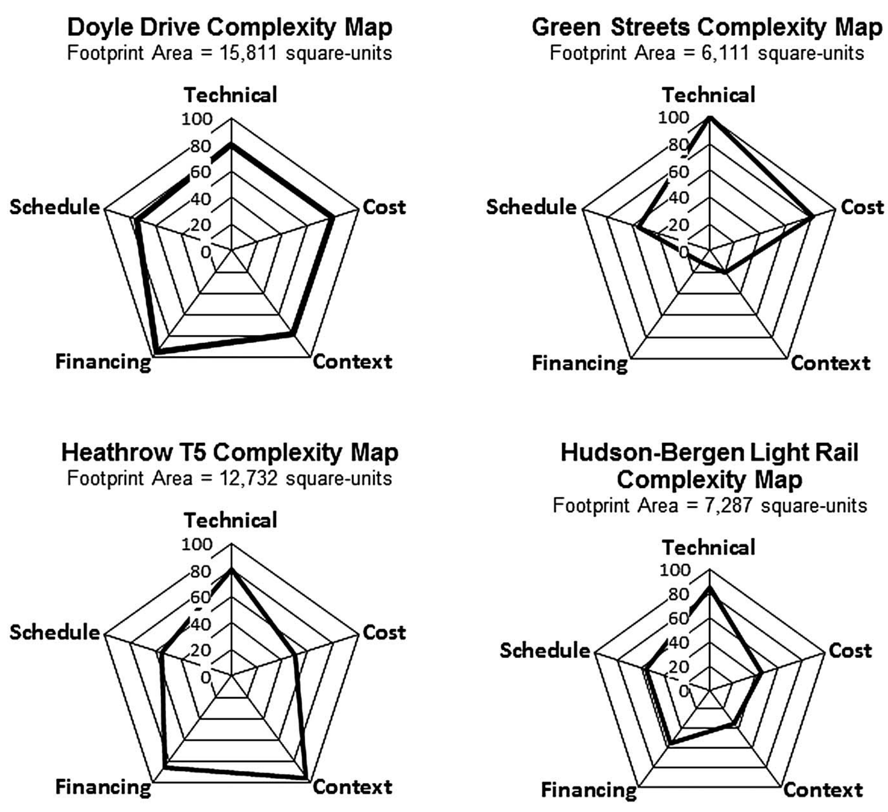

Fig. 3. Complexity footprints of the Doyle Drive, Green Street, Heathrow T5 Expansion, and Hudson-Bergen light rail projects

Table 5. Rated Case Study Project Complexity by Dimension and Complexity Footprint Area

Case study project	Complexity rating by dimension: Technical	Schedule	Cost	Context	Financing	Footprint area (units)
Doyle Drive	80	75	80	78	95	15,811
T-REXSE I-25/I-225	90	85	100	98	98	21,101
I-95 New Haven Harbor crossing	20	85	30	75	72	6,344
I-595 corridor	85	70	5	60	100	10,034
New Mississippi River Bridge	85	90	75	60	95	15,538
Louisville Southern Indiana Ohio River Bridges	85	55	100	95	90	17,060
Intercounty connector	55	80	72	85	90	13,733
Hudson-Bergen light rail	85	55	45	35	55	7,287
Detroit River international crossing	55	85	75	98	100	16,025
Northern gateway toll road	55	60	55	75	90	10,664
North Carolina tollway	85	90	75	70	95	16,346
I-40 crosstown	15	70	55	100	60	8,227
Lewis and Clark Bridge	85	55	30	100	5	4,874
Green Street	100	55	82	20	10	6,111
Texas SH161	40	75	70	90	95	12,792
Heathrow T5	80	55	50	95	85	12,732
Capital beltway	95	15	10	20	98	6,203
James River Bridge	90	95	60	55	90	14,551

Table 5 contains the complete ratings for all 18 projects. It shows that in 17 of 18 cases at least one of the two new dimensions was rated as having significant impact as opposed to the given agency's typical routine project. The area of the resulting footprint furnishes a method to compare the relative complexity between projects. The footprint is the sum of the areas of five scalene triangles. It is computed by knowing that the interior angle of a regular pentagon is 72° and using Eqs. (1) and (2):

$$A_x = 1/2ab(\sin 72°) = 0.127ab \tag{1}$$

$$F = \sum_{x=1}^{5} A_x \tag{2}$$

where A_x = area of triangle x; a = complexity rating to the left of the interior angle; b = complexity rating to the right of the interior angle; and F = area of the resultant complexity footprint.

The maximum area (all five rated at 100) = 23,776 units; and the average area (all five rated at 55) = 7,192 units. While no conclusions are drawn with the relative measurements, it is interesting to note that a project such as the I-95 New Haven Harbor Crossing could have a footprint that is less than average, but still have three of five complexity dimensions rated above average. This illustrates the dynamic characteristic of complex PM.

One can also track the impact of context on the technical and schedule dimensions. It is important to note that in the case study projects where the financing dimension was rated high, it was also considered a potential barrier to project execution. In other words, if the other four dimensions could not be optimized within the constraints of the financial plan, the project was dead. In fact, the Louisville-Southern Indiana Bridge project was stalled at the time of the interview for that very reason.

Conclusions

"Project management is about resolving a problem need" (Joham et al. 2009) and the resolution typically require the PM to allocate resources. To resolve a complex project's "problem need," the PM must be able to effectively prioritize the given problem's resource needs within the population of other project resource needs because any project's pool of resources is finite. Pragmatism suggests that conceptualizing some event (activity) involves being clear about what 'concept' is being used to think about that event. The framework presented in this paper provides a means to increase the clarity of concept by recognizing that project context and project financing can become the factors that literally drive the final project's technical solution as well as its ultimate cost and the actual period to deliver it. The five-dimensional model's concept as shown in Fig. 3 strives to add structure to the process of conceptualizing the complex project's scope of work. Additionally, the footprint area shown in Fig. 3 furnishes a quantitative method for comparing complex projects that are competing for resources as shown in Table 5.

The model is validated by the fact that all 18 complex project managers in four different nations were able to quickly grasp the concept, relate it to their specific project, and draw the complexity maps whose values are contained in Table 3. It can be further validated by comparing it to previous research on complex PM. It embodies the "Rethinking Project Management" initiative by furnishing a methodology to facilitate the intellectual movement from "Life Cycle Theory of Project Management towards Complexity Theory of Project Management" (Winter and Smith 2006). It answers the question posed by Whitty and Maylor (2009) of how the approach to a complex project would differ from a routine project by furnishing a methodology to prioritize project resources based on the complexity of project needs. Table 4 shows that the five-dimensional frameworks provides the definition to identify a complex project as one where more than the traditional three dimensions of cost, schedule and technical need to be managed. The five-dimensional models also act as a framework to provide "pragmatic approaches [that are] feasible, democratic, creative as well as useful, once the need for a multiperspective and interconnected view of project conceptualization has been accepted as inevitable . . . " (Joham et al. 2009).

In summary, the five-dimensional models for complex transportation PM and the radar complexity diagram can be viewed as tools for complex PMs to develop a proactive PM plan that conceives and addresses issues inherently outside their direct control. Thomas and Mengel (2008) call this PM "being conducted on the edge of chaos." Being able to deliver the complex transportation project without it slipping across that line into uncontrollable disorder is a critical skill required by a complex PM. This paper has shown that by viewing a complex project in five rather than three dimensions the PM can elevate the visibility of complex project context and financing using complexity mapping and thereby pragmatically conceptualize a scope of work that embodies both the controllable and uncontrollable factors that will be faced during the delivery of complex projects. The reader is referred to *A Guidebook for Managing Complex Projects* (Shane et al. 2011) for a more detailed explanation of the procedures used to implement the framework described in the paper.

Appendix. Complex Project Management Development Methods and Tools

The case study analysis of complex transportation projects yielded five complex project development methods and thirteen complex project management tools (Shane et al. 2011). Table 2 lists these findings. Below is a brief description of each.

Method 1: Define Critical Project Success Factors

The critical project success factors are typically comprised of both subjective and objective inputs. On complex projects, the team needs a simplifying heuristic to guide decisions and analyses. The critical project success factors provide just such a simplifying heuristic. The point of Method 1 is to identify the legislative and political directives, gather input from agency and project leaders, estimate project resource requirements and determine if they are currently available, assess community needs and influence over project feasibility, and ascertain project characteristics. These inputs are then used to define critical success factors in each of the five dimensions of the 5DPM model.

Method 2: Select Contract Based on Project Outcomes

Method 2 is one of three resource allocation methods in the complex management plan. Method 2 is intended to help the project team identify administrative resources (primarily procurement methods and contracts) that are best suited to the project and are most likely to facilitate project success. The most likely starting place for this is Method 2, Selection of Contracts, which should be part of a deliberate project management plan based on critical project outcomes and integrated with other resource allocation methods (Method 3 = Project Team and Method 4 = Cost Model).

Method 3: Assemble Owner-Driven Project Team

The owner's team is the driver of the project, selection of the appropriate people at the appropriate time is important in successfully delivering a complex project. Not only is having the right people important but so is giving them the authority needed to effectively execute their responsibilities. The inputs are used to identify the critical skill sets required for project success. The project team can then assess internal capabilities and determine any gaps in required and existing skills. This gap analysis will inform the procurement plan described in Method 2, as any gaps in required skill or knowledge will need to be added to the team through contracts

Method 4: Prepare Finance Plan and Early Cost Model

Understanding the financial model, where the funding is coming from, where costs are being expended, and the limitations on design and context flexibility imposed by funding is important to project success. Inputs to be considered come from the complexity analysis, complexity flowchart, the complexity map, and the critical success factors identified in Method 1. The inputs are used to identify all current available sources of funding with have a high degree of certainty. The next step is to compare the available funding to the expected cost and scope of the project. If the available resources are sufficient, the project team can incorporate the funding flows into the procurement plan and develop a relatively straight forward cost model using standard project management tools such as resource loaded CPM schedules, earned-value analysis, or cash-balance linked project draw schedules. However, if available project funding is insufficient, the project team must look for additional external funding sources or adjust the project scope or develop a phased approach to fit available funds.

Method 5: Define Political Action Plan

Legislators, community stakeholders, utilities, railroads, and many other individuals and groups may play a very important and influential role in a complex project, more so than in normal projects. Understanding the influence and how to positively direct this influence is important.

Political action plans can be targeted toward a specific stakeholder (such as attempts to change restrictive legislation to allow innovation on a specific project) or can be general in nature, such as a public information and communication plan aimed at improving project support across a wide range of stakeholders. The inputs are used to identify any "showstoppers" that will inhibit project success if they cannot be eliminated. This might include restrictive legislation, cooperation of utilities, acquisition of Rights of Way, expedited NEPA reviews, support of local community groups, etc. The most critical dimension should be analyzed first to determine the need for targeted political action plans, with subsequent dimensions analyzed in decreasing order of criticality.

Tool 1: Incentivize Critical Project Outcomes

Based on the previously identified outcomes there is a need to incentivize the designers and contractors on the project to meet these project goals. The incentives range from traditional schedule, cost, and safety incentives to the performance areas from various external factors such as social, environmental, public involvement, and traffic mobility.

Tool 2: Develop Dispute Resolution Plan

Realizing that complex projects offer greater numbers of dispute points a thoughtful dispute plan is helpful. The dispute resolution plans should be negotiated for neighborhood groups, USDOT 4(f) signatories, and other indirect stakeholders, integrated into Political Action Plan, and contractually stipulated between designer and owner if scope agreement issues arise. The goal of the dispute resolution plan should be to proactively identify and manage conflicts before they have a negative impact on cost, schedule, or risk.

Tool 3: Perform Comprehensive Risk Analysis

The risk analysis must include some clear and concise assignment of responsibilities and assignment of designated resources. The risk analysis must include not only traditional cost and schedule issues, but also context and financing issues, such as railroad, utilities, 4(f) issues, NEPA, appropriations/capital bill allocation (use it or lose it funding), effect of delays on private equity viability. The risk analysis outcomes can be used to develop aggressive mitigation plans, including possibility of re-allocating contingency within project

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segments or phases to prevent delays or cost increases. Early involvement from contractor group or construction specialty review board is effective to retrieve input on means, methods, and material supply issues.

Tool 4: Identify Critical Permit Issues

Development of timelines for environmental, USDOT 4(f), and other critical regulatory reviews is critical for successful projects, especially very early in the project life cycle. Flexible response mechanisms for permit issues as well as flexible planning and design for minimal impact from the permit issues must be developed for the success of the projects especially where uncertainty is high (e.g., geotechnical and subsurface conditions, SHPO sites, etc.).

Tool 5: Evaluate Applications of Off-Site Fabrication

Off-site fabrication must be considered for not only schedule control purposes, but also quality control, minimal public disruption such as noise and loss of access, and environmental impact control. Considering that complexity on projects may come from context issues, off-site fabrication can be a good solution for external issues that minimize road closures, disruption to local business, traffic delays, detour lengths and public inconvenience.

Tool 6: Determine Required Level of Involvement in ROW/Utilities

Determination of the required level of involvement in ROW/utilities should be based on the critical project success factors. Even when contractual responsibilities for coordinating ROW/utilities are assigned to the contractor or design-builder, it is the owner agency and general public, which will ultimately suffer if, ROW and utility (including railroads) issues are not integrated into the overall project. Paying for additional design staff to assist railroads and utilities with design reviews or planning can be an option for project's success. To the extent possible, it is important to incorporate ROW, railroads and utilities as project partners (rather than project adversaries) and to develop win-win solutions to issues involving potential delay of cost increase.

Tool 7: Determine Work Package/Sequence

Carefully designed work package/sequence can increase project success possibilities. Projects will suffer if the work packages are determined without consideration of available funding sources, available contractors' capabilities, and stakeholder's concern for the project's impact. The work package/sequence must be prepared based on high-certainty funding sources, local contracting capabilities, available work force, bonding issues, procurement planning (division of internal and external work), road closure and detour options, Road User Costs, and local access issues.

Tool 8: Design to Budget

Often, complex projects have complicated funding systems with fixed, expiring appropriations that cannot be exceeded and must be disbursed within a specified time frame, In other cases, portions of the project are underwritten by debt instruments and in some cases, entire project funding may not even be identified or secured. In these cases, designing within the budget is the only way to execute the project. However, design to budget should be administered strategically.

Tool 9: Co-Locate Team

Prior to the start of the project, it is very important to discuss the advantages and disadvantages concerning project team co-location. Some compromise may be necessary, but having the whole team together most of the time may increase the odds of achieving critical project success factors. Especially, on multijurisdictional (e.g., bi-state) projects, placing a dedicated, empowered, representative project team in a common location is important. Depending on project delivery system utilized, the co-location strategy can be incorporated for design-build partners or contracting team in later stages.

Tool 10: Establish Flexible Design Criteria

Establishment of flexible design criteria is closely related to project cost, schedule, and quality performance (e.g., designing to a budget) as well as critical permit issues as mentioned earlier. Flexible design criteria can minimize potential ROW, utility, and 4(f) conflicts. Flexible designs can be achieved through use of design exceptions, need-based review and approval processes, performance specifications, and mechanistic designs. Whenever possible, implementation of procurement protocols should be considered because they allow designers to work with major material suppliers/vendors early in the project life cycle.

Tool 11: Evaluate Flexible Financing

Alternative funding sources should not be overlooked to furnish the needed funds for a project. Several alternative funding sources are available, including GARVEE bonds, implementing hybrid forms of contracting such as public-private-partnerships project phasing to leverage different sources of financing, tolling and other revenue-generation approaches (congestion pricing, hot-lanes, etc), and monetization of assets and service options, such as franchising.

Tool 12: Develop Finance Expenditure Model

Project cash flows must be obtained and integrated into project phasing plans to balance anticipated inflows and outflows of funds. Utilization of resource-loaded project plans and network schedules is recommended to track expenditures and project cash needs.

Tool 13: Establish Public Involvement Plan

Stakeholder's needs and concerns are frequently the driver in developing design options and project delivery methods for some complex projects. Extensive public outreach is required for project success, especially for complex renewal projects. Public involvement early in the planning phase can be important in mitigating public disruption (such as with self-detour planning) and dissatisfaction.

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