# Graduate Students' Perceptions of Computer-Based Project and Systems Engineering Management Methods


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**Abstract**

*Systems Engineering Management (SEM) is an emerging practice that is being developed hand in hand with the maturation of systems engineering. While classical project management (PM) focuses on scheduling, budgeting, and scope management, SEM emphasizes the management of the project-product ensemble. Standards for SEM and PM that account for the intimate relationships between these domains have been evolving, but most SEM application still use some subset of traditional PM methods and tools, including Gantt chart, Program Evaluation and Reviewing Technique (PERT), Critical Path Method, System Dynamics, Earned Value Method, and Design Structure Matrix. Object Process Methodology has also been studied as a vehicle for Project-Product Lifecycle Management. This research has examined how systems engineers perceive as graduate students the extent to which computer-based PM methods support SEM. Analyzing structured questionnaires using factors that cover both classical PM issues and the project-product interaction, we verified that project and product are indeed viewed as two complementary facets of SEM, and that certain PM methods address both domains better than others with respect to particular examined factors. This integrated approach is particularly suited to educating systems engineers in remote areas via distance learning since its simplified and unified approach caters to students' holistic comprehension of PM and SEM as two facets of the same complex system.*


## 1. Introduction

Systems Engineering (SE) and Project Management (PM) are two tightly intertwined domains. 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 (SEM) as the integration of technical management and the parts of project management related to systems engineering.

This research explored perceptions of graduate students who are systems engineering practitioners of the extent to which seven known computer-based project management (PM) methods effectively support the SEM effort.

## 2. Research Population and Setting

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, one of three core mandatory courses in the Systems Design and Management (SDM) program at MIT's Engineering Systems Division. During the spring 2008 semester course, they studied the seven project management methods surveyed above and practiced them through specific homeworks, as listed in Table 1. The 24 respondents elected to do HW5 and participate in the study to benefit from a mulligan opportunity – grading the homeworks based on the best five out of six homeworks.

**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, 2008] served as a running case study for all of the homework assignments. It was a project of developing a UAV, by an imaginary *New Millennium Aerospace (NMA) Inc*., a government-contracted leading UAVs manufacturer. A rough specification and sketch of the UAV "pusher" vehicle concept was given to the students, as is shown in Figure 1. The payload is provided by the government as modified government furnished equipment (GFE), while the engine is supplied by an established commercial company (ECC) under a subcontract.

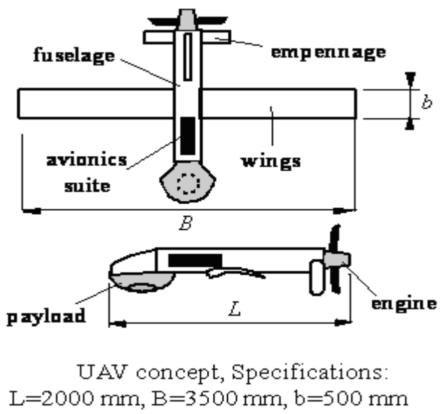


**Figure 1 – A rough specification and sketch of the UAV "pusher" vehicle concept**

For their first homework (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 the Critical Path Method (CPM), drew a project graph, estimated the early finish time (EF) 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. Students first translated the project graph from the previous assignment to a DSM representation. Next they added iterations to the project and analyzed their effect on the previous task sequence. They then had to consider partitioning the DSM to reveal meta-tasks. Finally, they estimated the effect of these changes on the critical path and estimated project completion time. 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 a previous homework assignment (HW2), HW5 called for creating two project plan versions, one using a Gantt chart model and the other using OPM [Dori, 2002]. 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.

## 3. 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. Furthermore, since the same system project case study—an Unmanned Aerial Vehicle—served as the basis for all the assignments throughout the entire course (except for the final projects), the experience students gained in applying all seven methods is free of system-specific bias.

### *6.1 The 14 project management factors and latent dimensions*

Recognizing that systems engineering management entails both the product and the project, 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 14 factors were introduced to all the participants in the same random order listed in Table 2.

Four of the 14 factors belong to the "classical" project management domain and are addressed by common project management methods. These include (1) budget/schedule measurement/ tracking, (2) budget/schedule forecasting, (3) resource management, and (4) iterations management. Four other factors fit in the product domain: (1) product planning, (2) product measurement/tracking, (3) product quality, and (4) performance quality. The remaining six factors are common to the combined product-project domain, as they cannot be uniquely associated with either the product alone or the project alone.

With respect to risk management, we adopted NASA's view of risk management as being common to both the project and the product domains [NASA, 2005]. This approach is founded on the premise that there are technical risks, which are mostly in the product domain, and managerial risks, which are mostly in the project domain, This is contrary to the approach of leading standards [ISO/IEC 15288, 2002; CMMI®, 2006], which view risk management primarily as a managerial issue and therefore relate to it as project domain issue.

**Table 2 – The 14 Systems Engineering Management Factors**

| Systems Engineering Management Factors | | Latent 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 |

*6.2 The survey questions and their analysis method*

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 homeworks, with respect to the following Project Management (PM) Considerations. Utilize the excel file entitled HW5 Q4 for this purpose. 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).*"

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' view of each project management method with respect to each factor, we compared the results received for each one of the 14 factors, in each systems engineering management method.

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 the latent dimensions of "project," "product," and "project-product". To this end we also chose to use in the instructions the phrase "Project Management (PM) Considerations" rather than "Systems Engineering Management Factors," which might have invoked their thought in the SEM direction.

To determine whether our classification of the 14 factors into the three domains—the *product* domain, the *project* domain, and the joint *project-product* domain—can be verified by the research participants' responses, we first analyzed the grades they had given for each factor and method combination. Alpha Cronbach Coefficient [Cronbach, 1951] was used to determine whether the domain-categorized factors can be considered a dimension, namely project dimension, product dimension, and a combined project-product dimension.

The Alpha Cronbach coefficient is used for estimating how well a set of variables measures a single one-dimensional underlying construct. It determines the internal consistency of items within a single test, indicating reliability. The reliability is in terms of the ratio between the true score variance of the "underlying construct" and the observed score variance of that one-dimensional construct, where the construct is the hypothetical variable that is being measured [52]. The Alpha Cronbach coefficient ranges in value from 0 to 1, when 0.70 is defined [53] as the cutoff value to be an acceptable reliability. It increases when the average inter-variables correlation increases. Therefore, high values of Alpha Cronbach provide evidence that the variables included in its calculation measure the same underlying construct. For this reason, Alpha Cronbach is often used in order to probe underlying constructs that the researcher wants to measure, as part of developing predicting variables and objective scales in surveys.

The variables for the Alpha Cronbach coefficient calculation were extracted from the Likert scale results and calculated 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 the four project factors 1, 2, 4 and 11 and the four product factors 6, 7, 8, and 9. The median of all the participants' rankings for each factor was calculated, and the sum of all 14 factors for each PM method was taken as that method's score.

## 4. Results and Analysis

We present and discuss the results of the participants' comparison of the seven project management methods they had studied, listed in Table 1, with respect to the 14 project management factors, listed in Table 2.

### *4.1 Methods Comparison by Factors*

Alpha Cronbach Coefficient was calculated for comparing between the methods with all 14 factors. The Alpha Cronbach coefficients, presented in Table 3, are higher than 0.70 for all but the Design Structure Matrix (DSM) method: System Dynamics (SD), Program Evaluation and Reviewing Technique (PERT), Critical Path Method (CPM), Earned Value Method (EVM), Gantt, and Object Process Methodology (OPM). Therefore we can use the participants' rankings for all the 14 factors for the sake of comparison between the six Project Management methods, from which DSM is excluded.

Figure 2 represents by the solid bars the sum of scores of the 14 factors participants assigned for each method. OPM scored the maximum sum, 885 points. Assigning a cutoff value of 664 points, which is 75% of this maximum score leaves us with three methods: OPM, SD, and EVM.

**Table 3 - 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 | | Object Process Methodology |
| **Cronbach's 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)

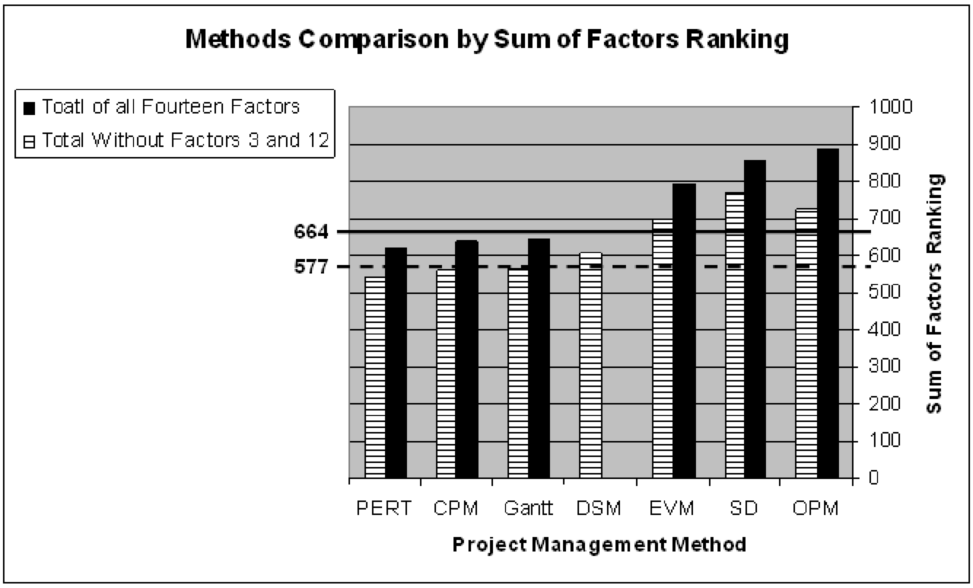


**Figure 2 – Project management Methods Comparison by Sum of Factors Rankings**

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. The dashed bars in Figure 2 present the sums of rankings of 12 factors. With these 12 factors, SD scored the maximum sum, 769 points. Assigning a cutoff of 75% of this value leaves four methods in the game: OPM, SD, EVM, and DSM.

Figure 3 shows for each of the three best methods the sum of scores participants assigned to that method for each one of the three dimensions. The project dimension scores (bars with vertical lines) are higher than the product dimension scores (bars with horizontal lines) for all three project management methods. The scores of the combined project-product dimension (bars with crosshatched lines) 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. 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.

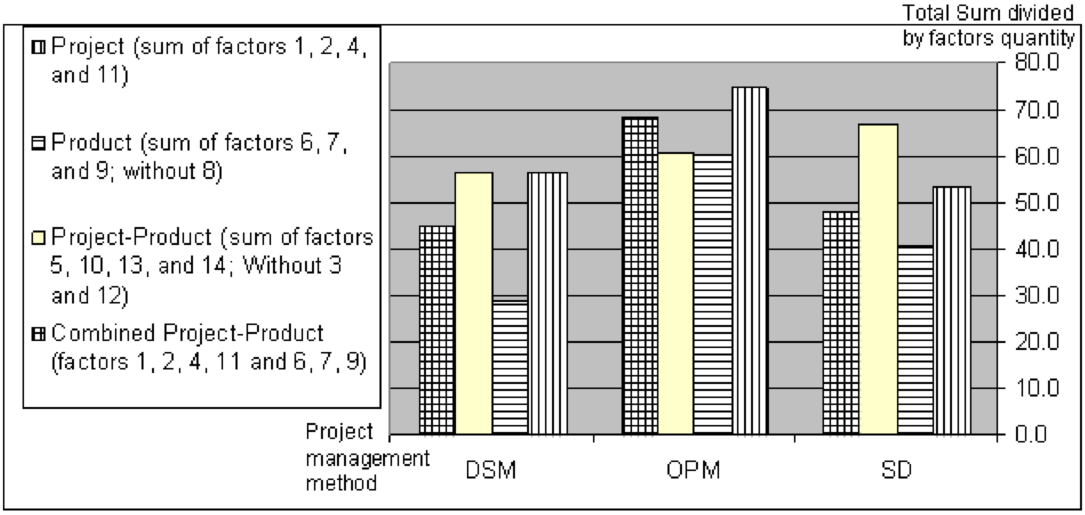


**Figure 3 – Project management methods comparison by dimensions**

## 5. Discussion and Summary

Since the research population contains a group of 24 mid-career systems engineers studying in the Systems Design and Management graduate program at MIT, the findings reflect their perceptions of the adequacy of each one of the seven project management methods to tackle each one of the 14 factors. We consider the results to be reflecting the systems engineering management practice in a larger context, since it the participants of this graduate program are also practicing systems engineers in companies across the USA with 5-8 years of practice.

Practitioners tend to use the examined seven project management methods in practice, for different purposes and in different contexts according to their perceived suitability based on their practice and experience. This survey provides a set of reliable factors to be used as means for an educated methods comparison.

This research has examined the suitability of seven project management methods for handling and solving problems associated with the project domain, the product domain, and the holistic project-product ensemble domain, as perceived by systems engineers. To this end, we defined 14 factors that were classified into one of these three domains. 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 project management methods to tackle each one of the 14 factors.

Considering 0.70 as the Alpha Cronbach coefficient cutoff acceptance value, the set of fourteen factors was found reliable to be used for the comparison of the seven project management methods. Assigning a cutoff of 75% of the maximum obtained score leaves four methods: SD, DSM, EVM, and OPM.

Three latent dimensions were predefined: the project, the product, and the project-product dimension. Using the participants' rankings, these 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. Three project management methods—SD, DSM, and OPM—were found more suitable than the others for use in systems engineering management. These three methods were found to address the project and product domains better than the other examined methods, both by dimensions analysis and ranking comparison analysis, with OPM scoring the highest in the methods comparisons.

This integrated approach is particularly suited to educating systems engineers in remote areas via distance learning since its simplified and unified approach caters to students' holistic comprehension of PM and SEM as two facets of the same complex system. Moreover, people primarily from developing countries whose first concern is use of technology to help deliver quality education to under-served sub-populations can benefit from this approach in particular. By integrating the seven project management methods, these methods and tools are derivable from the same unifying OPM model, simplifying not only the comprehension of the system and control of the project, but also the delivery of solid, model-grounded education to doers and practitioners anywhere in the world.

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