PRODUCT LIFECYCLE MANAGEMENT TECHNOLOGY ASSESSMENT: A CASE STUDY IN THE INDUSTRIAL EQUIPMENT INDUSTRY

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ABSTRACT

Product Lifecycle Management (PLM) adoption is very important for companies to sustain and stay competitive in market particularly to the organizations that involving from design to manufacturing. Many companies are struggling whether to adopt PLM because implementing PLM involves very extensive changes in intra and inter-organizational practices. PLM assessment is an important activity in the pre-implementation stage to determine the scope of implementation. However, the requirements and scope of implementation are always influenced by the users' paradigm of "needs" instead of the company's current PLM maturity level. This research covered the PLM assessment in using Capability Maturity Model (CMM) and Analytical Hierarchy Process (AHP) focused in PLM technology components. The research was based on case study approach conducted in an Industrial Equipment company. The scope of assessment was to investigate the technology components in respect to data, process and methodology. The empirical results showed PLM technology components prioritization determined through the hierarchy analysis could provide more consistent output compared to user's direct judgement. The authors argue that PLM assessment in technology components prioritization requires consideration of its maturity level because the outcomes provide a better guideline to define a strategic roadmap for PLM implementation.

Keywords- Product lifecycle management (PLM), PLM Assessment, Capabilility Maturity Model (CMM), Analytical Hierarchy Process (AHP).

1. INTRODUCTION

The industrial equipment (IE) industry is a capital-intensive and cyclical sector that tends to be severely hit by downturns when there is a significant contraction in capital expenditure. Cutting costs has become a priority over the past few years and today the trends for the leading industrial equipment manufacturers is toward greater productivity [1]. Pierfrancesco Manenti (2013) reported that in order to increase productivity along the product life cycle process, IE companies will need to tackle a number of challenges including (a) Effective managing global organizations; (b) Increasing product complexity; (c) Rapidly fulfilling diverse customer needs; (d) Effectively managing after-sales services; (e) Designing for serviceability. The product life-cycle process is the most important process for IE manufacturers [1]. IDC Manufacturing Insights suggested industrial equipment organizations shall modernize their IT landscape to speed up in decision making, streamline business processes, and breaking organizational silos; this can be supported via a unique platform that supporting the entire product life-cycle process, end to end and offers a single data source from product creation to service [1].

PLM is an integrated, information-driven strategy that accelerates the innovation and launch of successful products, built on a common platform that serves as a single repository of all product-related knowledge, data, and processes [2]. The four most important components for PLM are:- (a) PLM is a concept that focuses product definition information; (b) PLM concerns product definition information throughout the complete product lifecycle, from concept to end of life; (c) Product definition information is created, managed, disseminated and used; (d) This is done in order to integrate people, processes, systems and information [3].

PLM affects a wide range of processes within and outside the company. This makes PLM a complex organizational change effort. Many companies are struggling in PLM implementation. This is because PLM adoption includes very extensive changes in intra- and inter-organizational practices [4]. Grieves (2009) emphasizes that PLM implementation requires four aspects to be coordinated: people, processes, practices, and technology [5]. The challenges of PLM implementation can be related to the technology on one hand and business strategy on knowledge information management on the other hand [6].

Few organizations evaluated the true benefits of PLM systems and it has been reported that PLM implementations in industry render unsatisfactory results [3]. The key challenge in PLM implementation can be seen via organizational readiness, say maturity, to change the way it operates [7],[8]. In all these elements the organization has to make a coordinated plan from where it is today to where its vision is for tomorrow as well as to make coordinated transition, otherwise the whole plan suffers [6]. In this context, PLM maturity assessment will give a good measurement on how far a company to the full PLM implementation.

1.1 Research Objective

The objective of this study is to identify the priority of the critical PLM technology components in a PLM solution

adoption. There are 3 stages in PLM solution adoption i.e. Pre-implementation, Implementation and Post-implementation. In the preceding literature review, PLM assessment with regards to the pre-implementation were discussed about business alignment for People & Culture, IT infrastructure, Management, Process and tools. However there are not many research papers related to the evaluation of the PLM technology components especially in its adoption sequence. The purpose of this qualitative study is to explore the method to optimal sequence in adopting the PLM technology components during the preliminary stage of PLM implementation. The outcome of the assessment will help to understand the companies' readiness in adopting PLM at different functional areas, and subsequently this can be served as the guideline for them to define the PLM roadmap in the later stage.

The main research questions of this study are:

1. How shall the user paradigm of "needs" influence the PLM technology components selection during the pre-implementation phase?
2. How shall the PLM maturity level of the organization impact the PLM technology adoption?
3. How will the user preference in PLM adoption and the organization maturity level impact the priority of PLM technology component adoption sequence?

2. LITERATURE REVIEW

2.1. IE industry trends and challenges

The industrial equipment industry is currently in a phase of profound transformation, with companies redefining their business models from product to service [1]. Dassault Systèmes (2013) reported that IE landscape is characterized by its diversity and the complexity of its products and players [9]. It is also reported that today IE manufacturers are expected in (a) Delivery highly complex machines to market where the machines are comprised of electrical, automation mechanism, software and motion control; (b) Fast accessing up to date information from anywhere enabling collaboration on a global scale ensures that everyone has a voice in product development; (c) More customization which can lead to the transition to a development approach based on modularization which diversifies their product offering while keeping costs under control; (d) Faster quotation process to rationalize their part management to streamline their quotation and purchasing process; (e) Ensure manufacturing conformity where production lines have to be re-aligned and re-configured to keep these quality levels high and (f) Continuous improvement by adopting the tools and environment that promote cooperation and an exchange of ideas to encourage collaborative innovation [9].

To cope with the current difficult business conditions and in order to tackle the challenges in the market, IE manufacturers need to improve the effectiveness and efficiency of the product life-cycle process. This process is in fact the backbone of any IE organization, and optimizing it will rapidly bring significant productivity gains [1].

2.2. PLM

In today worldwide global market, innovation and mass products customization are the key driving factor for the companies. In this context IT support for product management becomes an important issue and many companies are in the process of adopting PLM as one of their key strategies [10]. PLM is inherently focused on the management of data, information and knowledge for creating product offerings that respond to customer needs [11].

The Product data are referring to the record of requirements, designs, development schedules, sourcing, etc. All elements of product data are incorporated into the processes undertaken by sales, purchasing, design, engineering and manufacturing teams no matter where they work in a global value chain [12],[13]. The process in PLM is referring to the managing of the whole life cycle of a product starting from generating an idea, concept description, business analyzes, product design and solution architecture and technical implementation, to the successful entrance to the market, service, maintenance and product improvement [2],[13].

Eventhough it is reported PLM will bring great values to the company however due to its magnitude of transformation a controlled and proper PLM implementation can be very challenging in practice [14],[11]. Baker (2002) stated that "nobody could have foreseen how big, messy, and tough this project would turn out to be" [3]. The reason is mainly due to lack of clear understanding of what PLM is and how it could fit with the needs and requirements of the companies in terms of product management. In this context, it is important to assess how far is a company from a full PLM implementation [6].

2.3. PLM solutions

Dassault Systèmes (2012) PLM platform in IE delivers three fundamentals of efficiency i.e. (a) System Stability where all participants need to access a single, consistent data source; (b) Process Standardization to ensure definition and capture of standard reference processes; (c) Correction and improvement on problems and improvement opportunities should be identified, analysed, and eliminated quickly [15]. There are few keys areas in PLM scoping have been discuss but not limited to the needs of IE industry there are: (a) Reuse of components and processes that already exist in the company. This will help to avoid recreating components can lead to significant time savings and many other savings in a domino effect throughout the product lifecycle [16]. (b) Enhanced integration of engineering software suites which allows engineers to stay immersed in designs and their design tools so they can focus on innovation instead of navigating multiple interfaces and

moving files [17]. (c) Requirements management for continuous communication, change management and traceability enforcement of customer requirements throughout the development cycle [18]. (d) Bill of Material (BOM) management to accommodate a variety of engineering and manufacturing models, including engineer-to-order, build-to-stock, build-to-order, and assemble-to-order. (e) Others PLM process enable greater agility in functions such as bidding, sourcing, procurement, and production. Other important and critical elements include multi-discipline product and process engineering; project and program management; portfolio management and supply chain management [13],[15].

2.4. PLM AND CMM

When talking about maturity models, most people first think of Capability Maturity Model Integration (CMMI) that has become an established model in the field of information systems development [7]. The first version of CMMI model was the CMM published in 1989 by Watts Humphrey, and later by the Software Engineering Institute (SEI) at Carnegie Mellon. CMM composed of five maturity levels i.e. Initial, Repeatable, Defined, Managed, and Optimized [8]. Batenburg (2006) proposed a PLM maturity model and aligned model to assess the relative position of companies on their road to full PLM implementation [10]. The idea of the PLM maturity assessment along the PLM process are to make the implementation of the extensive business issue of PLM better approachable and a more carefully planned process [6] and to avoid premature moves, which is to say to avoid implementing processes or systems in to an organization that is not yet able to utilize them [7]. Based on Vezzetti, Violante and Marcolin (2014) has reviewed the following PLM maturity model with regards to CMM:- Batenburg proposal was designed to assess the PLM achievements of individual companies or business units of a company; Saaksvuori and Immonen proposal referred to the generic maturity model CMM combined with the COBIT framework; Stark proposal discussed about the maturity model for PDM, which was an important component of PLM; Schuh proposal covered a set of lifecycle-oriented business process reference models which linked the necessary fundamental concepts, enterprise knowledge and software solutions to effectively deploy PLM; Kärkkäinen proposal defined the maturity of customer dimension, and they provided preliminary maturity level descriptions for this dimension; and lastly Terzi S. proposal assessed for new product development process that provided a snapshot of the company in order to offer a starting point for further analysis and the definition of a strategy for improvement in its processes of engineering and innovation [8].

2.5. AHP

Analytical Hierarchy Process (AHP) is a multi-criteria decision-making technique developed by Saaty (1980). It aims at quantifying relative priorities for a certain set of alternatives on a ratio scale, based on the judgment of the decision-maker, stressing the importance of the intuitive judgments of a decision-maker as well as the consistency of the comparison of alternatives in the decision-making process [10],[19]. The strength of this approach is to organize tangible and intangible factors in a systematic way and to provide a structured yet relatively simple solution to the decision making problems [10]. The task of any multi-criteria decision methodology is not to prescribe the "right" decision to be chosen, but to help decision makers to find an alternative that could best fits their needs and the general understanding of the problem [10].

3. RESEARCH METHODLOGY

In this study, the researchers have identified the keys areas of PLM technology components that were reviewed in the literature. Based on the selected technology components the researchers carried out an assessment to explore the company's preferences of its technology components adoption through prioritize its sequence based on the user's needs and areas of improvement. Following with this, the researchers continued the assessment on technology components to evaluate the company's current state of PLM maturity level. The purpose of this research is to allow the company have a clearer picture on the gap between its desire areas of improvements and its current state of maturity level. The objective of this study is to investigate the important of the needs analysis in PLM technology adoption via PLM maturity assessment and critical PLM component selection through the PLM Data, Process and Methodology.

3.1. Research Model

The research model was structured as follows: the first section was based user's direct perception of needs in PLM. The respondents were asked to rank the priority and sequence of the areas of improvement they needed. In the second section, we conducted Multi-Criteria Analysis (AHP) method to allow the company to define their needs in relation to their current position and status in defining the improvement sequence on technology adoption. Thirdly, we applied CMM method to asses the company's current state in the technology components that were grouped under Data (the solution system), Process (the workflow and communication) and Methodology (the company practices). The last part of this paper we discussed on the the analyzed result from section.1-2-3 to conclude the findings and summary. The researchers believed that the outcome of the assessment would help the researchers to understand the companies' readiness at different functional areas. Eventually, this can be served as the guideline to define the PLM roadmap in the later stage. The research model of this research has illustrated in Figure 1 below.

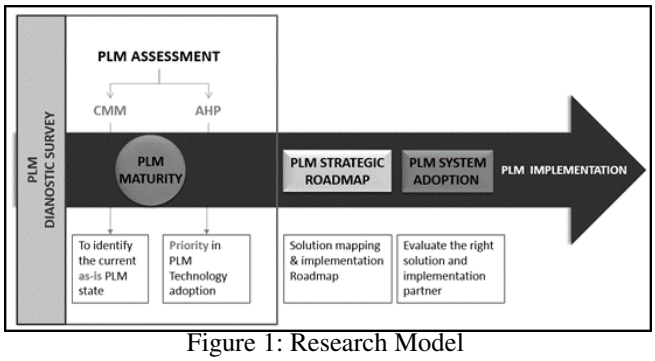

Figure 1: Research Model

Based on the preceeding literature reviews which discussed the challenges and areas of improvement in IE industry, the researchers have identified the most appropriate PLM technology components as Figure 2 below.

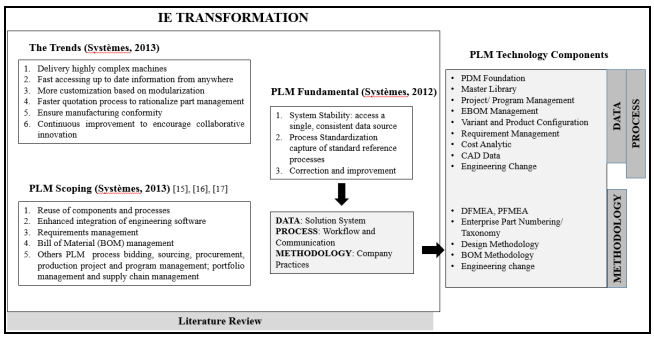

Figure 2: PLM Technology Components

As indicated in Figure 2, the PLM technology components are grouped under Data, Process and Methodology. Data are referred to the available solution system in the organization and its status in managing the data information; Process is referred to the available workflow for communication across various teams and Methodology is referred to the company and industry best practices which has deployed. Data components will cover Product Data Management (PDM) foundation, Master library, Project/Program management, Engineering Bill of Material (EBOM) management, Variant and Product Condiguration, Requirement management, Cost Analytics and CAD data. Process components will cover the same components as stated in Data including Engineering change process. Methodology components will cover DFMEA & PFMEA, Enterprise Part Numbering/ Taxonomy, Design Methodology, BOM Methodology and BOM Methodology.

3.2. The Case Company

The selected case study company (COM01) is a multi-national company (MNC) that core business is Industry Equipments (IE) manufacturing. COM01 is a local representative office in Malaysia that focusing in sales and project management, in which also acting as the main central hub in Asia that coordinating and communicating with Europe (Design Central) and China (Manufacturing Central) on project related matters. In order to increase the market share and vision to be an once-stop system provider, COM01 is experiencing rapid grow and product expansion in the recent year through acquisition of other companies' products. Due to the extensive acquisition process, today COM01 is facing challenges in retrieving the up-to-date information from the systems as need. Therefore, there are requirements to consolidate information from various ICT systems. Some of the challenges faced by COM01are summarized as follows:

a) Data are stored in vary Product Center located at Europe and Asia. No centralize platform to enable share, capture and retrieve the information. Product information is isolated and is not synchronized. Heterogeneous information managed by different teams in different geos with different tools requires a lot of effort to reconcile.
b) Due to the massive acquisition process, various enterprise solutions are still in individual island and managed through the local team. The process of standardization did not apply across.
c) Product Portfolio is not up-to-date and most of the product information is referred to product or project costing in Europe. Limited reference available in Asia database, this lead to inaccurate of costing budgeting during the proposal stage and lower the competitiveness of the product costing.

In realizing of the above challenges, today COM01 has identified the following key improvement areas as part of the transformation program and would like to overcome those challenges through PLM solution adoption:-

a) To setup an ICT improvement task force to evaluate and consolidate the IT infra, standardizing the product database, standardizing the ERP enterprise system
b) To centralize and consolidate products data for update-to-date product information retrieval.
c) To establish a multi-site collaboration platform that allowing dispersed design team to collaborate on the same design effectively.
d) To improve on accurate profit margin assessment via tight project cost monitoring
e) To increase the work efficiency in term of information searching with governs policy and workflow.

It has perceived that PLM solution that comes with the functional technology components is able to address the above requirements. COM01 has decided to undergo the PLM assessment in order to identify the priority of the critical technology components and its PLM maturity status prior to its PLM adoption.

3.3. AHP Assessment

In this assessment, we made a pair wise comparision in the technology components under Data (D1,D2,D3…), Process (P1,P2,P3…) and Methodology (M1,M2,M3…) normalizing the resulting matrix and follow by averaging the values in each row to get the corresponding rating in

order to establish priorities amongst the elements in the hierarchy. Results for Data as indicated in Table 1.

Table 1: AHP matrix for Data

	D1	D2	D3	D4	D5	D6	D7	D8
D1	**1.00**	0.33	1.00	3.00	0.20	0.14	0.14	0.14
D2	3.00	**1.00**	1.00	5.00	0.14	0.20	0.14	3.00
D3	1.00	1.00	**1.00**	7.00	0.20	1.00	0.20	5.00
D4	0.33	0.20	0.14	**1.00**	0.14	0.20	0.14	3.00
D5	5.00	7.00	5.00	7.00	**1.00**	0.33	5.00	7.00
D6	7.00	5.00	1.00	5.00	3.00	**1.00**	5.00	7.00
D7	7.00	7.00	5.00	7.00	0.20	0.20	**1.00**	7.00
D8	7.00	0.33	0.20	0.33	0.14	0.14	0.14	**1.00**

3.4. CMM Assessment

Through the interview session, the researchers further evaluated the company's PLM maturity level based on the identified PLM components. The rating in this assessment was based on researchers' observation and judgment. The measurement criteria was based on CMM by MattH [20] which defined as Initial, Repeatable, Define, Manage and Optimize.

4. RESULTS AND DATA ANALYSES

From the results shown in Table 2 and Figure 3, they have indicated the result from the empirical study in prioritize the PLM technology components was not identical to the initial user ranking. From the empirical result of AHP it has showed that among DATA- PROCESS- METHODOLOGY, DATA has weightage of 73% where COM01 would like to put more focus to improve the management system. With this information, we dive into the PLM technology component in DATA and identifying the top three components; and we found that the total weightage for Requirement Management, Variant & Product Configuration and Cost Analytic have contributed 75% of overall scoring among all eight PLM components as listed in DATA. This means Requirement Management, Variant & Product Configuration and Cost Analytic are the critical improvement areas where the COM01 was keen to look into.

However, the result derived from the AHP assessment could only tell us the preference of case study company on the critical areas where they wanted to look into the improvement and solution. The researchers compared the top three shortlisted results from AHP and CMM. The outcomes showed that Requirement Management, Variant & Product Configuration and Cost Analytic which were having the high priority in AHP were having CMM maturity level at 2-3-2 respectively.

To further evaluate the PLM component implementation sequence, the researcher multiplying AHP result and CMM status and consequencely, the output from these result analysis showed that maturity has direct impact to the result of implementation sequence.

Priority index (Pi) = Preference of User (PoU) x PLM Maturity Level (PML)

And the result shows that priority index for COM01 in this case are in order of (1) Variant & Product Configuration; (2) Requirement Management; (3) Cost Analytic

Table 2: PLM Assessment's result for case company

Code	PLM Component	User Ranking (UR)	Preference of User (PoU)	PLM Maturity Level	The GAP (UR)-(PoU)	Priority Index (Pi)= (PoU) x
	DATA	**USER**	**AHP**	**CMM**		
D1	PDM Foundation	6	7	Level.3: Define	1	10%
D2	Master Library	5	5	Level.3: Define	0	18%
D3	Project/ Program Management	4	4	Level.2: Repeatable	0	19%
D4	EBOM Management	8	8	Level.3: Define	0	9%
D5	**Variant and Product Configuration**	**2**	**2**	**Level.3: Define**	**0**	**80%**
D6	**Requirement Management**	**3**	**1**	**Level.2: Repeatable**	**-2**	**58%**
D7	**Cost Analytic**	**1**	**3**	**Level.2: Repeatable**	**2**	**36%**
D8	CAD Data	7	6	Level.3: Define	-1	12%
	PROCESS	**USER**	**AHP**	**CMM**		
P1	PDM Foundation	4	9	Level.2: Repeatable	5	4%
P2	Master Library	5	7	Level.2: Repeatable	2	7%
P3	Project/ Program Management	2	4	Level.2: Repeatable	2	28%
P4	EBOM Management	9	8	Level.2: Repeatable	-1	4%
P5	**Engineering Change**	**1**	**1**	**Level.1: Initial**	**0**	**30%**
P6	**Variant and Product Configuration**	**3**	**3**	**Level.3: Define**	**0**	**47%**
P7	Requirement Management	6	5	Level.2: Repeatable	-1	24%
P8	**Cost Analytic**	**7**	**2**	**Level.2: Repeatable**	**-5**	**32%**
P9	CAD Data	8	6	Level.3: Define	-2	12%
	METHODOLOGY	**USER**	**AHP**	**CMM**		
M1	**DFMEA, PFMEA**	**3**	**3**	**Level.2: Repeatable**	**0**	**33%**
M2	Enterprise Part Numbering/ Taxonomy	5	4	Level.2: Repeatable	-1	22%
M3	**Design Methodology**	**1**	**1**	**Level.3: Define**	**0**	**142%**
M4	BOM Methodology	4	5	Level.2: Repeatable	1	7%
M5	**Engineereing Change**	**2**	**2**	**Level.1 Initial**	**0**	**21%**

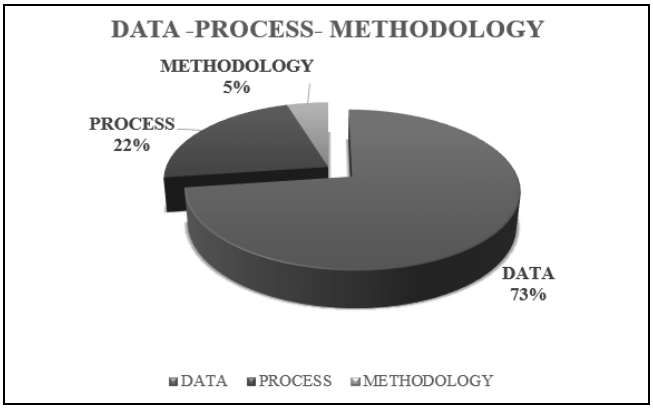

Figure 3: AHP empirical result for Data- Process- Methodology

5. DISCUSSION

This research showed the areas to be covered in the PLM assessment focused on technology components and suggested the sequence in preparing the technology components prior to the PLM implementation. Throughout the entire assessment process, researchers recognized that user would have direct influence in the technology components selection. This could be based on the user working experience over the years and how they were dealing with the day to day operational challenges, as well as the user's desired in improving their needs in work operation. However, the empirical result obtained from AHP and the initial user ranking was not identical in the

technology components prioritization. The results obtained from AHP method should be refered because it provides more analytical measures and consistency compared to direct user judgement.

The result also showed that, the empirical results from AHP for the areas of improvement might not be necessary aligned to its maturity level at the moment. Based on the cost analytic result in Data it was identified to be the top priority to be addressed but its maturity level was still at level.2 i.e. repeatable. It is always arguable the higher maturity level should have higher priority for implementation because it will give an optimal result with minimal effort and shorter timeline required. In order to have more rationalized results in prioritization, researchers multiplying the output results of AHP and CMM to obtain the priority index. This has given another dimension for researchers in data analysis.

This research was based on one case study. The results might not be able to reflect the entire IE industry. The researchers recognized that there were still room for improvements in fine-tuning the PLM technology components selection to cater for bigger scope of PLM adoption, e.g. Supplier management, ERP integration and etc. Future research could also investigate how to integrate the necessary business alignment in the later stage and the relationship or the precedency of each technology components along implementation process, as the current researches did not cover those areas.

6. CONCLUSION

This paper is an empirical case study research on PLM assessment via qualitative method. Research through interview could help to collect more in depth information and clarity through observation. All inputs provided by respondents were important as it would give direct impact to the results of the assessment outcome.

Based on the results of the PLM assessment, researchers suggests that COM01 should look into solution harmonization on Variant and Product configuration, Requirement management and Cost analytic solution. This would help COM01 in standardizing the data information to improve the time search for the right information. COM01 also needed to have more accurate product or project costing info to refer to in proposal preparation stage to increase its competitiveness. Researchers would like to suggest that COM01 could further improve in Engineering Change process by (1) incorporating with other functional teams (2) to capture the lessons learned and (3) to enable knowledge capitalization.

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