# PLM Software Selection Model for Project Management Using Hierarchical Decision Modeling with Criteria from PMBOK Knowledge Areas

James Eastham, David Tucker, Sumir Varma, Scott Sutton

Dept. of Engineering and Technology Management, Portland State University, Portland, OR - USA

*Abstract*--this paper presents a methodology for product lifecycle management (plm) software selection utilizing the nine knowledge areas of the project management body of knowledge (pmbok). The methodology utilizes a five process gate approach where the plm offerings are researched, sorted, paired down, evaluated, and implemented. The primary decision model utilizes hierarchical decision modeling (hdm). Prioritizations are assigned to the pmbok knowledge areas utilizing a pair-wise comparison survey and then assessed across the different plm system offerings. The proposed decision methodology is meant to serve only as a guide to assist with selection of plm software from a project management perspective. To validate the model, several case studies are presented that apply the selection methodology to different industries: semiconductor, information technology (it), and automotive supply.

## I. INTRODUCTION

Product Lifecycle management (PLM) is the integration of several tools within an organization to help streamline all of the activities in the product development lifecycle. PLM systems help to create a common platform for product development and improve communication and collaboration throughout an organization [1].

PLM systems originated with the introduction of Computer Aided Design (CAD) and the Product Data Management (PDM) systems in the 1980's [2]. A decade later formal PLM systems were introduced, positioned as a cradle to grave solution for product development. During this period PLM expanded beyond the product based elements of CAD and PDM; including elements of other essential product development systems such as [1]:

- Computer Aided Engineering (CAE)
- Computer Aided Manufacturing (CAM)
- Customer Relationship Management (CRM)
- Supply Chain Management (SCM)
- Enterprise Resource Planning ERP

The PLM systems of today include many additional features and integrated components including elements to support strategic capabilities, design capabilities, data management capabilities, collaborative capabilities, and foundational capabilities [3]. The following table provides a summary of the features commonly available in PLM systems offerings today.

TABLE 1: PLM FEATURES OVERVIEW

| Strategic Capability | Design Capability | Data Management Capability | Collaborative Capability | Foundational Capability |
|---|---|---|---|---|
| Product Strategy | Design Collaboration | BOM | Supply Cain | Component & Materials Management |
| Product Roadmaps | Software Dev. | Specifications | Sourcing & Cost Management | Engineering Change Management |
| Product & Portfolio Management | Quality Assurance | Configuration Management | Sales & Service Management | Document Management |
| Idea Management | Requirements Management | Operations Mgmt. | | |
| Stage Gate Management | | Software Programs | | |
| Program Management | | Asset Management | | |
| | | Assembly/Packaging | | |
| | | Reliability & Qualification | | |
| | | Testing data | | |
| | | Compliance & Regulatory | | |

## II. PROJECT MANAGEMENT AND PLM SOFTWARE

The Project Manager has an important role in an organization and in product development as they facilitate the entire project. In this critical role, it is imperative to be integrated with the environment to where the product is created and implemented [24]. Specifically, the project manager needs to formulate and implement plans that guide a project through its lifecycle. The use of PLM systems to support the project management activities in a meaningful and integrated way would help support efficiency of the organization.

However, the PLM system needs to support the project management activity while concurrently integrating with the company's systems and environment. To support this, several frameworks were researched on structured methodologies and approaches for selection of Product Development and Project Lifecycle Management systems.

Many commercial solutions are available for PLM today that can either be complete packages or integrated solutions. As indicated by Ameri and Dutta, PLM is different from other technological purchases that an organization will embark on because the organization needs to have a strategy for the implementation of the system and integration with other processes [1]. The following figure identifies some of the systems that are available today.

This paper looks to solve some of the selection questions around PLM systems by developing a framework for selection a PLM system from the perspective of the Project Manager. This analysis will "Focus on the process, not the provider", as indicated by Jusko in choosing the right PLM Provider [4]. For the analysis and selection model for PLM software focused on Project Management, the same methodology will be utilized.



Fig. 1: PLM Products Available

The literature provides some guidelines for generic scoring of PLM options, as well as critical areas that a company should examine for each of the PLM software candidates. To better accommodate the selection of PLM with respect to Project Managers perceptive and work function groups it was decided to utilize the knowledge areas in the Project Management Body of Knowledge (PMBOK) as the criteria for selecting the PLM systems that best addresses the need of the Project Manager. The following table identifies the knowledge areas of the PMBOK and provides the corresponding definitions for each area.

To support the usage of the PMBOK knowledge areas for the criteria selection of PLM software the existing body of knowledge was researched and the corresponding mapping or classification that occurs was identified. The following figure illustrates the linkage and overlap between the published selection criteria and the corresponding PMBOK knowledge areas [19].

TABLE 2: PMBOK KNOWLEDGE AREA DEFINITIONS

| Knowledge Area | Definition |
|---|---|
| Integration | Integration management includes all of the elements that are necessary to unify the project and combine all of the other areas of management together into a cohesive manageable project [5]. |
| Scope | Scope management ensures that the project contains all of the work required to execute the project. It notes that only the work that is part of the project can be included in the scope of the project, anything in excess to the scope should not be included [6]. |
| Time | Time management is the process of developing the master timeline for the project and includes all of the necessary processes to develop and maintain a clear and concise timeline [7]. |
| Cost | Cost management includes all the necessary activity to estimate and manage costs on a project [8]. |
| Quality | Project Quality Management includes all the activities needed to determine and guarantee that the final product meets the customer's satisfaction throughout the planning process and into production of the product [9]. |
| Human Resources | Project Human Resource Management entails the processes that plan for and lead the project team throughout the project lifecycle [10]. |
| Communication | Project Communication Management includes the processes required to ensure communication between the team members and stakeholders during the life of the project [11]. |
| Risk | Risk Management includes all of the processes required to identify and assess risks on a project, including mitigation planning if required [12]. |
| Procurement | Procurement Management includes all the necessary processes required to plan for the sourcing and purchasing of items required to implement a project into production [13]. |

| Existing Body of Knowledge | Research Criteria | Integration Management | Scope Management | Time Management | Cost Management | Quality Management | Human Resource management | Communication Management | Risk Management | Procurement Management |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **PMBOK Knowledge Areas** | | | | | | | | |
| Choosing the Right Mgmt. Software [21] | Time Analysis | | | ■ | | | | | | |
| | Resource Analysis | ■ | | | | | ■ | | | |
| | Cost Analysis | | | | ■ | | | | | |
| | Performance / Cost Reporting | ■ | | | ■ | | | ■ | | ■ |
| | Local Structures (WBS, Resource) | | ■ | | | | ■ | | | |
| | Multiple Project Capabilities* | | | | | | | | | |
| | Project Tracking | ■ | | ■ | | | | | | |
| | Charting (activity mapping) | | | ■ | | ■ | | | | |
| Software PM Tools: Making a Practical Decision Using AHP [22] | Task Scheduling | | | | | | | | | |
| | Resource Management | ■ | | | | | | | | |
| | Collaboration | | | | | | | ■ | | |
| | Time Tracking | | | ■ | | | | | | |
| | Estimating | | ■ | ■ | ■ | | | | | |
| | Risk Assessment | | | | | | | | ■ | |
| | Change Management | ■ | ■ | | | | | | | |
| | Reporting / Charts | | | | | | | ■ | | |
| | File Attachment | | | | | | | ■ | | |
| | E-mail notification | | | | | | | ■ | | |
| | Process/Methodology | ■ | | | | | | | | |
| | Portfolio Management** | | | | | | | | | |
| Using General System Approach for PLM Software Selection & Evaluation [23] | General administration | | | | | | ■ | ■ | | |
| | Product architecture & integration | ■ | | | | | | | | |
| | Ability to Integrate applications | ■ | | | | | | | | |
| | Product data management | ■ | | | | | | | | |
| | Document management | ■ | | | | | | ■ | | |
| | Information storage | | | | | | | ■ | | |
| | Workflow & event management | | | | | | ■ | | | |
| | Sourcing | | | | | | | | | ■ |
| | Product transition | ■ | | | | | | | | |
| | Product development | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| | Change Management | ■ | | | | | | | | |
| | Requirements Management | | ■ | | | | | | | |
| | Visualization tools | | | | | | | ■ | | |
| | Project Management planning & management | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |

\* Propose using the PMI Standard for Program Management

\*\* Propose Using the PMI Standard for Portfolio Management

Fig. 2: Current Body Of Knowledge And The Pmbok Knowledge Areas

As indicated by the above figure, the current body of knowledge for selecting PLM systems corresponds with the knowledge areas of the PMBOK. Strong linkages exist for the areas such as integration and communication, followed by the "iron triangle of project management": scope, time, and cost.

III. STAGE GATE SELECTION MODEL

To accommodate the process of building a decision model for PLM selection, the paper proposes a Stage Gate Process Model where the selection process is driven by the functional requirements of the of the PMBOK knowledge areas. PLM offerings are narrowed to recommendation through multiple gates that reduce the pool of alternative systems until a single concise selection is implemented.

The following figure illustrates the stage gate process that is proposed by this analysis. Each of the process gates will be discussed individually below.
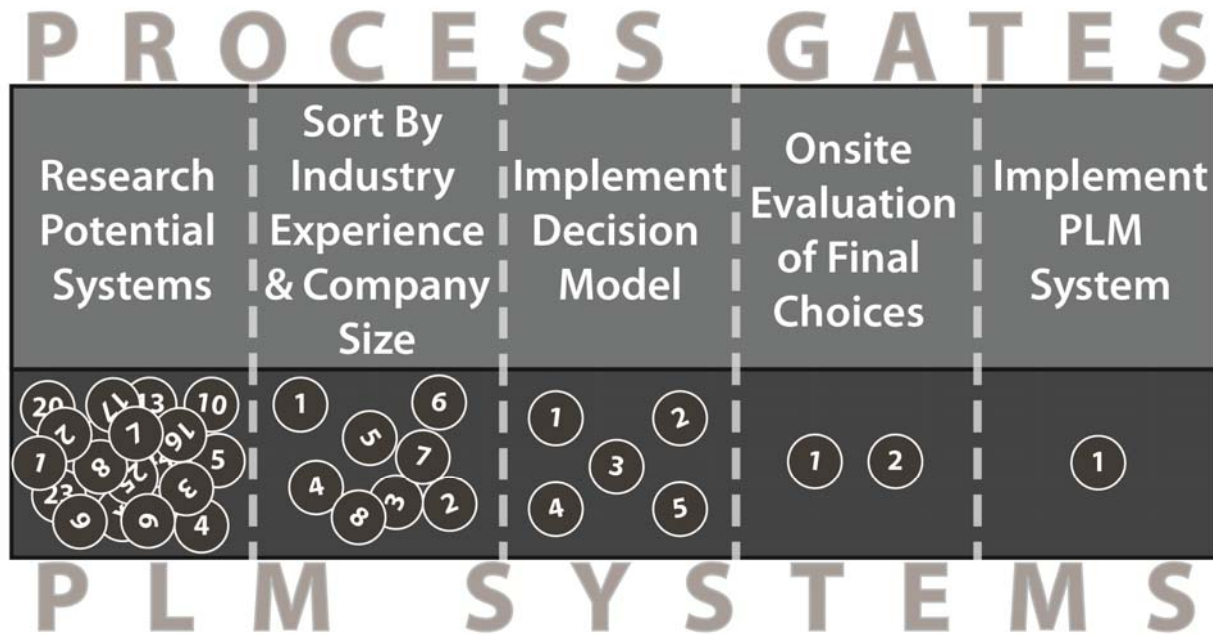
Fig. 3: Stage Gate Process and Methodology

The stage gate process as defined includes stage details in Table 3.

*A. Stage 1: Plm Offering Research*

The first stage in the selection process involves market and benchmarking research on the different systems that are available. This phase can be very time consuming as there are many offerings that change rapidly. The usage of standard internet search engines was used for the collection of PLM products that were analyzed for this project. It is recommended to keep a running log in a spreadsheet to document the web address and contact information for the different manufactures as this process yields many alternative systems.

*B. Stage 2: Initial Screening*

The second stage of the selection process involves in-depth research of each alternative system, with emphasis placed on whether or not a given vendor professed experience with a given industry and the size of firm the offering was tailored. M. Liberatore and B. Pollack-Johnson's research finds firm size is the number one environmental factor influencing the selection of PM software [14]. Experience in the given industry was selected as part of the screening process as to benefit from the added experience and lessons learned of prior implementations. Only PLM options with specific experience in a given industry and size made it through the initial screening process. The screening process flow chart is shown in the following figure.

TABLE 3: STAGE GATE PROCESS DESCRIPTION

| Stage | Description |
|---|---|
| Stage 1: | Research Potential Systems<br>During this phase it is recommended to compile as many offerings in the PLM market as possible organizing information on the target industry type, company size, and how the software satisfies the PMBOK knowledge areas. |
| Stage 2: | Sort by Industry Experience and Target Company Size<br>Filter the offerings by target industry and company size down selecting the initial offering PLM systems that apply to the industry and business category desired. |
| Stage 3: | Implement Decision Model<br>Use a decision model that weights the importance of the knowledge areas of the organization to the features of the PLM systems. A model and methodology will be proposed for this selection below. |
| Stage 4: | Onsite Evaluation of Final Choices<br>The top winners of the selection model should be contacted for discussion on implementation plans, costs, infrastructure required, and anything other detail required for evaluation |
| Stage 5: | Implement PLM System<br>Work with PLM provider on implementation project management. |
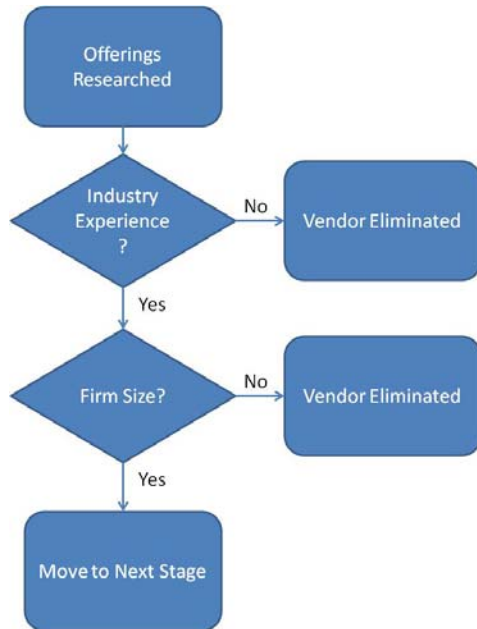
Fig. 4: Initial Down Selection Process

A summary of the industry experience research and company size experience is shown in Fig. 5 and Fig. 6. Based on guidelines published by the Small Business Administration [20], target sizes were categorized as small, medium, and large based on employee sizes of <100, 101-999, and 1000 and greater, respectively.

Hierarchical Decision Modeling was used to further down select the PLM offerings. The HDM model is shown in Fig. 7.

This screening was based on pair-wise comparison weighting of the nine PMBOK knowledge areas as described in the introduction. A survey was created in MS-Excel and distributed to Project and Program Managers in an electronic format. This survey contained the nine pair-wise comparisons. Fig. 8 shows an example of the survey for the integration knowledge area.

| Name | Industry | Aras Innovator | Windchill | Omnify Empower PLM | ActionWorks | CMPRO | Notixia eShop | XVL Studio | CA Clarity | Alibre Design | PowerSteering Enterprise | Accolade | Planisware 5 | Complete Configurator | Planview Enterprise Product Portfolio Management | Portfolio Intelligence | Infor PLM Optiva | Journyx ProjectXecute | Korrigo | Agile 9.2 | Team Center | SAP PLM | PLM 360 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry Experience | Semiconductor | X | X | X | X | | | | X | | X | X | | | X | | X | | | X | X | X | X |
| | Automotive | X | X | | X | | X | X | X | X | X | X | X | | X | | X | | | X | X | X | X |
| | IT | X | X | X | X | | X | X | X | | X | X | X | | X | | X | X | | X | X | X | X |

Fig. 5: Company Size Experience of PLM Offerings

| Name | Industry | Aras Innovator | Windchill | Omnify Empower PLM | ActionWorks | CMPRO | Notixia eShop | XVL Studio | CA Clarity | Alibre Design | PowerSteering Enterprise | Accolade | Planisware 5 | Complete Configurator | Planview Enterprise Product Portfolio Management | Portfolio Intelligence | Infor PLM Optiva | Journyx ProjectXecute | Korrigo | Agile 9.2 | Team Center | SAP PLM | PLM 360 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Target Company Size (Employee) | Small (Less than 100) | | | X | | | | | | | | | | | | | | | X | X | X | X | X |
| | Medium (101-999) | X | X | X | X | X | X | X | X | X | X | | X | X | | X | X | X | X | X | X | X | X |
| | Large (More than 1000) | X | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X |

Fig. 6: Firm Size Experience of PLM Offerings
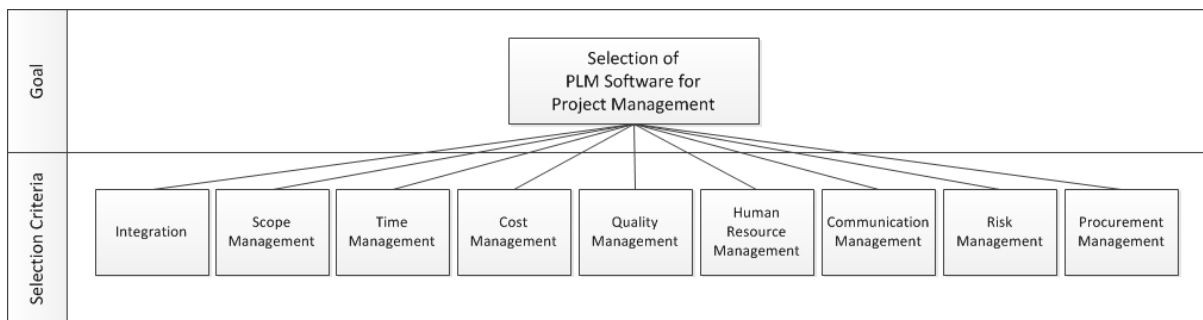


Fig. 7: HDM Model for Stage 3 Selection

| Level #1 | | | |
|----------|-------|-------|--------|
| Item #1 | Score | Score | Item #2 |
| Integration | 30 | 70 | Scope |
| Integration | 70 | 30 | Time |
| Integration | 20 | 80 | Cost |
| Integration | 70 | 30 | Quality |
| Integration | 90 | 10 | Human Resources |
| Integration | 40 | 60 | Communication |
| Integration | 50 | 50 | Risk |
| Integration | 40 | 60 | Procurement |

Fig. 8: Pair-Wise Survey Example

Each expert was asked to compare each of the pairs, assigning a ratio between comparative contributions of each element of the pair to the goal of PLM selection such that the total for each pair equaled 100 (MOGSA approach) [15]. As indicated in Fig. 8, Integration was not viewed as important as Scope as the participant scored the relative ratio 30/70, with scope being most important and the total equaling 100. The software program PCM Software v1.3, developed by Bruce J. Bailey, was used to calculate all the pair-wise weights [16]. A screenshot from the software output is shown in Fig. 9. The example shows the names for each participant along the left (rows) and the knowledge areas along the top (columns). The software calculates overall statistics such as mean, minimum, maximum, standard deviation, and inconsistency for each comparison.

Inconsistency in pair wise comparison is a gauge of how consistent, or reliable, the participant was in their assignments. A common approach is to remove/omit results which are found to be inconsistent based on the inconsistency calculation [17]. Inconsistencies were calculated for each survey based on the following:

*Inconsistency*

$$= \sqrt{\frac{1}{9}[(\sigma_{cA})^2 + (\sigma_{cB})^2 + (\sigma_{cC})^2 + (\sigma_{cD})^2 + (\sigma_{cE})^2 + (\sigma_{cF})^2 + (\sigma_{cG})^2 + (\sigma_{cH})^2 + (\sigma_{cI})^2]}$$

Where:
cA: Criteria A, Integration
cB: Criteria B, Scope
cC: Criteria C, Time
cD: Criteria D, Cost
cE: Criteria E, Quality
cF: Criteria F, Human Resources
cG: Criteria G, Communication
cH: Criteria H, Risk
cI: Criteria I, Procurement
σ: Standard Deviation of the Pair Wise Normalized Values

Using Saaty's Analytic Hierarchy Process [18] as a guide, the team decided to omit participant results which were greater than 10% in the case studies below. All other surveys were considered valid. Once the pair-wise weights for each knowledge area were calculated and any inconsistent surveys omitted, an overall average weight was calculated for each firm for each area as shown below:

$$w_k = \frac{\sum_{i=1}^{N} P_{i,k}}{N} \quad \forall k$$

Where:
$w_k$: *Average firm weight for knowledge area k*
$P$: *Weight for Participant i for knowledge area k*
k: *Knowledge area (1 through 9)*
i: *Participant number*
N: *Total participants for firm*

```
================= R e l a t i v e   W e i g h t s =================
                      Project Title: ETM545

Users        1    2    3    4    5    6    7    8    9    Incn
Mark       0.15 0.05 0.22 0.20 0.07 0.06 0.13 0.07 0.06 0.084
Patty      0.11 0.13 0.09 0.11 0.11 0.08 0.14 0.12 0.10 0.021
Sepideh    0.10 0.16 0.19 0.01 0.14 0.05 0.14 0.17 0.05 0.078
Bashkar    0.10 0.22 0.08 0.04 0.11 0.11 0.20 0.08 0.06 0.051
Cheryl     0.08 0.12 0.13 0.12 0.08 0.05 0.15 0.12 0.14 0.051
Arthur     0.23 0.18 0.18 0.05 0.06 0.05 0.07 0.10 0.08 0.028
Mean       0.13 0.14 0.15 0.09 0.09 0.07 0.14 0.11 0.08 0.048
Min        0.08 0.05 0.08 0.01 0.06 0.05 0.07 0.07 0.05
Max        0.23 0.22 0.22 0.20 0.14 0.11 0.20 0.17 0.14
Std Dev    0.05 0.06 0.06 0.07 0.03 0.03 0.04 0.04 0.03



 ESC=Exit, F1=Help, F2=Name/Items, F3=Save, F4=Display, ←┘=Pairs.
```

Fig. 9: PCM Software Output Example

A binary score was derived for the knowledge areas for each PLM offering by researching each offering. A zero (0) or one (1) was assigned as shown in the example in Fig. 10. If the team felt the PLM offering, based on researching the vendor's published materials, satisfied a given knowledge area, a one was assigned, if not a zero was assigned. As highlighted in the conclusion section, a more sophisticated and finer scoring method is recommended; the team used a binary method in an effort to validate the model.

Using the firm average weights along with the binary scoring for each functional group, a total score was calculated for each PLM offering.

$$PLM_k = \sum_{i=1}^{9} w_i \cdot s_i \quad \forall k$$

Where:

$w_i$: $Average\ firm\ weight\ for\ knowledge\ area\ i$
$PLM_k$: $Overall\ score\ for\ PLM\ offering\ k$
$s_i$: Score for PLM software for knowledge area i (zero or one)
i: PMBOK knowledge area

This final score, $PLM_k$, was used to downselect the PLM offerings with the highest scores considered for evaluation (next stage) and the lowest scores resulting in elimination of the offering from consideration. Fig. 11 shows a model output example, with each PLM offering overall score.

FIG 10: BINARY SCORING FOR PLM OFFERINGS FOR EACH PMBOK FUNCTIONAL GROUP

| | Criteria | | Aras Innovator | Windchill | Omnify Empower PLM | ActionWorks | CMPRO | Notixia eShop |
|---|---|---|---|---|---|---|---|---|
| | Name | Definition | by Aras Corp. | by PTC | by Omnify Software | by Action Technologies Inc. | by Professional Systems Associates | by Notixia |
| PMBOK Functional Groups | Integration Management | This process coordinates the other areas to work together throughout the project. | 1 | 1 | 1 | 1 | 1 | 1 |
| | Scope Management | is a set of processes used to ensure that the project includes all of the requirements and no new requirements are added in a way that could harm the project. | 1 | 1 | 0 | 0 | 1 | 0 |
| | Time Management | involves processes to ensure that the project is completed on schedule. | 1 | 0 | 1 | 0 | 0 | 0 |
| | Cost Management | involves processes to ensure that the project is completed on budget. | 1 | 0 | 1 | 0 | 1 | 0 |
| | Quality Management | ensures that the project meets its requirements, or does what it is expected to do. | 1 | 1 | 1 | 1 | 0 | 1 |
| | Human Resource management | includes all of the processes used to develop, manage and put the project team together. | 1 | 0 | 0 | 0 | 0 | 0 |
| | Communication Management | determines what information is needed, how that information will be sent and managed, and how project performance will be reported. | 0 | 0 | 0 | 0 | 0 | 1 |
| | Risk Management | involves identifying, managing and controlling risk of a project. | 1 | 1 | 0 | 0 | 0 | 0 |
| | Procurement Management | is the group of processes used to acquire the materials and services needed to complete the project. | 1 | 0 | 0 | 0 | 1 | 1 |
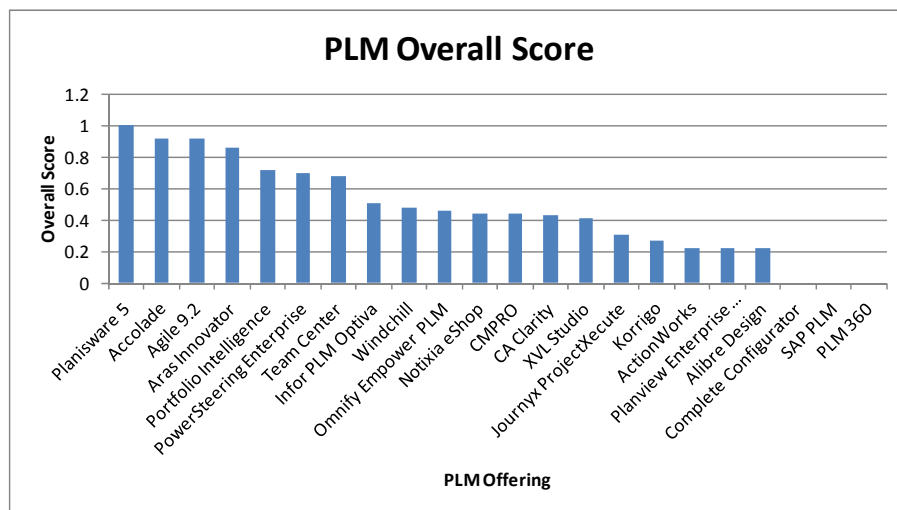


Fig. 11: PLM Offering Overall (Total) Score Example

*C. Stage 4: Evaluation & Final Selection*

The fourth stage of selection involves the contacting of the top scorers of the HDM stage four selections and completing rigorous on-site evaluation. During this phase it is recommended to discuss elements such as integration with current infrastructure, similar products, implementation planning, technical support, knowledge of current cost of the system, and other items that are important to the individual organization. The best case scenario for the fourth stage would be trial run evaluations on several products in which the project managers of the organization could evaluate the software services in the actual environment. Final selection could then be based these evaluations.

IV. MODEL RESULTS & VALIDATION:
SEMICONDUCTOR CASE STUDY

A medium sized semiconductor firm was selected as a case study for model validation. As described in the sections above. PLM offerings which did not have experience in the semiconductor industry as well as offerings which were not experienced with the firm size were omitted. The initial screening removed about 1/3 of the offerings from further evaluation. The offerings removed were: CMPRO, Notixia eShop, XVL Studio, Alibre Design, PowerSteering Enterprise, Accolade, and Planview Enterprise.

Six experts were surveyed from the semiconductor company. These participants were all in a Project Manager or Program Manager role. Each participant had many years of experience, and three were PMP certified. Standard deviations were calculated and analyzed during the pair-wise process to see if any outliers existed. The control chart is shown in Fig. 12. No survey results were excluded based on this analysis.

Pair-wise average results for the semiconductor case are shown in Fig. 13. Time, scope, communication, integration, and risk (in order) were given the top highest weights, followed by quality, procurement, scope, and human resources. Based on discussions with the participants, time scored the highest as time to market for the market sector this company competes in is more important than other factors like cost. If products are delayed they can miss entire market opportunities which can results in overall product volume decreases of millions of units. Scope also scored high because the company must develop products in parallel with customers, often creating custom components for customers. It is not uncommon for customers to change their specifications mid-stream during development. Communication scored high because the company relies on global teams for product development. Communication across different sites is often difficult due to time zone, location, and functional organizational issues.
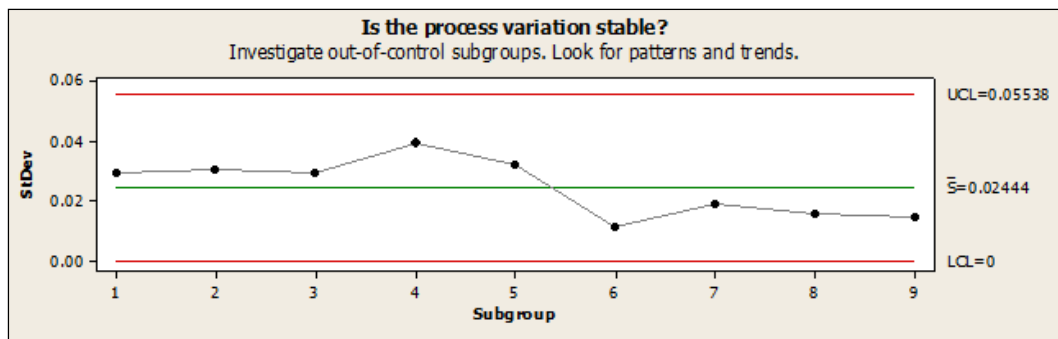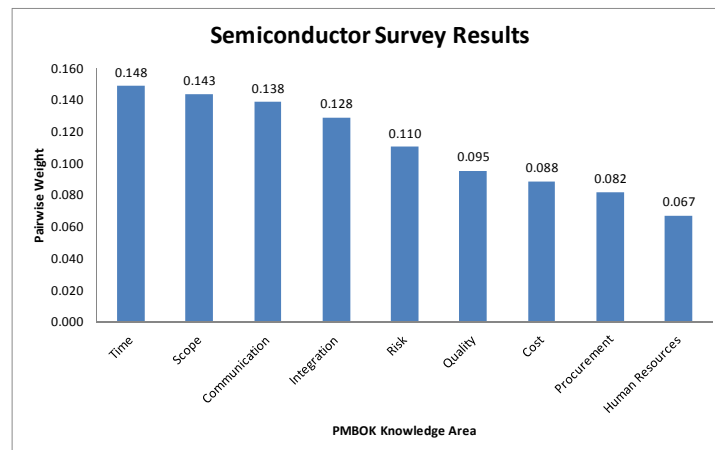


Fig. 12: S Control Chart



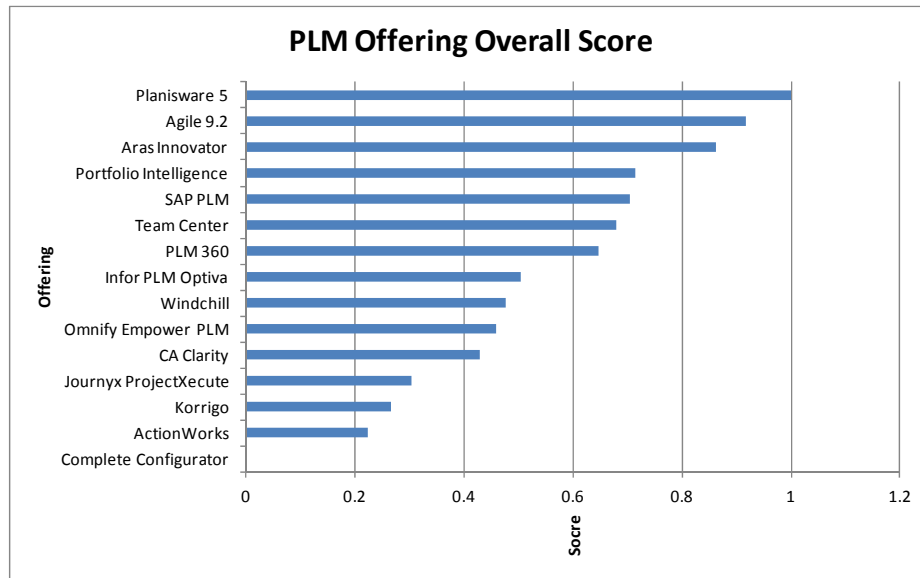Fig 13: Semiconductor Pair-Wise Survey Results

Fig. 14: PLM Offering Overall Score for Semiconductor Company

PLM scoring was calculated using the weights and method discussed in the section above. Based on the selection process, the top three choices (in order) were: Planisware 5, Agile 9.2, and Aras Innovator. The number of offering which could move to the evaluation stage would depend on how many options the firm could reasonably evaluate. At a minimum, the top three should be evaluated. Fig. 14 shows the overall relative scoring for each offering. Appendix B shows a scoring rollup with shaded cells for offering areas which scored a zero.

## V. MODEL RESULTS & VALIDATION: AUTOMOTIVE CASE STUDY

The automotive company selected for the case study was a medium sized firm. Omnify Empower, CMPRO, Complete Configurator, Portfolio Intelligence, Journyx, and Korrigo were omitted from further consideration based on the initial screening criteria (i.e. firm size and offering experience). Three experts were surveyed for the automotive case study. Upon analyzing the survey weight, one survey warranted further analysis as the results were notably different from the others. Fig. 15 shows a summary of the calculations. This survey was excluded from the analysis.

Pair-wise survey results are shown in Fig. 16. Cost, scope, quality, communication, and time were the top five weights, followed by risk, integration, human resources, and procurement (in order). In talking to the company, it was clear that cost is the biggest challenge with product development, which validated the pair-wise results. Product lifecycles are very long and the market is very cost competitive. Scope followed next, and reinforced the feedback that scope changes can have a huge impact on product development.

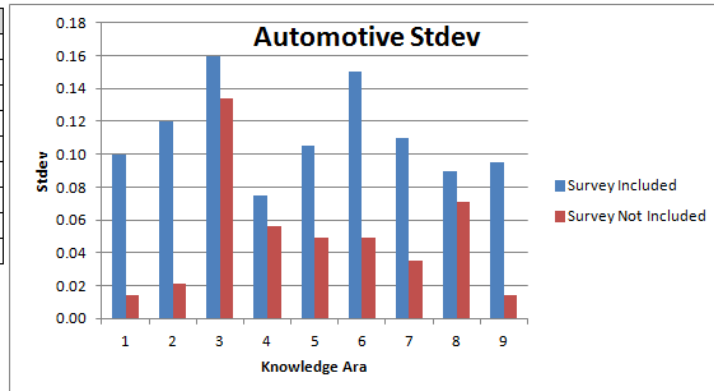| Knowledge Area | Survey Included | Survey Not Included |
|---|---|---|
| Integration | 0.10 | 0.01 |
| Scope | 0.12 | 0.02 |
| Time | 0.16 | 0.13 |
| Cost | 0.08 | 0.06 |
| Quality | 0.11 | 0.05 |
| Human Resources | 0.15 | 0.05 |
| Communication | 0.11 | 0.04 |
| Risk | 0.09 | 0.07 |
| Procurement | 0.10 | 0.01 |



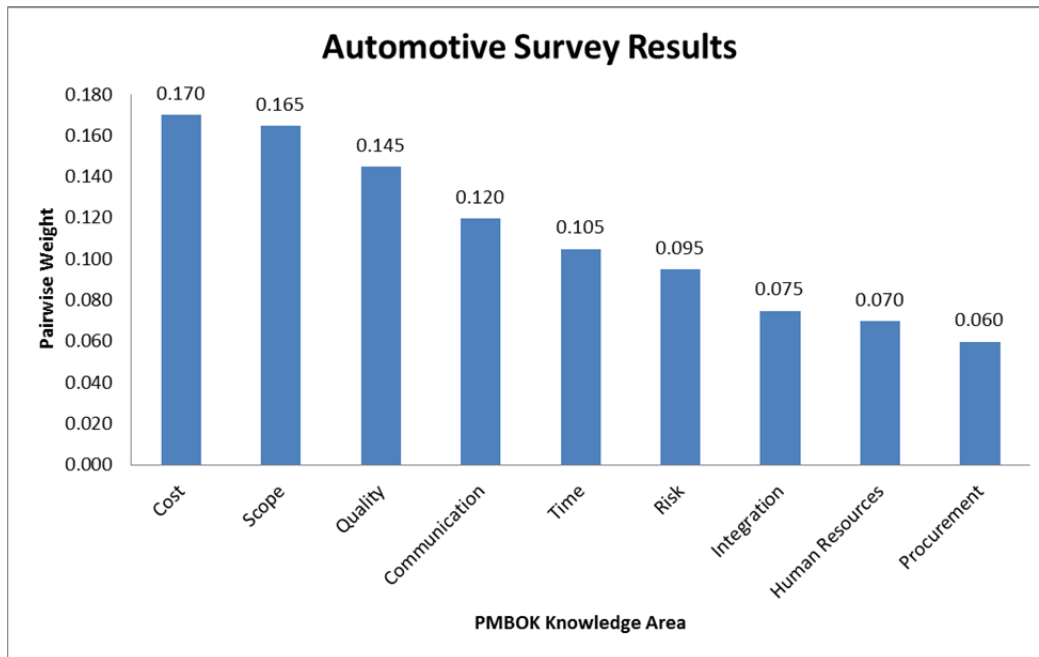Fig. 15: Standard Deviation With and Without Survey Participant

Fig. 16: Automotive Pair-Wise Weight Results

Based on the weights shown above, the PLM offerings were scored. Planisware 5, Agile 9.2, Accolade, Aras Innovator, SAP PLM, PowerSteering Enterprise, PLM360, and Team Center took the top spots as shown in Fig. 17.

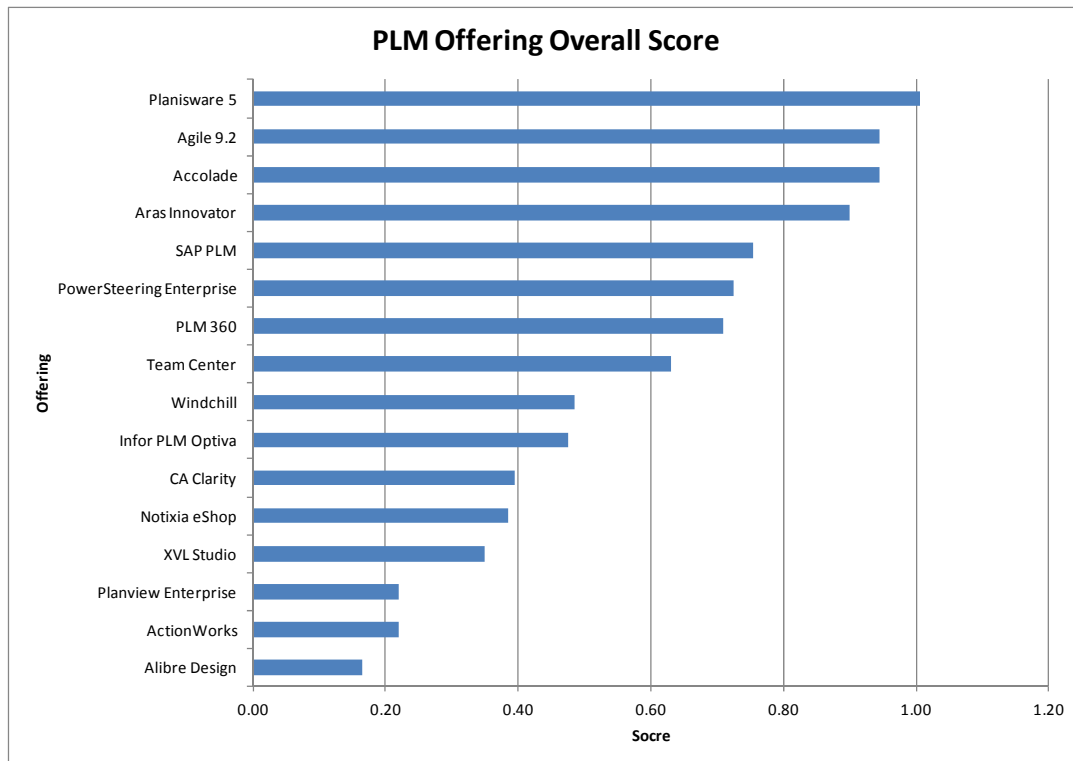Appendix C shows the complete rollup and scoring for the automotive case study.



Fig. 17: PLM overall scoring for automotive

## VI. MODEL RESULTS & VALIDATION: IT CASE STUDY

Two large software IT firms were surveyed, one expert from each participated. Only two offerings were eliminated during the initial Screening: CMPRO and Journyx. Individual weights as well as overall average weights were calculated for study. Table 4 below shows the individual weights was well as the overall weights. Because the weights turned out to be so close to each other, the team used the average for this case study.

TABLE 4: IT PAIR-WISE WEIGHT SUMMARY

| Knowledge Area | IT Part. 1 | IT Part. 2 | Soft Mean | Average Weight |
|---|---|---|---|---|
| Integration | 0.16 | 0.16 | 0.16 | 0.16 |
| Scope | 0.09 | 0.09 | 0.09 | 0.09 |
| Time | 0.11 | 0.11 | 0.11 | 0.11 |
| Cost | 0.12 | 0.12 | 0.12 | 0.12 |
| Quality | 0.10 | 0.10 | 0.10 | 0.10 |
| Human Resources | 0.08 | 0.07 | 0.08 | 0.08 |
| Communication | 0.11 | 0.10 | 0.11 | 0.11 |
| Risk | 0.14 | 0.16 | 0.15 | 0.15 |
| Procurement | 0.10 | 0.09 | 0.10 | 0.10 |

Fig. 18 shows a summary of the pair-wise weights for each knowledge area. Integration and Risk scored the highest, followed by cost, time, communication, quality, procurement, scope and HR (in order). In speaking with the participants after the survey, they communicated that integration is very

critical in IT. Risk scored very high because implications related to mistakes/errors are very important.
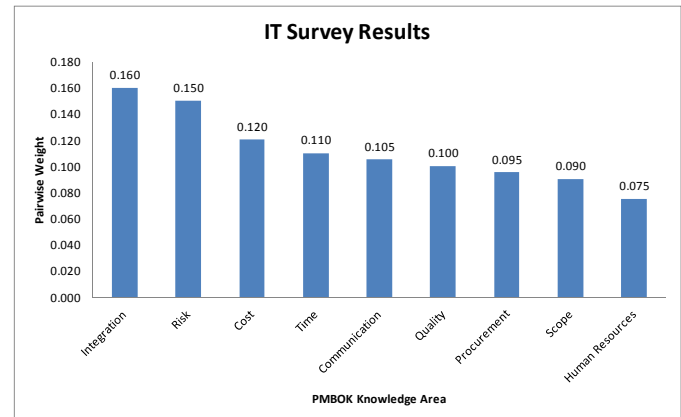

Fig. 18: It Pair-Wise Weights by Knowledge Area

The average pair-wise weights, shown in Fig. 18 were applied to the PLM offerings and overall scores were calculated, using the methods discussed in the previous sections. Agile 9.2, Accolade, and Aras Innovator were clearly the top 3 scores, with a second grouping including Team Center, PLM 360 and SAP PLM. Fig. 19 shows the overall summary.

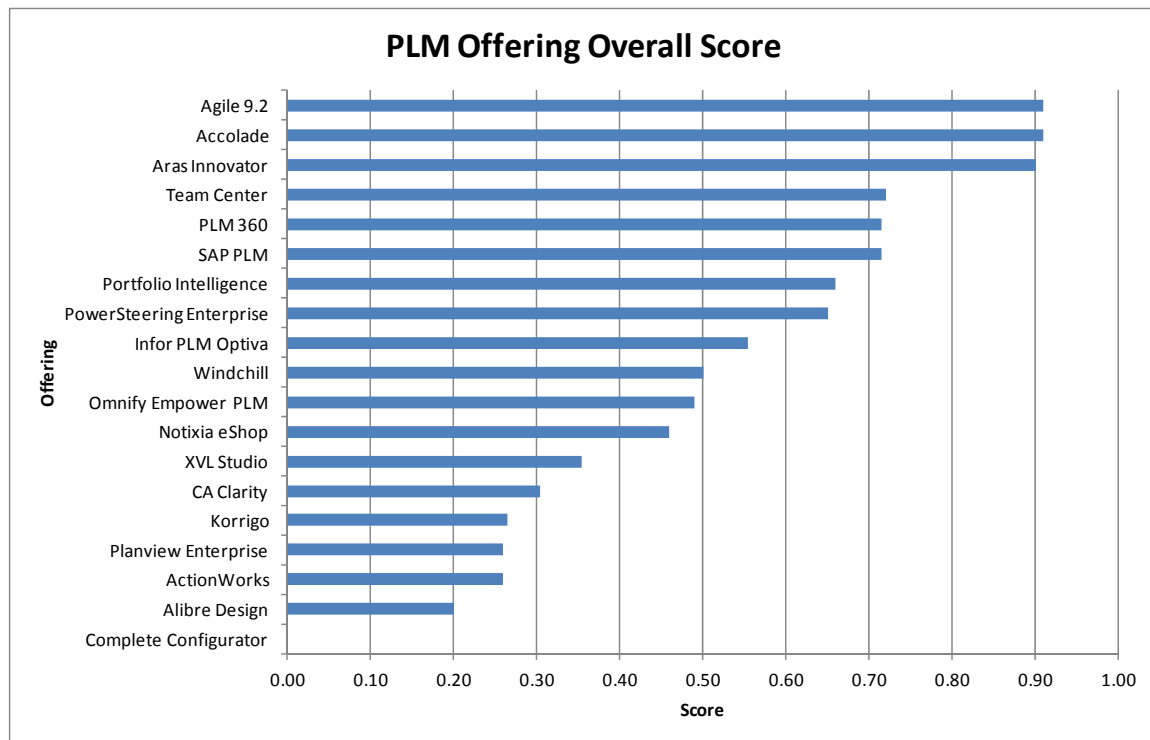Appendix D contains the overall summary for the IT study.


Fig. 19: Overall Scoring For It

## VII. CONCLUSION AND FUTURE WORK

The five stage approach for selecting PLM software can be implemented by organizations looking for a methodology to sort through the various systems that are available in the market. Fig. 20 shows a summary of the case study with raw results and an overall comparison chart.

Fig. 21 compares the valuations of the knowledge areas across multiple industries. This figure clearly illustrates how the industries are in fact different when it comes to how they assess projects using the PMBOK framework.
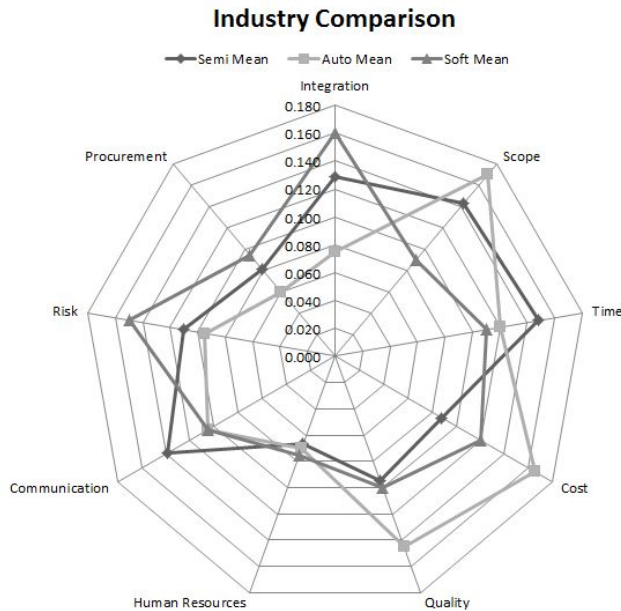


Fig 21 Knowledge Area Comparisons
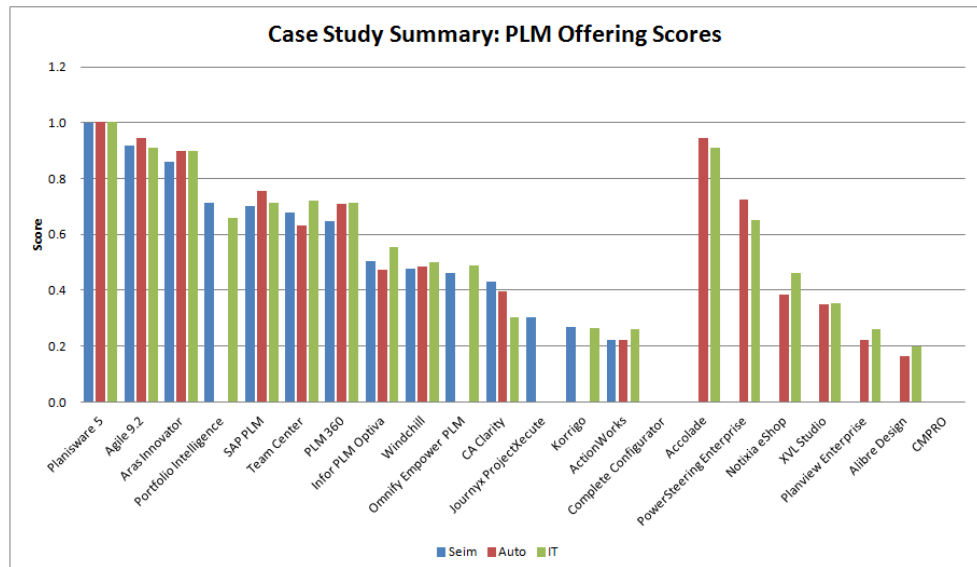
Several improvements can be implemented to the five stage process in order to optimize the process and provide additional value in the results. In Stage 1, additional factors could be utilized for evaluation such as Identification of Market Position, Company Stability, Customer Service, and Location. This improvement would essentially "pull in" the activities in the fourth stage of the process.

For Stage Three it is recommended to implement a variable scoring value in place of the binary attribute scoring. For this type of evaluation the user could essentially apply a metric to the capabilities of the PLM software. This improvement would yield better clarity in the differences between the various software systems. Additionally, a criteria level could be added to the HDM model, to help managers and executives provided their higher-level input into the model. The team suggests considering the PMBOK process groups (i.e. initiating, planning, executing, monitoring, and closing) for this purpose. Pair-wise comparisons could be used for this process as it was used with the nine knowledge areas. This improvement would strengthen the model by focusing not only on the PM inputs but also taking into the consideration the needs of the organization as a whole. For example, the model could down select PLM offerings based on individual organizational struggles. If an organization struggled with the planning phase than monitoring, the model could comprehend this in the scoring process.

Finally the model could be expanded to include information related to lifecycle management and portfolio tracking capabilities, thereby helping the organization better manage derivative projects and manage historical data.



Fig. 20: PLM Score Summary

## REFERENCES

[1] F.Ameri, et al, (2005). Product lifecycle management: closing the knowledge loops. Computer-Aided Design & Applications, 2(5), 577-590.

[2] "Product Life Cycle Management | What Is PLM?" Product Life Cycle Management. PLM Info, n.d. Web. 13 Nov. 2012. <http://www.product-lifecycle-management.info/what-is-plm/plm-benefits.html>.

[3] "PLM Software - CMPRO Features." Product Lifecycle Management Features in PLM Software CMPRO. N.p., n.d. Web. 03 Nov. 2012. <http://www.psasys.com/CMPRO_Features.html>

[4] J.Jusko, 2009, March 12. *How to Choose a PLM Provider* [Online]. Available: http://www.industryweek.com/product-development/how-choose-plm-provider

[5] Project Integration Management, A *Guide to the Project Management Body of Knowledge (PMBOK Guide, 4th edition).* Newtown Square, PA: Project Management Institute, 2008. ch. 4 pp 71-102

[6] Project Scope Management, A *Guide to the Project Management Body of Knowledge (PMBOK Guide, 4th edition).* Newtown Square, PA: Project Management Institute, 2008. ch. 5 pp 103-129

[7] Project Time Management, A *Guide to the Project Management Body of Knowledge (PMBOK Guide, 4th edition).* Newtown Square, PA: Project Management Institute, 2008. ch. 6 pp 129-164

[8] Project Cost Management, A *Guide to the Project Management Body of Knowledge (PMBOK Guide, 4th edition).* Newtown Square, PA: Project Management Institute, 2008. ch. 7 pp 165-188

[9] Project Quality Management, A *Guide to the Project Management Body of Knowledge (PMBOK Guide, 4th edition).* Newtown Square, PA: Project Management Institute, 2008. ch. 8 pp 189-214

[10] Project Human Resource Management, A *Guide to the Project Management Body of Knowledge (PMBOK Guide, 4th edition).* Newtown Square, PA: Project Management Institute, 2008. ch. 9 pp 215- 242

[11] Project Communications Management, A *Guide to the Project Management Body of Knowledge (PMBOK Guide, 4th edition).* Newtown Square, PA: Project Management Institute, 2008. ch. 10 pp 243- 272

[12] Project Risk Management, A *Guide to the Project Management Body of Knowledge (PMBOK® Guide, 4th edition).* Newtown Square, PA: Project Management Institute, 2008. ch. 11 pp 273-312

[13] Project Procurement Management, A *Guide to the Project Management Body of Knowledge (PMBOK Guide, 4th edition).* Newtown Square, PA: Project Management Institute, 2008. ch. 12 pp 313- 344

[14] M Liberatore, et al, "Factors Influencing the Usage and Selection of Project Management Software," *IEEE Transactions on Engineering Management,* Vol. 30, No. 2 (May 2003), 164-174.

[15] T. Daim, ETM530. Class Lecture, Topic: "MOGSA Hierarchy HDM: Mission Objectives Goals Strategies and Actions", WC309, Faculty of Engineering & Technology Management, Portland State University, Portland, OR, USA, April 5th, 2012.

[16] B.J Bailey, "PCM Software: A software Product for the Pairwise Comparison Method of Judgement Quantification – written for EMGT 506"

[17] E. Triantaphyllou, "Reductions of pairwise comparisons in decision making via a duality approach", Journal of Multi Criteria Decision Analysis- 8, pp 299-310 (1999)

[18] T.L Saaty, "A scaling methods for priorities in hierarchical structure", Journal of Mathematical Psychology-15, pp 234-281 (1977).

[19] Project Integration Management, A *Guide to the Project Management Body of Knowledge (PMBOK Guide, 4th edition).* Newtown Square, PA: Project Management Institute, 2008. Appendix F. pp 411-415

[20] U.S. Department of Commerce, *Statistics about Business Size* [Online]. Available: http://www.census.gov/econ/smallbus.html

[21] A. Allnoch, "Choosing the Right Project Management Software for Your Company," *IIE Solutions,* March, 1997.

[22] N. Ahmad, et al, "Software Project Management Tools: Making a Practical Decision Using AHP," *IEEE Proceeding of the 30th Annual IEEE/NASA Software Engineering Workshop SEW-30,* 2006.

[23] K. Chuang, et al, "Using General System Approach For Product Lifecycle Management Software Selection And Evaluation," *Review of Business Information Systems*, First Quarter, 2009.

[24] T. Anderson. ETM545. Class Lecture, Topic: "Project Life Cycle", Willow Creek Campus, Faculty of Engineering, Portland State University, Portland, OR, Sept. 26, 2012.

APPENDIX A: SURVEY EXAMPLE

| Directions For Survey | | | |
|---|---|---|---|
| This survey is for Hierarchical Decision Model that will be used to select the correct PLM System that should be adopted by companies interested in New Product Development.<br>The method of analysis of this survey is Pairwise Comparison. Using this methodology, 100 points can be distributed between two different criteria, where the more important Item is rated with a higher score. The following examples illustrate this concept: | | | |
| | | *Example 1:* | |
| Item #1 | Score | Score | Item #2 |
| Integration | 10 | 90 | Scope |
| | | *Example 2:* | |
| Item #1 | Score | Score | Item #2 |
| Integration | 70 | 30 | Scope |
| | | | |

| Knowledge Areas | |
|---|---|
| Keyword | Definition |
| *Integration* | Integration Management Includes the processes and activities needed to identify, define, combine, unify, and coordinate the various processes and project |
| *Scope* | Scope Management includes the processes required to ensure that the project includes all the work required , and only the work required to complete the project |
| *Time* | Time Management includes the processes required to manage timely completion of the project. |
| *Cost* | Cost Management includes the processes involved in estimating, budgeting, and controlling costs so that the project can be completed within the approved budget. |
| *Quality* | Project Quality Management includes the processes and activities of the performing organization that determine quality policies, objectives, and responsibilities so that |
| *Human Resources* | Human Resources Management includes the processes that organize, manage, and lead the project team. |
| *Communication* | Communications Management includes the processes required to ensure timely and appropriate generation, collection, distribution, storage, retrieval, and ultimate |
| *Risk* | Risk Management includes the processes of conducting risk management planning, identification, analysis, response planning, and monitoring and controlling of the |
| *Procurement* | Procurement Management includes the processes necessary to purchase or acquire products, services, or results needed outside the project team. |

| Decision Model |
|---|

| Item #1 | Score | Score | Item #2 |
|---|---|---|---|
| Integration | | 100 | Scope |
| Integration | | 100 | Time |
| Integration | | 100 | Cost |
| Integration | | 100 | Quality |
| Integration | | 100 | Human Resources |
| Integration | | 100 | Communication |
| Integration | | 100 | Risk |
| Integration | | 100 | Procurement |
| Scope | | 100 | Time |
| Scope | | 100 | Cost |
| Scope | | 100 | Quality |
| Scope | | 100 | Human Resources |
| Scope | | 100 | Communication |
| Scope | | 100 | Risk |
| Scope | | 100 | Procurement |
| Time | | 100 | Cost |
| Time | | 100 | Quality |
| Time | | 100 | Human Resources |
| Time | | 100 | Communication |
| Time | | 100 | Risk |
| Time | | 100 | Procurement |
| Cost | | 100 | Quality |
| Cost | | 100 | Human Resources |
| Cost | | 100 | Communication |
| Cost | | 100 | Risk |
| Cost | | 100 | Procurement |
| Quality | | 100 | Human Resources |
| Quality | | 100 | Communication |
| Quality | | 100 | Risk |
| Quality | | 100 | Procurement |
| Human Resources | | 100 | Communication |
| Human Resources | | 100 | Risk |
| Human Resources | | 100 | Procurement |
| Communication | | 100 | Risk |
| Communication | | 100 | Procurement |
| Risk | | 100 | Procurement |

APPENDIX B: SEMICONDUCTOR PLM SCORING

| Criteria | Software Types | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | Aras Innovator | Windchill | Omnify Empower PLM | ActionWorks | CA Clarity | Planisware 5 | Complete Configurator | Portfolio Intelligence | Infor PLM Optiva | Journyx Project Xecute | Korrigo | Agile 9.2 | Team Center | PLM | PLM 360 |
| | by Aras Corp. | by PTC | by Omnify Software | by Action Technologies Inc. | by Computer Associates | by Planisware | by Complete Information | by Three Olive Solutions LLC | by Infor | by Journyx Inc. | by First Trace Inc. | by Oracle Corp. | Siemens | SAP | Autodesk |
| Integration Management | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| Scope Management | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| Time Management | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 |
| Cost Management | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| Quality Management | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| Human Resource management | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 |
| Communication Management | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
| Risk Management | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| Procurement Management | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Integration Management | 0.128 | 0.128 | 0.128 | 0.128 | 0.000 | 0.128 | 0.000 | 0.128 | 0.128 | 0.000 | 0.128 | 0.128 | 0.128 | 0.128 | 0.128 |
| Scope Management | 0.143 | 0.143 | 0.000 | 0.000 | 0.143 | 0.143 | 0.000 | 0.143 | 0.000 | 0.000 | 0.000 | 0.143 | 0.000 | 0.143 | 0.143 |
| Time Management | 0.148 | 0.000 | 0.148 | 0.000 | 0.148 | 0.148 | 0.000 | 0.148 | 0.000 | 0.148 | 0.000 | 0.148 | 0.148 | 0.000 | 0.000 |
| Cost Management | 0.088 | 0.000 | 0.088 | 0.000 | 0.000 | 0.088 | 0.000 | 0.088 | 0.088 | 0.088 | 0.000 | 0.088 | 0.088 | 0.088 | 0.088 |
| Quality Management | 0.095 | 0.095 | 0.095 | 0.095 | 0.000 | 0.095 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.095 | 0.000 | 0.095 | 0.095 |
| Human Resource management | 0.067 | 0.000 | 0.000 | 0.000 | 0.000 | 0.067 | 0.000 | 0.067 | 0.067 | 0.067 | 0.000 | 0.067 | 0.067 | 0.000 | 0.000 |
| Communication Management | 0.000 | 0.000 | 0.000 | 0.000 | 0.138 | 0.138 | 0.000 | 0.138 | 0.138 | 0.000 | 0.138 | 0.138 | 0.138 | 0.138 | 0.000 |
| Risk Management | 0.110 | 0.110 | 0.000 | 0.000 | 0.000 | 0.110 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.110 | 0.110 | 0.110 | 0.110 |
| Procurement Management | 0.082 | 0.000 | 0.000 | 0.000 | 0.000 | 0.082 | 0.000 | 0.000 | 0.082 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.082 |
| Sum | 0.862 | 0.477 | 0.460 | 0.223 | 0.430 | 1.000 | 0.000 | 0.713 | 0.503 | 0.303 | 0.267 | 0.918 | 0.680 | 0.703 | 0.647 |

| Offering | Overall Score |
|---|---|
| Complete Configurator | 0.00 |
| ActionWorks | 0.22 |
| Korrigo | 0.27 |
| Journyx ProjectXecute | 0.30 |
| CA Clarity | 0.43 |
| Omnify Empower PLM | 0.46 |
| Windchill | 0.48 |
| Infor PLM Optiva | 0.50 |
| PLM 360 | 0.65 |
| Team Center | 0.68 |
| SAP PLM | 0.70 |
| Portfolio Intelligence | 0.71 |
| Aras Innovator | 0.86 |
| Agile 9.2 | 0.92 |
| Planisware 5 | 1.00 |



PLM Offering Overall Score
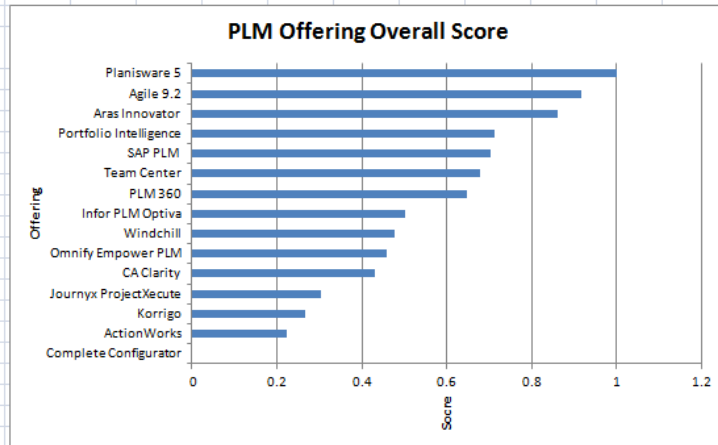
APPENDIX C: AUTOMOTIVE PLM SCORING

| Criteria | Software Types | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Aras Innovator | Windchill | ActionWorks | Notixia eShop | XVL Studio | CA Clarity | Alibre Design | PowerSteering Enterprise | Accolade | Planisware 5 | Planview Enterprise Product Portfolio | Infor PLM Optiva | Agile 9.2 | Team Center | SAP PLM | PLM 360 |
| | by Aras Corp. | by PTC | by Action Technologies Inc. | by Notixia | by Lattice Technology Inc. | by Computer Associates | by Alibre Inc. | by PowerSteering Software | by Sopheon Corp. | by Planisware | by Planview Inc. | by Infor | by Oracle Corp. | Siemens | SAP | Autodesk |
| Integration Management | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Scope Management | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 |
| Time Management | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| Cost Management | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| Quality Management | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 |
| Human Resource | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 |
| Communication | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
| Risk Management | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |
| Procurement Management | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| Integration Management | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 | 0.000 | 0.000 | 0.000 | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 |
| Scope Management | 0.170 | 0.170 | 0.000 | 0.000 | 0.170 | 0.170 | 0.000 | 0.170 | 0.170 | 0.170 | 0.000 | 0.000 | 0.170 | 0.000 | 0.170 | 0.170 |
| Time Management | 0.120 | 0.000 | 0.000 | 0.000 | 0.000 | 0.120 | 0.000 | 0.120 | 0.120 | 0.120 | 0.000 | 0.000 | 0.120 | 0.120 | 0.000 | 0.000 |
| Cost Management | 0.165 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.165 | 0.165 | 0.165 | 0.000 | 0.165 | 0.165 | 0.165 | 0.165 | 0.165 |
| Quality Management | 0.145 | 0.145 | 0.145 | 0.145 | 0.000 | 0.000 | 0.000 | 0.000 | 0.145 | 0.145 | 0.145 | 0.000 | 0.145 | 0.000 | 0.145 | 0.145 |
| Human Resource | 0.070 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.070 | 0.070 | 0.070 | 0.000 | 0.070 | 0.070 | 0.070 | 0.000 | 0.000 |
| Communication | 0.000 | 0.000 | 0.000 | 0.105 | 0.105 | 0.105 | 0.105 | 0.105 | 0.105 | 0.105 | 0.000 | 0.105 | 0.105 | 0.105 | 0.105 | 0.000 |
| Risk Management | 0.095 | 0.095 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.095 | 0.095 | 0.095 | 0.000 | 0.000 | 0.095 | 0.095 | 0.095 | 0.095 |
| Procurement Management | 0.060 | 0.000 | 0.000 | 0.060 | 0.000 | 0.000 | 0.060 | 0.000 | 0.000 | 0.060 | 0.000 | 0.060 | 0.000 | 0.000 | 0.000 | 0.060 |
| Sum | 0.900 | 0.485 | 0.220 | 0.385 | 0.350 | 0.395 | 0.165 | 0.725 | 0.945 | 1.005 | 0.220 | 0.475 | 0.945 | 0.630 | 0.755 | 0.710 |

| Offering | Overall Score |
|---|---|
| Alibre Design | 0.17 |
| ActionWorks | 0.22 |
| Planview Enterprise | 0.22 |
| XVL Studio | 0.35 |
| Notixia eShop | 0.39 |
| CA Clarity | 0.40 |
| Infor PLM Optiva | 0.48 |
| Windchill | 0.49 |
| Team Center | 0.63 |
| PLM 360 | 0.71 |
| PowerSteering Enterprise | 0.73 |
| SAP PLM | 0.76 |
| Aras Innovator | 0.90 |
| Accolade | 0.95 |
| Agile 9.2 | 0.95 |
| Planisware 5 | 1.01 |



PLM Offering Overall Score
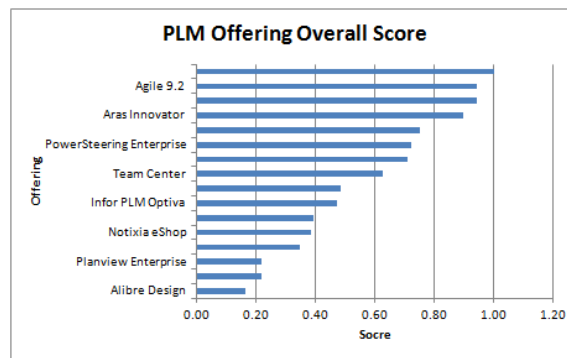
APPENDIX D: IT PLM SCORING

| Offering | Overall Score |
|---|---|
| Complete Configurator | 0.00 |
| Alibre Design | 0.20 |
| ActionWorks | 0.26 |
| Planview Enterprise | 0.26 |
| Korrigo | 0.27 |
| CA Clarity | 0.31 |
| XVL Studio | 0.36 |
| Notixia eShop | 0.46 |
| Omnify Empower PLM | 0.49 |
| Windchill | 0.50 |
| Infor PLM Optiva | 0.56 |
| PowerSteering Enterprise | 0.65 |
| Portfolio Intelligence | 0.66 |
| SAP PLM | 0.72 |
| PLM 360 | 0.72 |
| Team Center | 0.72 |
| Aras Innovator | 0.90 |
| Accolade | 0.91 |
| Agile 9.2 | 0.91 |
| Planisware 5 | 1.01 |



PLM Offering Overall Score