Systems Engineers' Perceptions on the Adequacy of Project Management Methods for Systems Engineering Management

Amira Sharon
Technion
Israel Institute of Technology
Haifa 32000, Israel
amirash@technion.ac.il

Dov Dori
Technion, Israel Institute of Technology
Haifa 32000, Israel, and
Engineering Systems Division
Massachusetts Institute of Technology, Cambridge, MA
dori@mit.edu

Olivier L. de Weck
Engineering Systems Division
Massachusetts Institute of Technology
77 Massachusetts Avenue,
Cambridge, MA 02139
deweck@mit.edu

Abstract. Systems Engineering Management (SEM) is being developed hand in hand with the maturation of systems engineering. SEM Standards concern relationships between SEM and Project Management (PM). PM methods have traditionally focused on scheduling, budgeting, and scope management, but SEM emphasizes the management of the project-product system under development. Most SEM applications use traditional PM methods and tools, including Gantt chart, PERT, Critical Path Method, System Dynamics, Earned Value Method, and Design Structure Matrix. Object Process Methodology has also been recently studied as a vehicle for Project-Product Lifecycle Management. We examine how systems engineers perceive the extent to which PM methods support SEM. We verified that project and product are viewed as two complementary facets of SEM, and that certain PM methods address both domains better than others with respect to particular examined factors. Careful management of the joint project-product ensemble is a most critical success factor for SEM to enable an enterprise to deliver and support a product, underscoring the need for a novel integrating Project-Product Lifecycle Management paradigm and methodology to better address issues of large-scale product-project system.

Introduction

Systems Engineering (SE) and Project Management (PM) are two tightly intertwined domains. This observation is expressed in at least two prominent SE handbooks. The first is the Systems Engineering Handbook of the International Council on Systems Engineering [INCOSE 2004], which addresses the strong relationships between SE and PM, providing framework and guidelines. The second handbook is the NASA Systems Engineering Handbook [NASA 1995], over one third of which is devoted to "management issues in systems engineering." Indeed, indicated in this Handbook is the fact that it covers topics that are also considered to be in the domains of Project Management/Program Control (PM/PC), "reflecting the unavoidable connectedness of these three domains."

Indeed, systems engineering involves two types of management: technical management, which is considered an integral part of systems engineering, and project management, which is frequently integrated into the technical management part by virtue of dealing with the same issue—the system or product to be delivered—and through the tight, long-lasting relationships between systems engineers and project managers of that same system or product.

Known also as engineering management, technical management is the management of the systems engineering process. It concerns standardized use of specifications, interface control documents, design reviews, and formal change control. Project management is complementary to engineering management in that it addresses the managerial aspects of such issues as delivery schedule and cost control.

Pertinent literature has been struggling with delineating the border between the project management and the engineering management domains. For example, the INCOSE SE Handbook [INCOSE 2004] indicates that "although there are some important aspects of project management in the Systems Engineering process, it is still much more of an engineering discipline than a management discipline. It is a very quantitative discipline, involving tradeoff, optimization, selection, and integration of the products of many engineering disciplines."

Along these lines, the INCOSE SE Handbook includes under the technical management umbrella elements of planning, scheduling, reviewing, and auditing of the Systems Engineering process. It calls for also including in the technical management the Systems Engineering Management Plan (SEMP) and the Systems Engineering Master Schedule (SEMS). In doing so, the SE Handbook further underscores the tight links and dependencies between the project management and the technical management domains.

Systems engineering differs from systems management, as engineering is an analytical, advisory and planning function, while management is concerned primarily with decision-making [NASA 1995]. This distinction is all too often highly irrelevant, not only because the same individuals—the systems engineering managers—perform both roles, but also because judicious decisions must be based on sound engineering analysis. Due to the multidisciplinary and highly complex nature of current and currently developed systems, engineering efforts apply science and technology, as well as technical planning, management, and leadership activities [Frank 2000]. Systems engineering managers must therefore rely on a combination of technical skills and management principles that address both complex technical and managerial issues.

Much of the confusion regarding these definitions and the attempts to draw the line between the technical and the project management aspects is rooted in historical reasons of the engineering and management domains growing as disparate disciplines in both academia and industry. The prevailing view was that engineers are professionals who got their education in engineering schools and master the scientific and technological aspects of the system or product to be delivered, while managers are a different kind of professionals, taught primarily in business schools to manage people, enterprises, and projects, but are much less verse in the science and technology aspects of the task at hand.

Ideally, a balanced mix of engineering and managerial skills is required to successfully run a real-life large-scale project, especially when the end result of the project is a complex functioning system or product. Following this train of thought, we adopt the notion of systems engineering management as the integration of technical management and the parts of project management related to systems engineering.

Why Integrate Project and Product Management?

The implementation of systems engineering requires collaboration of multidisciplinary teams, coordination of processes, methods and tools, allocation of resources, and utilization of adequate facilities within enterprises [Cook, Kasser & Ferris 2003]. While the standards surveyed above discuss these issues, project managers are left on their own when it comes to tailoring the standards, models, and best practices to their specific project and system or product's needs and circumstances. A framework and process for integrating perspectives of a complex system development with its enterprise and project processes is clearly missing [Cook, Kasser & Ferris 2003]. Furthermore, empirical investigations have shown that the relationships and interactions between the architecture of products, their development projects, and the organizational teams involved, should be aligned in order for a company to become successful [Eppinger & Salminen 2001].

The impact of systems engineering on program cost was recognized over a decade ago, when it has been established that approximately 80% to 90% of the development cost of a large system is predetermined by the time only 5% to 10% of the development effort has been completed. By the time system-level design is complete, 85% of the costs have been committed, and the cost to extract defects goes up exponentially [DSMC 1999]. Therefore, careful management of the joint project-product system is perhaps the most critical success factor for systems engineering management to enable an enterprise to deliver and support a product. Failure to closely manage the intricate web of resource constraints emanating from both domains for meeting a development and test objectives is a recipe for inadequate performance and project time and cost overruns.

This observation calls for a fresh look at the way projects and technical programs are managed in an attempt to bring them together under the same conceptual model of a grand project-product system. With this realization in mind, we have conducted a comparison survey of Project Management Methods, which are widely used by systems engineers in their practice of systems engineering management.

Project Management Methods

Methods for project planning and control have been developed over the last decades; some are still widely used with little or no changes. To determine the extent to which, and ways by which, common project planning and control methods are perceived to effectively support Systems Engineering Management, we have included in our research seven PM methods that are used among systems engineering practitioners. The seven PM methods examined in our study are described briefly in this section.

The Critical Path Method (CPM) is a network model of the project that depicts tasks along with dependency information, duration, and the slack time for each activity. CPM chart time is deterministic, resulting in a fixed estimate of the time required to complete the project. Like CPM, the Program Evaluation and Reviewing Technique (PERT) is a network model that depicts tasks along with dependency information and duration, allowing for assigning parametric probabilities to task completion times in accordance with optimistic, pessimistic, and likely estimations. The Gantt chart is likely the most widely used PM method. It comprises horizontal scheduling bars with time flowing from left to right, allowing for both planning and tracking of project schedule. System Dynamics (SD) started with Forrester [Forrester 1961; 1973] and has been used to model complex development projects in order to improve their performance [Lyneis & Ford 2007]. SD models are used for project planning, addressing planned budget, schedule, resources, risks, and past experience, and mapping iteration issues and rework loops. The Design Structure Matrix (DSM) is a square matrix representation of interactions among entities in a system. In project management, it enables modeling and analyzing dependencies among components, tasks, or teams in a project. Eppinger et al. [Eppinger, Whitney, Smith & Gebala 1994] used a matrix representation in the context of project management to capture both the sequence of and the technical relationships among design tasks. Browning [Browning 2001] suggested four different types of DSM: Component-based, task-based, parameter-based, team-based. Used for project performance measurement, the Earned Value Management (EVM) is a control method based on conversion of scope of work to budget terms. The basic idea behind EVM is comparing planned and actual work in order to determine budget and schedule propagation. EVM was elaborated in recent years and became an ANSI standard, which provides a forecast to a project's end along with indications of exceptions to the plan.

Object Process Methodology

The potential use of Object Process Methodology (OPM) [Dori 2000] for project planning and management has been recently studied in the context of the Project-Product Lifecycle Management (PPLM) framework [Sharon, Dori, & de Weck 2009; 2009A; Sharon, Perelman & Dori 2008]. The goal of the PPLM research is to develop a methodology for managing the lifecycle of the product to be developed hand-in-hand with the lifecycle of the project within the scope of which the product is developed.

OPM is a formal yet intuitive paradigm for systems architecting, engineering, development, lifecycle support, and evolution. It has been used for modeling natural and artificial complex systems, where artificial ones might comprise humans, physical objects, hardware, software, regulations, and information. As its name suggests, the two basic building blocks in OPM are (stateful) objects—things that exist (at some state), and processes—things that transform objects by creating or destroying them, or by changing their state. OPM serves as the underlying conceptual modeling paradigm and language for PPLM.

The PPLM approach facilitates a combined product-project model using a common ontology, a conceptual model, and supporting software environment. The expected value of such a holistic, integrated conceptual model is the provision of both superior product lifecycle engineering and project management capabilities, yielding significant cut in time to market, reduced risk, and higher product quality. Object-Process Diagram (OPD) is the graphic representation of an OPM model, which has also an equivalent textual representation. Figure 1 shows an Object-Process Diagram (OPD) of the UAV project model, which served as a case study in our research. Tasks are modeled as processes, denoted by ellipses, while deliverables are objects, modeled by rectangles, which can include specifications, drawings, approvals, reports and other document types, prototypes, simulation and analysis results, as well as the final product. Structural links include whole-part (the black triangle) connecting a whole to its part(s), and characterization (black-on-white triangle), connecting an object with its attribute(s).

Research Population and Setting

Our research aimed at exploring practitioners' perceptions of the adequacy of and the extent to which each one of the seven project management methods mentioned above effectively support the SEM effort. The research population consisted of 24 mid-career systems engineers from companies across the USA with 5-8 years of practice, who were among about 80 graduate students in the Systems Project Management course. During the spring 2008 course, the participants studied these project management methods and practiced them through targeted homework assignments, listed in Table 1.

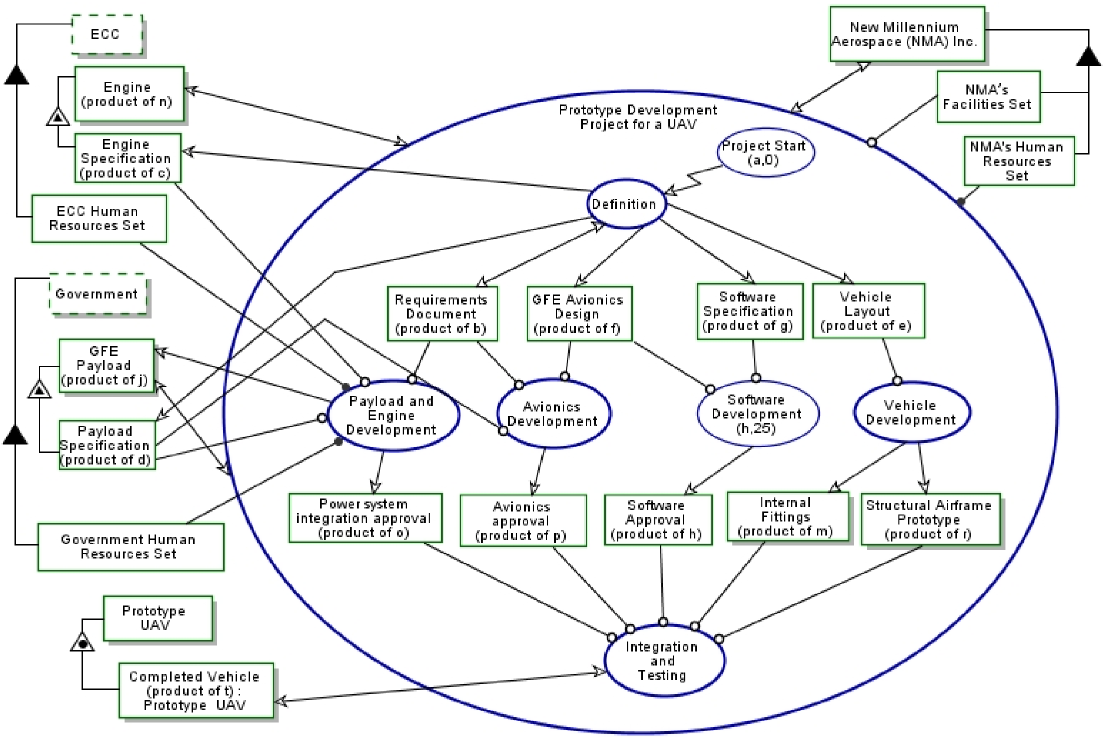

Figure 1 - Object-Process Diagram (OPD) of the UAV project

The entire student population was informed about HW5 being part of a research and non-mandatory. The 24 respondents elected to do HW5 and participate in the study. Some of their motivation was the option they were given of having their final grade based on the best five out of six homework assignments.

Table 1 - The seven investigated project management methods

Project management method – short name	System Dynamics	Program Evaluation and Reviewing Technique	Critical Path Method	Design Structure Matrix	Earned Value Method	Gantt chart	Object Process Methodology
Project management method – full name	SD	PERT	CPM	DSM	EVM	Gantt	OPM
Homework assignment	HW1	HW2	HW2	HW3	HW4	HW5	HW5

An Unmanned Aerial Vehicle (UAV) case study [de Weck & Lyneis 2008] served as a running case study for all of the homework assignments. This case study concerns a project of developing a UAV by a fictitious government-contracted leading UAVs manufacturer, *New Millennium Aerospace (NMA) Inc.* A rough specification and sketch of the UAV "pusher" vehicle concept was given to the students. For HW1, all the students were tasked with creating a simple SD model and exploring its behavior. They examined the impact of uncertainties in project assumptions on cost and schedule. In HW2, they created a project plan using CPM, drew a project graph, estimated the early finish time of the project and identified the critical path and slack times. Using PERT, they had to analyze the impact of changes in individual task times on the critical path and consider probability distributions of task times and their effect on the project schedule. HW3 called for applying DSM. For HW4, the students focused on tracking projects and computing the various metrics defined in EVM terms of cost and schedule in order to assess the overall performance of the project and to critically analyze and interpret the results. Finally, based strictly on the text given in HW2, HW5 called for creating two project plan versions, one using a Gantt chart model and the other using OPM. They were then asked to compare all the seven project management methods they had studied in the course with respect to a set of 14 project management factors, as described in the next section.

Research Methodology

Since the investigated project management methods were taught in the course during lectures and practiced through homework assignments, we assumed that the participants had identical knowledge of, and training level in, these methods.

Recognizing that systems engineering management entails both the product and the project viewpoints, we defined 14 factors that account for both major classical project management issues and aspects of the joint project-product ensemble, which is at the focus of Systems Engineering Management. These were introduced to all the participants in a random order, listed in Table 2. Four of the 14 SEM factors, categorized in the project dimension, are addressed by common project management methods: budget/schedule measurement/tracking, budget/schedule forecasting, resource management, and iterations management. Four other factors fit in the product domain: product planning, product measurement/tracking, product quality, and performance quality. The remaining six factors, categorized in the project-product dimension, are common to the combined product-project domain. The 24 research participants were instructed to rank each one of the 14 factors for each one of the seven systems engineering management methods using a Likert scale [Likert 1932] of 1 to 5, where 1 is poor, 2 is fair, 3 is good, 4 is very good, and 5 is excellent. N/A was denoted by 0.

The question posed to the participants was phrased as follows: "Please compare the project models or representations you have done so far as homework assignments, with respect to the 14 Project Management considerations. Wherever you believe a correlation exists between a model and a PM consideration, provide a short written explanation of the relationship and grade its strength numerically (between 1 and 5 as specified)."

Since the participants were practicing systems engineers, their views of the project management tools tended to reflect the application of these methods in systems engineering management more than in project management. To examine the participants' views of each project management method with respect to each factor, we compared the responses for each one of 14 factors with respect to each one of the seven PM methods. The students were not instructed in any way to think specifically of the considerations as related to "project," "product," or "project-product" dimensions. Our aim was to explore whether their unguided perceptions towards the 14 different factors would reflect recognition of these factors as related to our three predefined latent dimensions of "project," "product," and "project-product." To avoid any potential influence on the responses, in the instructions we elected to use the phrase "Project Management (PM) considerations" rather than "Systems Engineering Management factors," which might have diverted the respondents to go in the SEM direction.

Table 2 – The 14 Systems Engineering Management Factors

SEM Factor		Dimension
1	Budget/Schedule measurement/tracking	Project
2	Budget/Schedule forecasting	Project
3	Inter-relationships (process & product)	Project-Product
4	Resource management	Project
5	Stakeholders/agents tracking	Project-Product
6	Performance quality	Product
7	Product quality	Product
8	Product planning	Product
9	Product measurement/tracking	Product
10	Risk management	Project-Product
11	Iterations management	Project
12	Information resolution level	Project-Product
13	Ease of communication	Project-Product
14	Change management	Project-Product

To determine whether our classification of the 14 factors into the three latent domains can be verified by the research participants' responses, we first analyzed the grades they had given for each factor and method combination. Using Alpha Cronbach coefficient [Cronbach 1951] we determined whether the domain-categorized factors can be considered a dimension, namely project dimension, product dimension, and project-product dimension. The sum of all the participants' Likert scale rankings for each factor was calculated, and the sum of all 14 factors for each PM method was taken as that method's score. The variables for the Alpha Cronbach coefficients for each PM method were calculated from the Likert scale results for each group of factors defined for each domain: (a) The project domain, consisting of factors 1, 2, 4, and 11, (b) The product domain, consisting of factors 6, 7, 8, and 9, and (c) The project-product domain, consisting of factors 3, 5, 10, 12, 13, and 14. Additionally, we calculated the Alpha Cronbach coefficient also for a fourth potential dimension—the *combined* project-product domain, which is the combination of eight factors: the four project factors 1, 2, 4 and 11 and the four product factors 6, 7, 8, and 9.

Results and Analysis

Alpha Cronbach coefficient serves as a basis for comparing between the methods, initially using all 14 factors. The Alpha Cronbach coefficients, presented in Table 4, are higher than 0.70 for all but the Design Structure Matrix (DSM) method. Therefore we can use the participants' rankings for all the 14 factors for the sake of comparison between the six PM methods, from which DSM is excluded. When excluding two factors which are in the Project-Product latent domain—factor 12 (Information Resolution Level), and factor 3 (Inter-relationships, process & product)—DSM exceeds an Alpha Cronbach coefficient value of 0.7. Excluding these two factors for all the seven PM methods, we are left with a set of 12 factors that can be reliably used for the comparison of all the seven PM methods. Figure 8 represents by the dark bars the sum of scores of the 14 factors participants assigned for each method.

Table 4 - All Factors Set Reliability

Project Management Method	SD	PERT	CPM	DSM	EVM	Gantt	OPM
Full name	System Dynamics	Program Evaluation and Reviewing Technique	Critical Path Method	Design Structure Matrix	Earned Value Method	Gantt Chart	Object Process Methodology
Cronbach Alpha	.743	.793	.754	.640	.757	.760	.855
Best Improved	-	-	-	.702[1]	-	-	-

[1]Improved by deletion of factor 12 – Information Resolution Level and factor 3 - Inter-relationships (process & product)

OPM scored the maximum sum, 885 points. A cutoff value of 664 points, which is 75% of this maximum score, leaves us with three methods: OPM, SD, and EVM. The light grey bars in Figure 2 represent the sums of rankings of the 12 factors (where factors 3 and 12 are excluded). With these 12 factors, SD scored the maximum sum, 769 points.

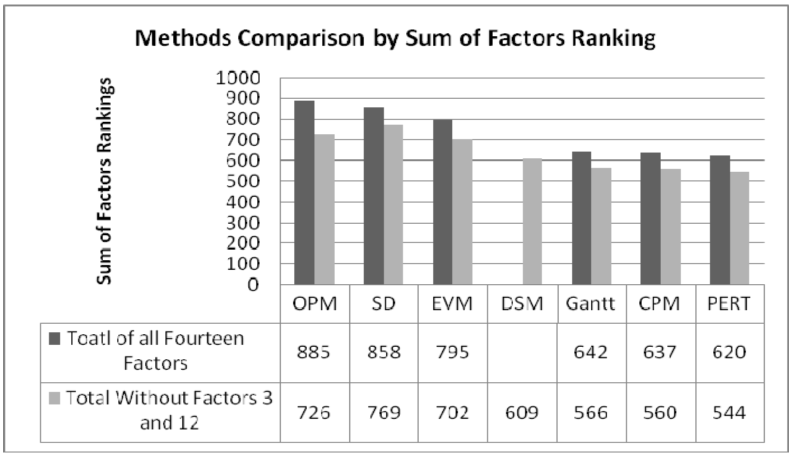

Figure 2 – Project management methods comparison by sum of factors rankings

Assigning a cutoff of 577, which is 75% of this maximum, leaves four methods in the game: OPM, SD, EVM, and DSM. The sum of all the participants' rankings for each factor was calculated, and the sum of the 12 factors for each PM method was taken as that method's final score. Alpha Cronbach coefficient for each PM method based on the participants' rankings for the four factors, 1, 2, 4, and 11, of the project latent domain is presented in Table 5. Since we evaluated *project* management methods, we expected an Alpha Cronbach coefficient with value of .70 or higher to be obtained for all the seven methods, indicating that the factors in the underlying project domain are handled by all the seven PM methods. Surprisingly, however, as Table 5 shows, such above-the-cutoff values were found only for four PM methods: SD, PERT, DSM, and OPM. The remaining three methods, namely CPM, EVM, and Gantt, did not pass the 0.70 Alpha Cronbach Coefficient cutoff acceptance value. Even for the best improved result, which was obtained by removing factor 11 – iterations management, these three methods still remain below the 0.70 cutoff value (see bottom line of Table 5).

Table 5 - The Project Dimension (factors 1, 2, 4, and 11)

Project Management Method	SD	PERT	CPM	DSM	EVM	Gantt	OPM
Full name	System Dynamics	Program Evaluation and Reviewing Technique	Critical Path Method	Design Structure Matrix	Earned Value Method	Gantt Chart	Object Process Methodology
Cronbach Alpha	.738	.700	.422	.744	.505	.511	.731
Best Improved	-	-	.608(1)	-	.512(1)	.613(1)	-

(1)Improved by deletion of factor 11 – Iterations Management

Applying a similar analysis for the product domain, we calculated the Alpha Cronbach coefficient for the four factors 6, 7, 8, and 9 of the product latent domain for each project management method. As Table 6 shows, the product dimension was found for three methods: SD, OPM, and DSM. The latter got in as having a product dimension only after removing factor 8 – product planning.

Table 6 - The Product Dimension (factors 6, 7, 8, and 9)

Project management method	SD	PERT	CPM	DSM	EVM	Gantt	OPM
Full name	System Dynamics	Program Evaluation and Reviewing Technique	Critical Path Method	Design Structure Matrix	Earned Value Method	Gantt Chart	Object Process Methodology
Alpha Cronbach	.775	.472	.402	-.343(1)	.414	.655	.746
Best improved	-	.486(3)	.601(2)	.725(2)	.560(4)	.678(5)	-

(1) The value is negative due to a negative average covariance among items.
(2) Improved by deletion of factor 8 – Product Planning
(3) Improved by deletion of factor 7 – Product Quality
(4) Improved by deletion of factor 9 – Product measurement/tracking
(5) Improved by deletion of factor 6 – Performance Quality

The project-product dimension was found to characterize only two methods: EVM and OPM (see Table 7). The results reflect the participants' perception that only these two methods have an underlying project-product latent dimension.

Table 7 - The Project-Product Dimension (factors 3, 5, 10, 12, 13, and 14)

Project Management Method	SD	PERT	CPM	DSM	EVM	Gantt	OPM
Full name	System Dynamics	Program Evaluation and Reviewing Technique	Critical Path Method	Design Structure Matrix	Earned Value Method	Gantt Chart	Object Process Methodology
Cronbach Alpha	.251	.535	.624	.523	.723	.605	.706
Best Improved	.435[1]		.687[1]	.579[1]	-	.651[1]	-

[1]Improved by deletion of factor 5 – Stakeholders/ agents tracking

In view of the small number of methods found for the project-product dimension, we also examined the combined project-product domain, namely the combination of four project factors 1, 2, 4 and 11 with the four product factors 6, 7, 8, and 9. While the "original" project-product domain is based on six dual-domain factors, the latter is a combination of eight factors of which four are "purely" from the project domain and four—from the product domain.

Table 8 - The Combined Project-Product Dimension

Project Management Method	SD	PERT	CPM	DSM	EVM	Gantt	OPM
Full name	System Dynamics	Program Evaluation and Reviewing Technique	Critical Path Method	Design Structure Matrix	Earned Value Method	Gantt Chart	Object Process Methodology
Cronbach Alpha	.807	.655	.565	.703	.524	.451	.826
Best Improved	-	.734[1]	.690[1]	-	-	.570[2]	-

[1] Improved by deletion of factor 8 – Product Planning
[2] Improved by deletion of factor 2 – Budget/Schedule forecasting

Although no such underlying dimension was predefined for the survey, the participants' rankings that yields Alpha Cronbach of 0.70 or higher might potentially reflect that the project and product dimensions are cognitively inseparable. The combined project-product dimension, presented in Table 8, was found for OPM, SD, DSM, and PERT. The latter became acceptable after elimination of factor 8 – product planning, even though for the product dimension it had not reached the cutoff value.

Methods comparison by dimension

Comparison of the seven PM methods by dimension can be conducted with the methods for which all dimensions were found – System Dynamics (SD), Design Structure Matrix (DSM), and Object Process Methodology (OPM). The comparison, presented in Table 9, is based on the sums of scores participants assigned to each factor for each project management method. Each sum was divided by the quantity of factors used for calculating that sum. The sum of all fourteen factors is not applicable for DSM since only by excluding factors 12 and factor 3 it passed the 0.70 threshold. The same rationale was followed for calculating the sums for the project-product and the combined project-product factors. The sum of the product factors was calculated for all three methods without factor 8 – product planning, since DSM got in as having the product dimension only after removing this factor.

Based on the data presented in Table 9, Figure 10 shows for each of the three methods in Table 9 the sum of scores participants assigned to that method for each one of the three dimensions. The values on the vertical axis represent the normalized total sum, which is the total sum divided by number of factors (see Table 9), for each project management method. The project dimension scores (darkest grey bars) are higher than the product dimension scores (lightest grey bars) for all the three PM methods. The scores of the combined project-product dimension (dark grey bars) are reasonably situated between the project and the product dimension scores. OPM scored the highest in three dimensions – project dimension, product dimension, and the combined project-product dimension. While for SD and DSM, the project-product dimension scores are higher than those of the combined project-product dimension, the result is reverse for OPM. This may indicate that the dimensions perception is more complex: for OPM, a project-product dimension is acceptable, but the separate project dimension and product dimension are not only acceptable, but also rank higher. For SD and DSM the perception of dimensions is reversed.

Discussion

Based on their practice and experience, practitioners tend to use the examined seven project management methods in practice for different purposes and in different contexts. This survey provides a set of reliable factors to be used as means for an educated methods comparison, as presented in Table 10. Because of the diversity of the SEM vocation and the wide range of practitioners' training and experience, it is very difficult, if at all possible, to find a group of systems engineers who are homogeneous in their knowledge and application of PM methods. Therefore, a reasonable research population for our purpose would be students at a graduate program, who are also practicing systems engineers, and are at about the same stage of their graduate studies at systems and management programs. Such is our research group of 24 mid-career systems engineers studying in the Systems Design and Management graduate program at MIT. Furthermore, in the specific course in which the research was conducted, the investigated project management methods were taught using the same system project case study—an Unmanned Aerial Vehicle—as the basis for all the assignments. This enabled us to assume identical knowledge of, and training level in, the examined methods, as well as non system-specific bias.

Table 9 - Sum calculations for comparison of methods by dimensions

		OPM	SD	DSM
Sum of all 14 Factors	Total Sum	885	858	N/A
	Divided by 14	63.2	61.3	N/A
Sum without Factors 3 and 12	Total Sum	726	769	609
	Divided by 12	60.5	64.1	50.8
Sum of Project factors (1, 2, 4, and 11)	Total Sum	214	299	226
	Divided by 4	53.5	74.8	56.5
Sum of Product factors (6, 7, and 9; without 8)	Total Sum	122	181	87
	Divided by 3	40.7	60.3	29.0
Sum of Project-Product factors (5, 10, 13, and 14; Without 3 and 12)	Total Sum	267	242	226
	Divided by 4	66.8	60.5	56.5
Sum of Combined Project-Product factors (1, 2, 4, 11 and 6, 7, 9)	Total Sum	336	480	313
	Divided by 7	48.0	68.6	44.7

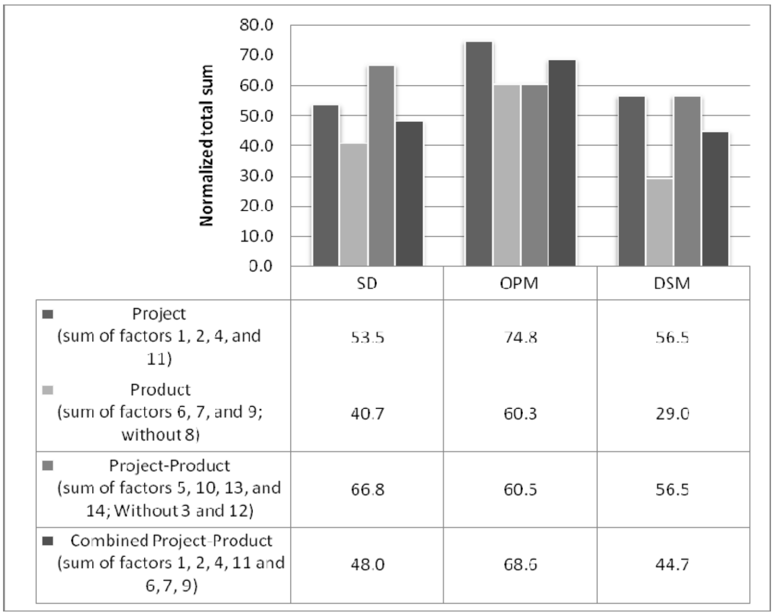

Figure 10 – Project management methods comparison by dimensions

Due to the required profile of the students in this program, the participants are not only students, but also practicing systems engineers in companies across the USA with 5-8 years of practice. Therefore, we consider the results to be reflecting the systems engineering management practice in a larger context. The cases where the latent dimensions were found acceptable indicate that the participants' rankings of the given factors reflect their perception of the factors as related to the defined dimensions. Although the participants were not instructed to group the factors in any specific way, they cognitively combined the factors in their minds in a way that three out of the seven examined methods—SD, DSM, and OPM—were found to handle well both the project dimension and the product dimension. The project-product dimension was also found acceptable for OPM, as well as for EVM. This dimension is composed of six factors which were defined as not directly associated with either the product alone or the project alone. For EVM, only the project-product dimension was found acceptable, but neither the project dimension nor the product dimension alone was found acceptable. Examining the elaborate responses participants provided along with their rankings, reveal that they consider EVM to be a project tracking method, while the other methods were perceived more suitable for project planning and less for progress tracking. While the three project management methods—SD, DSM, and OPM—have passed the 75% cutoff value for the sum rankings, for the defined factors, EVM also scored high enough to pass the 75% threshold.

Table 10 - Summary of methods comparison findings

Method Full name	System Dynamics	Program Evaluation and Reviewing Technique	Critical Path Method	Design Structure Matrix	Earned Value Method		Object Process Methodology
Pass of 75% cutoff for all 14 factors	ν	-	-	N/A	ν	-	ν
Pass of 75% cutoff for 12 factors	ν	-	-	ν	ν	-	ν
Project Dimension	ν	ν	-	ν	-	-	ν
Product Dimension	ν	-	-	ν	-	-	ν
Project-Product Dimension	-	-	-	-	ν	-	ν
Combined Project-Product Dimension	ν	ν	-	ν	-	-	ν

The "big" picture reflected by the results is that SD, DSM, EVM, and OPM were found to address SEM better than the other PM methods examined. These four methods can be considered as being project-product oriented rather than just project-oriented. Therefore, they are likely to have greater utility as methods for systems engineering management.

The fact that out of the four methods, only OPM was found suitable in all the three examined dimensions, is an indication that OPM might potentially become a common paradigm and language [INCOSE 2004] for communication among stakeholders and management of multidisciplinary teams of experts who are partners in the systems engineering management process. It is an encouraging finding within the Project-Product Lifecycle Management (PPLM) framework research aimed at developing a methodology for managing the lifecycle of the product to be developed hand-in-hand with the lifecycle of the project within the scope of which the product is developed.

Summary

This research has examined the suitability of seven project management (PM) methods for systems engineering management (SEM), as perceived by systems engineers, with respect to 14 factors. Since SEM is about handling and solving problems associated with the intricate relationships of the product with the project that delivers it, we classified the 14 factors into three domains: the project domain, the product domain, and a holistic project-product ensemble domain. Our research population, a group of 24 mid-career systems engineers studying in the Systems Design and Management graduate program at MIT, ranked the adequacy of each one of the seven examined project management methods to tackle each one of the 14 factors. The set of fourteen factors was found reliable for comparison of six out of the seven examined project management methods. After excluding two factors, a set of 12 factors was reliably used for comparison of all seven PM methods.

Using the participants' rankings, the three predefined dimensions were analyzed using Alpha Cronbach coefficient to examine the extent to which the participants perceived the 14 factors as domain-related. The findings support the notion of the project and the product as being two complementary facets involved in systems engineering management. Four project management methods—SD, DSM, EVM, and OPM—were found more suitable than the others for use in systems engineering management. These four methods were found to address the defined domains better than the other examined methods.

OPM was found the most suitable method both by dimensions analysis and ranking comparison analysis. The results may imply that OPM should be favorably considered as a suitable method for managing product-project ensembles within systems engineering management. Applying the Project-Product Lifecycle Management (PPLM) methodology, it might become the actual bridge between systems engineering and project management, enabling the simultaneous expression of the function, structure and behavior of both the project and the product within a holistic integrated conceptual model. OPM is currently in the process of becoming an ISO standard for enterprise standards. When completed, this endorsement will enable accelerated dissemination of OPM as a basis for enterprise standards in general and for PPLM in particular.

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