EX-ANTE PLM MISFIT ANALYSIS METHODOLOGY: A COGNITIVE FIT APPROACH

Jen-Her Wu, Department of Information Management, College of Management, National Sun Yat-sen University, Kaohsiung, Taiwan, R.O.C., jhwu@mis.nsysu.edu.tw
Shin-Shing Shin, Department of Information Science and Management Systems, National Taitung University, Taitung, Taiwan, R.O.C., shing@nttu.edu.tw
Te-Min Chang, Department of Information Management, College of Management, National Sun Yat-sen University, Kaohsiung, Taiwan, R.O.C., temin@mail.nsysu.edu.tw
Alok Gupta, Department of Information and Decision Sciences, Carlson School of Management, University of Minnesota, Minneapolis, U.S.A., agupta@csom.umn.edu
Ming-Fu Hsu, Department of Information Management, College of Management, National Chi Nan University, Nantou, Taiwan, R.O.C., hsumf0222@gmail.com

Abstract

Commercial off-the-shelf (COTS) Product Lifecycle Management (PLM) systems have been introduced by companies to facilitate their new product development process to shorten the product time to market, reduce the product development cost, and meet the dynamic demands of customers. However, PLM implementation is not an easy job and some of the attempted projects failed. A common problem encountered in adopting PLM packages has been the issue of misfits, i.e., the gaps between the specifications offered by a PLM package and those required by the adopting organization, which easily causes the project to fail. Current approaches for the ex-ante analysis of PLM misfits are extremely limited. This paper develops a methodology grounded in the extended cognitive fit theory for the misfit analysis. This approach can assist in identifying and representing consistent set of information for functions and workflow processes across business requirements and the PLM package. Particularly, Petri nets that are of graphical representations and easy to understand are employed to model the function-embedded workflow process. A case study is presented to examine the feasibility of this approach. We conclude that with our methodology, PLM analysts or adopting organizations can systematically identify potential misfits and the degree of misfit between the business requirements and PLM packages in an ex-ante analysis to mitigate the risks in PLM implementations.

Keywords: Product lifecycle management (PLM), Ex-ante misfit analysis, Cognitive fit theory, Petri nets

1 INTRODUCTION

The continuous proliferation of new products and the need for a quick response to market changes has engaged more companies to seek competitive advantages through the adoption of commercial off-the-shelf (COTS) systems, such as the product lifecycle management (PLM) system. PLM is the process of managing the product development phases from concept to design to production. It incorporates business data and processes across suppliers and clients to provide shortened product design schedule, lowered product development cost, and accelerating product time to market. PLM becomes remarkably essential nowadays because companies need to face the dynamically changing market demands, complicated product function requirements, and coordination among resources in the new product development process.

To facilitate companies in their PLM process, many COTS PLM systems have been developed by system integration vendors such as PTC, Oracle, SAP, Dassault, and IBM. The PLM system aims to integrate data, processes, people and business systems and produces a product information repository for companies. According to PLM vendors, the software value grows exponentially, which amounts to \$1.2 billion in the worldwide market in 2006, and increases to \$1.03 trillion in 2012 (YRI 2012). This indicates a tremendous demand from companies to introduce PLM systems to enhance their product competitive strength.

The early applications of PLM systems were limited to such industries as automobile, machinery design and aerospace engineering. Recently, more and more high-tech electronic industries are attracted to adopt PLM systems. It was pointed out that following the applications of Enterprise Resource Planning (ERP), Supply Chain Management (SCM) and Customer Relationship Management (CRM), PLM will be one of the major application systems installed in high-tech industries (Chiang and Trappey 2007; Demoly et al. 2013).

PLM system implementation is definitely a complex exercise in technology innovation and change management (Grönvall 2009; Bokinge and Malmqvist 2012). As a consequence, it is inevitable that some attempted PLM implementations fail. Among Taiwanese companies, the success rate of PLM implementation is less than 50 percent (Stark 2005). To properly implement a PLM system, the company needs to consider costs, infrastructure requirements, changes in processes, and strategy (Silventoinen et al. 2010). Once the maturity assessment on the company’s readiness to adopt PLM reflects a satisfactory outcome, a company can next consider an ex-ante analysis on which COTS PLM systems to meet the company’s requirements before implementing the PLM project.

A typical problem in choosing the COTS PLM system has been the issue of misfit due to the gaps between the specifications offered by a PLM system and those required by the adopting organization (Antti and Anselmi 2004; Stark 2005). Such misfit gaps easily cause the failure of the PLM implementation. Companies should adopt a PLM system that fits their requirements in order to improve performance and reduce the implementation risks. Better understanding of the misfits before implementation provides valuable insights for the ex-ante evaluation and thereby reduces the risk of project failure. Unfortunately, because of the variability and the complexity of COTS PLM implementation projects, the analysis methodology is often ill-structured and done in an ad hoc way. In fact, this kind of difficulty is common to any COTS system adoption such as ERP (Rolland and Prakash 2000; Light 2005) and CRM (Finnegan and Currie 2010).

Consequently, this research focuses on analyzing PLM misfit when choosing a COTS PLM system. We conceptualize the ex-ante evaluation for PLM misfit as interlinking comprehension of the business requirements and PLM packages with misfit identification. Particularly, we consider cognitive fit theory (CFT) as the theoretical foundation which considers a solver's problem solving performance as a consequence from the interaction between the problem representation and the problem-solving task. The aim of our research is thus to contribute to this endeavor by presenting an ex-ante evaluation methodology for PLM misfit based on the extended cognitive-fit model. A real case is demonstrated to examine its feasibility accordingly.

The rest of this paper is organized as follows. Section 2 describes the theoretical foundation for this study where the cognitive fit theory and its extended versions are included. In Section 3, a general PLM misfit analysis model is developed, followed by the descriptions of the modeling tool and the modelling process. Section 4 exemplifies the application in a real case to examine the feasibility. Finally, we summarize findings of this study to provide insights for organizations when they are about to implement the PLM system.

2 THEORETICAL BACKGROUND

In this section we present the theoretical perspectives that provide the methodical constructs for the PLM misfit analysis. The theoretical foundation is based on cognitive fit theory and its extended models. This involves comprehending both business requirements and PLM package candidates by identifying misfit between them in terms of functions and processes.

Cognitive fit theory views problem solving performance as resulting from the interaction between the problem representation and the problem-solving task (Vessey 1991), which takes place within a mental model (Zhang 1997). The mental model is derived from the interaction of the appropriate problem-solving processes on the information in the problem representation and the given task (Vessey 1991). When the mental model has the characteristics of both the problem representation and the given task in human working memory, the solver then acts on the mental model to produce a solution (Aggarwal et al. 1996). Furthermore, if the types of information in the problem representation and the task match, a consistent mental model results and the problem-solving performance is enhanced. Such a phenomenon is referred to as cognitive fit.

Sinha and Vessey (1992) applied the cognitive fit model with a problem-solving tool to predict problem-solving performance. They found that matching the type of information provided by the tool to that in the task and the problem representation would lead to effective and efficient problem-solving performance. After several tests, they concluded that both the influence of a match between the problem-solving tool and the task, and that between the problem representation to the task enhance the performance. These results supported the cognitive fit theory for matching the problem-solving tool to the task and for matching the problem representation to the task. The conceptual model of their research approach is shown in Figure 1.

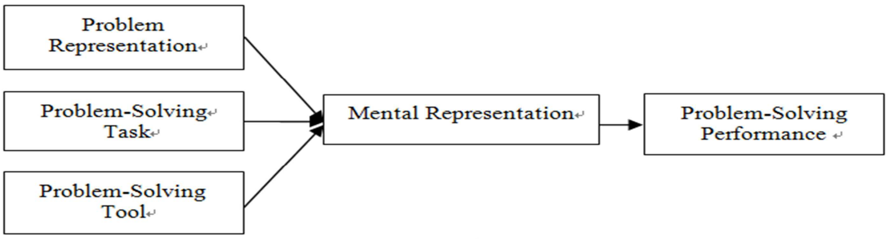


Figure 1. Extended Cognitive Fit Model with Problem-Solving Tool

In addition, several research works (Zhang and Norman 1994; Zhang 1997) argued that lots of cognitive tasks required the interwoven process of internal and external information. Shaft and Vessey (2006) therefore modified the cognitive fit model to reflect that both the internal and external representation of a problem domain and the interactions among them contribute to the mental model for a task solution, as shown in Figure 2. They developed and empirically tested a general model of interacting software maintenance tasks. Their findings concluded that cognitive fit moderated the relationship between the internal and external representation of the problem domain and the problem solving task.

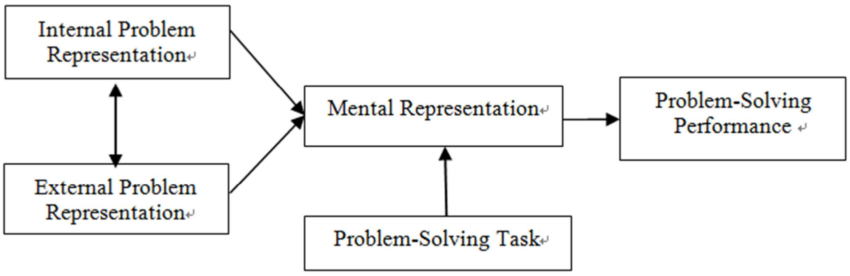


Figure 2. Extended Cognitive-Fit Model with Internal/External Problem Representations

3 PLM MISFIT ANALYSIS

3.1 PLM Misfit Analysis Model

PLM systems are extremely complicated COTS packages. Before implementing a PLM system, business analysts must comprehend both the business requirements and the corresponding specifications in a PLM package to identify any in-between misfits. One major difficulty in conducting such an analysis is the challenge of avoiding information overload that an analyst may experience due to large volume of information and complex relationship between business requirements and technical PLM specifications. To successfully identify the misfit, this large amount of complex information and relationship needs to be represented and presented to an analyst in a comprehensible form. The other difficulty lies in creating a mapping between business requirements and the PLM specifications. This is challenging because the business requirements are primarily described from the business perspective while the specifications are described primarily from the technological perspective.

These difficulties highlight the need for PLM misfit analysis methodology. As discussed in the previous section, cognitive fit theory provides a foundation to provide better identification and formulation of appropriate knowledge structures in long-term memory to enhance problem-solving task performance (Vessey 1991; Vessey and Galletta 1991; Vessey and Weber 1986). We apply these principles in the design of PLM misfit analysis model to focus analysts' choice and naturally restrict the knowledge structures used to solve misfit analysis problem.

We believe that the PLM misfit analysis as a whole can be viewed as the extended cognitive fit model with internal/external problem representations (Shaft and Vessey 2006) to reflect the fact that both the internal business requirements and external COTS PLM specifications, the interactions among them, and the matched problem solving tool contribute to the mental model for task solution (see Figure 3). The PLM misfit analysis task solution is determined by the analyst's comprehension of the business requirements and PLM specifications, as well as the knowledge of misfit identification task. When cognitive fit does not exist, the analyst's comprehension and the knowledge do not coincide, which may easily lead to the situation that the analyst's attention is devoted to comprehension of the information at the expense of misfit identification, resulting in lower misfit identification task performance. On the other hand, when the analyst's comprehension of the internal requirements and external specifications, and the misfit identification knowledge are matched, the cognitive fit occurs in the analyst's mental model, resulting in enhanced problem-solving performance.

More specifically, regarding the PLM misfit identification task, we need to consider the constructs that reflect the overall PLM misfit. Goodhue and Thompson (1995) proposed the model of task-technology fit (TTF) to indicate the impact of information system functionality on users' task requirements. A good match between technology and the task will result in positive enhancement of the users' task performance. The TTF model has been widely employed in various information system studies ever since. Furthermore, Gribbins et al. (2006) extended TTF to include process as one of the variables to influence IT fit. The fit between business processes and IT functionality will have a positive impact on the system performance. Therefore, we consider the two dimensions of functional misfit and process misfit as the misfit identification bases. That is, we represent both the internal business requirements and external PLM packages using the functional capabilities and workflow processes to facilitate the misfit identification task.

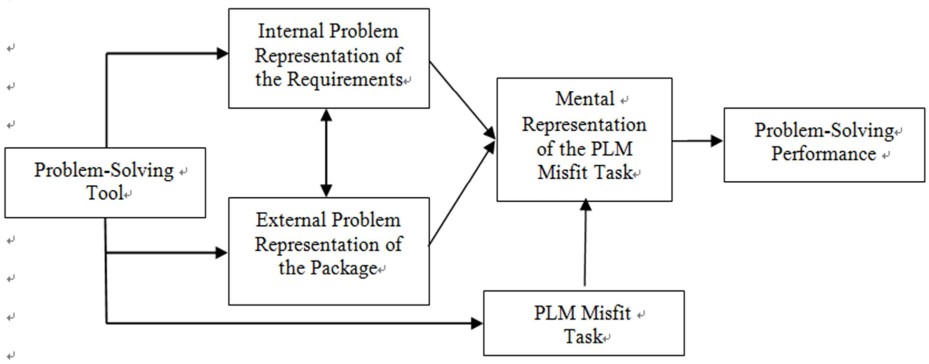


Figure 3. General Model of PLM Misfit Analysis

3.2 Problem-Solving Tool

In addition to the match between the problem representation and the problem-solving task, Sinha and Vessey (1992) show that problem-solving tool can be of help if the type of information emphasizes in the tool matches that in the task and the problem representation as indicated in the extended cognitive fit model (Figure 1). An appropriate problem-solving tool can ease the problem-solver's mental loads and enhance the cognitive fit. Therefore, it is essential to employ problem-solving tools to assist the PLM misfit analysis task.

To identify the misfit, we compare the functional capabilities and workflow processes desired by the business requirements with those provided by the COTS PLM package. Such a comparison can be done through the aid of a workflow modeling tool, which serves as the problem-solving tool in our case. Among all workflow modeling tools, we adopt the Petri nets (Petri 1962) to model the function-embedded workflow processes. Petri nets were originated from Automata theory. It is a design language to model business processes, and an analysis technique to verify the correctness of those processes. It adopts simple graphical representations to describe dynamic concurrent behaviors of workflows. Due to its visualization of graphical structure and rigidity of mathematic theory, Petri nets have been widely applied in the fields of engineering and computer science (Murata 1989; Pouyan et al. 2011).

The fit between Petri nets modeling tool and the misfit task representation is apparent. The misfit analysis should not be solely based on functionality comparison. The COTS PLM package may provide sufficient functional modules but not adhere to the common practices the company imposes. Instead, both functional capabilities and workflow processes that describe the common practices should be considered at the same time. Since Petri nets are well-known workflow modelling tools, its adoption indeed facilitates the misfit task representation. On the other hand, the fit between Petri nets modeling and the misfit problem representation is also noticeable. Petri nets adopt graphical structure to model the workflow. The graphical format can be easily understood and digested by human analysts. Therefore, the graphical information illustration indeed facilitates the misfit problem representation. We therefore believe that using Petri nets to model the workflow process, the performance by the misfit analyst can be enhanced as indicated from the extended CFT.

Mathematically defined, a Petri net consists of two disjoint sets, P (places) and T (transitions) and a binary relation F $\subseteq$ (P×T) $\cup$ (P×T) where places (drawn in circles) denote distributed states, transitions (drawn in rectangles) denote functions or tasks, and F denotes the process. Each (P×T) pair can be connected in a sequential manner or using AND/OR operands to form multple routes. In addtion, routing constructs of the process can be divided into sequential, parallel, conditional and iterative constructs (Grigorova, 2003). Figure 4 shows a Petri net example to represent a certain workflow process.

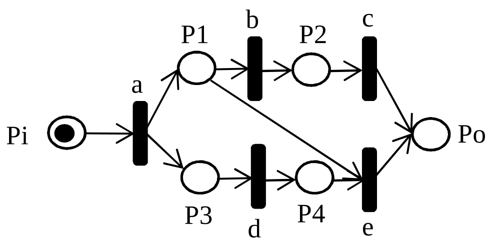


Figure 4. A Petri net example of a workflow process

In this example, the mathematical structure includes:

P= {*pi*, *p*1, *p*2, *p*3, *p*4, *po*}

T = {*a*, *b*, *c*, *d*, *e*}

F = {(*pi*, *a*), (*p*1, *b*), (*p*1, *e*), (*p*2, *c*), (*p*3, *d*), (*p*4, *e*), (*a*, *p*1), (*a*, *p*3), (*b*, *p*2), (*c*, *po*), (*d*, *p*4), (*e*, *po*)}

Apparently, if we have two Petri net process representations, F_1 and F_2, it is easy to judge their similarity or difference by comparing the (P×T) pairs in both F_1 and F_2 sets, which provides the foundation to derive the PLM misfit degree in our study.

3.3 Modeling Process

Based upon the extended cognitive fit theory and the proposed modeling tool, we develop the Petri nets modelling process for the representations of the internal business requirements and the external PLM specifications as shown in Figure 5.

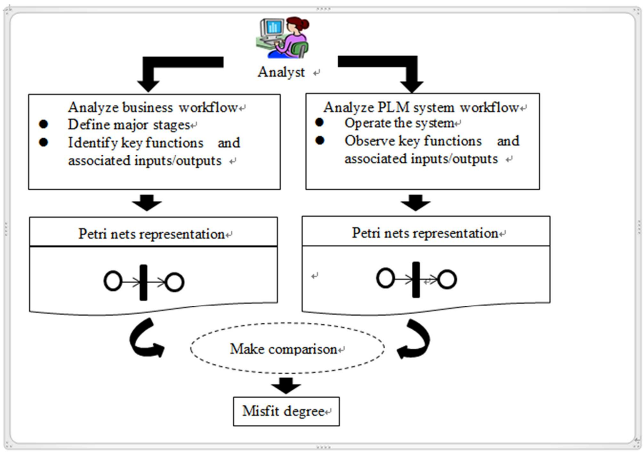


Figure 5. Workflow Modeling Process

The modeling process starts from the internal business requirements analysis. To gain better examination, we suggest a top-down approach to exposing the function-embedded workflow processes. That is, the analyst can first identify the major stages of the business requirements toward PLM, followed by their major functions and associated inputs/outputs in each of the stages. Functions are then connected via the inputs/outputs and routing constructs. The workflow process is then transformed into a Petri net representation.

On the other hand, the workflow of an external PLM system is also analyzed. By operating the system cautiously, the analyst records the major functions, their inputs/outputs, and the in-between connections. With all these kinds of information gathered, the workflow process of the PLM system can be described and transformed into a Petri net representation.

With both the internal and external function-embedded workflow processes modeled by Petri nets, we can easily perform the misfit analysis by comparing their F processes in the mathematical structure. Figure 6 shows an example of two Petri net representations. Both F_1 and F_2 are expressed as follows:

F_1 = {(pi, a), (a, p1), (p1, b), (b, p2), (p2, c), (c, p3), (p3, d), (d, po) }.

F_2 = {(pi, a), (a, p1), (p1, b), (b, p2), (p2, d), (d, p3), (p3, c), (c, p4), (p4, e), (e, po)}

If we would like to know how deviated F_2 is from F_1, we can first compute the relative complement of F_2 in F_1, i.e., $F_1 \setminus F_2$. Then the misfit degree can be defined as $|F_1 \setminus F_2| \div |F_1|$ where $|\bullet|$ the cardinality of a set $\bullet$.

The relative complement of F_2 in F_1 in tis example is

$F_1 \setminus F_2$ = { (p2, c), (c, p3), (p3, d), (d, po)}

Therefore, the misfit degree of F_2 away from F_1 is 4/8 = 50%, which reflects distinct discrepancy between these two processes, as opposed to the seemingly high overlaps among the functions both processes enclose. Again, this comparison result will be visualized via graphical representation for the analyst to easily comprehend.

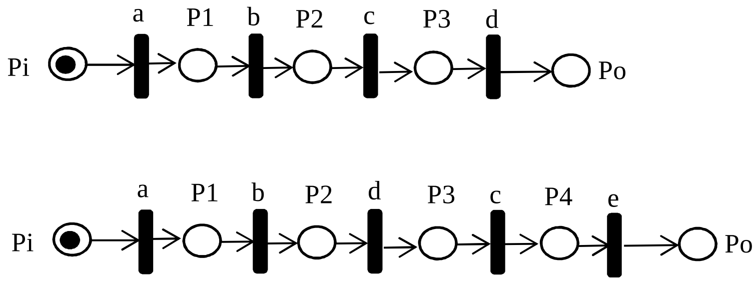


Figure 6. Two Petri Net Representations Under Comparison

4 CASE STUDY

Company A is the world's largest provider of independent semiconductor manufacturing services. Ever since founded, the company is devoted to delivering IC packaging and testing services to its customers. Currently, the company owns international sales locations including Taiwan, South Korea, Malaysia, Singapore, Japan, China, U.S.A., and many major cities in Europe. The number of employees is 66,000 worldwide and the annual revenue is around U.S. $8.3 billons in 2014.

The semiconductor industries are highly competitive. For company A, each order requested by customers is different in terms of packaging. Therefore, each order received in company A involves a new product development process. It is then essential for the company to quickly respond to the varying demands, and finish packaging and testing of the product in time. The importance of a PLM system to aid the new product development cannot be emphasized more for company A.

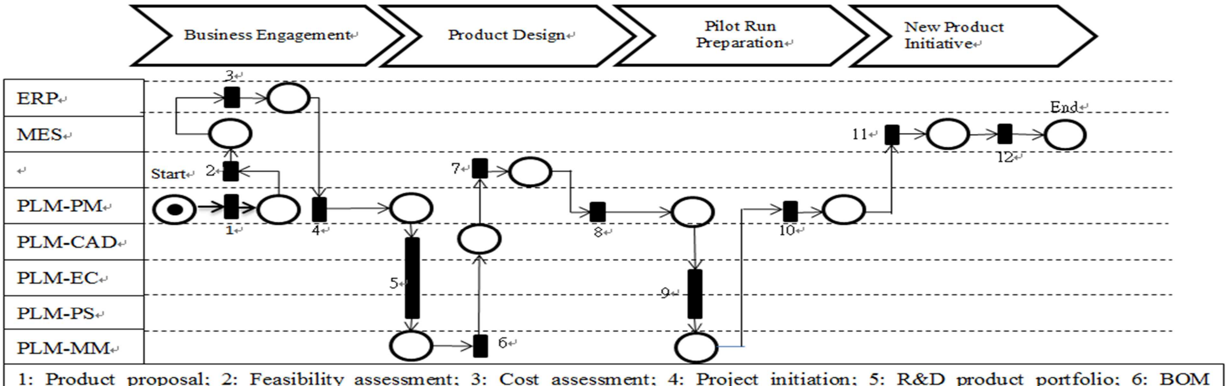
Since the need for the PLM system is apparent, the next issue for company A is to consider which COTS PLM package to adopt. To this end, the company assigns a special team to conduct the analysis via the misfit analysis model we proposed. Following the modelling process, the team first analyzes the company's internal business requirements of the PLM. The major stages for new product development process of company A can be categorized into business engagement, product design, pilot run preparation, and new product initiative (NPI). Table 1 lists key functions and their associated inputs/outputs in each of these stages. The function-embedded workflow process is then transformed into the Petri net depiction as shown in Figure 7, which indicates the problem-solving tool to aid the internal representation of business requirements in the PLM misfit analysis task.

After the internal problem representation is developed, the team then performs the external problem representation of a PLM package provided by a major PLM vendor. This PLM system carries similar new product development processes with an additional after-sales service process following the NPI stage. The workflow process is transformed into the Petri net depiction as shown in Figure 8.

Once both of the function-embedded workflows for the internal representation of business requirements and for the external representation of a PLM package are modeled, it is easy to perform the deviation analysis between these two Petri net depictions. The result can also be visualized via graphical representation as shown in Figure 9.

Table 1 New Product Development Process of company A

Stage	Inputs	Functions	Outputs	Supporting PLM functionality
Business Engagement	Customer demand	Proposal writing Order received Project initiation	Project proposal Feasibility report Cost analysis Product planning Product specifications	Project management Document management Workflow management
Product Design	Product specifications Product planning	Product packaging design Structure analysis Manufacturing process design	Product design portfolio BOM Product list Manufacturing process specifications Risk analysis	CAD Document management Workflow management Project management Product structure Engineering change
Pilot Run Preparation	Product design portfolio BOM Product list Manufacturing process specifications	Material management Process parameter settings Tool preparation	Process parameter setting document Tool preparation specifications	Document management Workflow management Engineering change
New Product Initiative	Process parameter setting document	Product packaging production Product testing production Reliability testing	Product testing report Reliability testing report	Document management Workflow management



1: Product proposal; 2: Feasibility assessment; 3: Cost assessment; 4: Project initiation; 5: R&D product portfolio; 6: BOM generation; 7: Process analysis; 8: Risk analysis; 9: Process parameters setup; 10: Tool preparation; 11: Product manufacturing; 12: Product testing

Figure 7 Petri Net Depictions of Business Requirements of Company A.

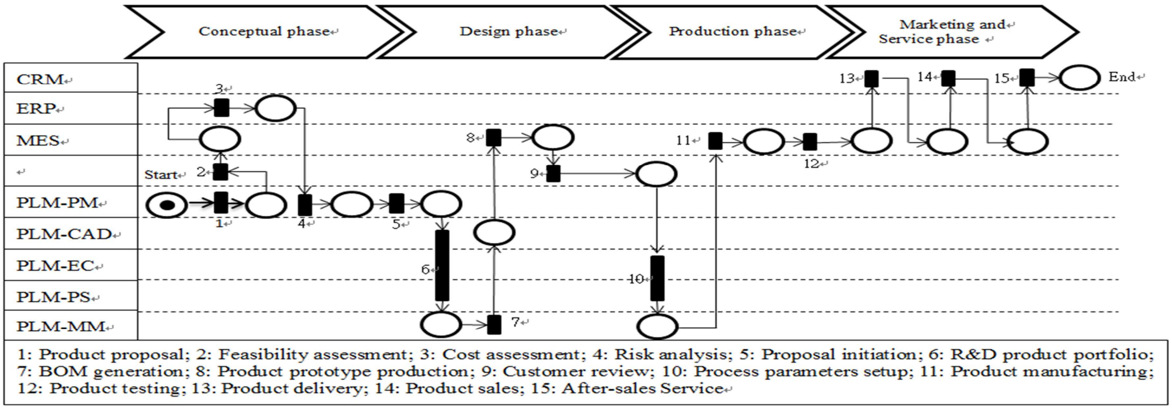


Figure 8 Petri Net Depictions of a PLM system workflow

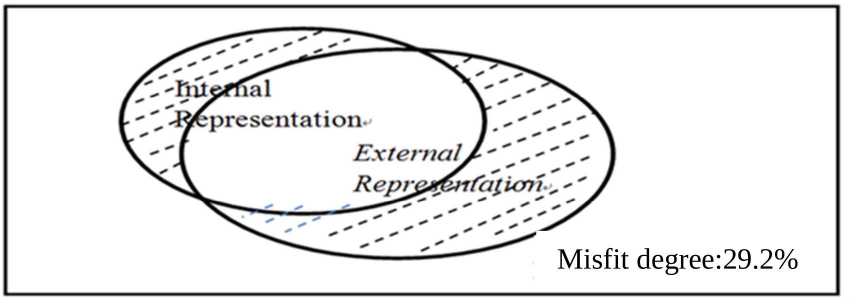


Figure 9. Visualization of Misfit Analysis Result

The misfit degree of the specific PLM package away from the business requirements can be derived from the relative complement. In this specific case, for example, the functional deviations lie in the process analysis and tool preparation desired by the company's business requirements, and in customer review and sales service provided by the PLM package. In addition, the major process deviations lie in when to perform risk analysis and the after-sales service. The misfit degree is calculated as 29.2% [1], which indicates a certain degree of misfit existing between business requirements and the PLM package provided, and therefore the team looks for other PLM packages for further misfit analysis until satisfied.

5 CONCLUSIONS

As more companies seek for capabilities to meet the dynamically changing market demands, to accelerate product time to market, and to coordinate resources in new product development, an appropriate COTS PLM system to adopt is essential for companies to overcome these challenges. An ex-ante analysis methodology for PLM misfit is the first step to promote heightened levels of PLM implementation success. In this research, we developed a general PLM misfit analysis methodology

[1] There are 7 (P×T) deviation pairs in $|F_1 \setminus F_2|$ and 24 (P×T) pairs in $|F_1|$. The misfit degree is thus calculated as 7/24 = 0.292

based on extended cognitive fit theory, which asserts both the internal and external problem representations, the interactions among them, and the matched problem solving tool contribute to the mental model for task solution. We further adopted Petri nets as the problem-solving tool to model the internal and external workflow processes. A real case is demonstrated to examine the feasibility of our proposed misfit analysis model.

From the viewpoint of managerial implications and academic research, our research results contribute to the solution for ex-ante PLM analysis in several ways. First, prior research on PLM evaluations seldom emphasizes on well examining the system misfit with internal business requirements and external PLM specifications. In fact, better understanding of the misfit sheds lights on the system needs and reduces the risk of implementation failure significantly. Therefore, our research pioneers a new direction for the PLM analysis.

Second, we analyzed the PLM misfit problem by following the problem-solving guideline of design science research methodology (DSRM) to integrate design as a major component of research (Peffers et al. 2008). DSRM aims to create innovations with effective and efficient analysis, design, implementation, and use of information systems (Denning 1997). In particular, Hevner et al. (2004) argued that any design artifact should rely upon the application of rigorous methods in its construction. Our study on the ex-ante PLM misfit analysis model is grounded on the extended cognitive fit theory. The process is further examined through the real case we illustrated. It therefore allows for researchers to follow in conducting any similar IS research works.

Although our study provided valuable insights into PLM misfit analysis, it is not yet completed. Especially, we aim to continue the work to develop a decision support system (DSS) for the ex-ante PLM misfit analysis task. More evidence should be provided for the DSS usability. Once the DSS is soundly developed, PLM consultants or adopting organizations can easily apply the system to identify the misfits and significantly reduce the risk of PLM implementations.

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