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A PLM COMPONENTS MONITORING FRAMEWORK FOR SMEs BASED ON A PLM MATURITY MODEL AND FAHP METHODOLOGY

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ABSTRACT

Right PLM components selection and investments increase business advantages. This paper develops a PLM components monitoring framework to assess and guide PLM implementation in small and middle enterprises (SMEs). The framework builds upon PLM maturity models and decision-making methodology. PLM maturity model has the capability to analyze PLM functionalities and evaluate PLM components. A proposed PLM components maturity assessment (PCMA) model can obtain general maturity levels of PLM components based on key performance indicators. Investment decisions should be made from the relatively weaker PLM components based on the results of PCMA. One developed method of the fuzzy analytical hierarchy process (Fuzzy AHP) is applied to extract the premier improvement component needed. The results of a first empirical assessment in a swimming industry are presented, which could be used as benchmark data for the other Small and Medium sized Enterprises (SMEs) to develop their own PLM components monitoring framework to increase the success of their PLM implementation.

INTRODUCTION

PLM is an important business improvement and strategic approach for enterprises. It supplies sets of solutions for collaboration, data management, and requirement management from a product's lifecycle starting date to its end-of-life. However, PLM is rather a concept than a system. Enterprises cannot adopt and implement PLM well at the right time. PLM maturity models have been developed and used to assess the PLM implementation situation and determine the relative position of the enterprise by comparing PLM maturity levels with other enterprises. First, we give an overview of PLM maturity models and study the benefits and restrictions of these maturity models in section A. Next, we define the maturity dimensions based on PLM functionalities in section B. In section C, multi-criteria decision making methodologies are studied in order to select the optimal PLM components among various PLM functionalities, in the right context, at the right time.

A) PLM maturity models

The success of PLM motivates a significant number of companies to adopt and implement PLM. PLM maturity models can make the implementation of PLM more accessible and better planned. Evaluation of PLM maturity is essential and advantageous. The objective of this section is to review the important works, and analyze the strengths and weaknesses of these models.

Several important maturity models are worth analyzing. CMMI *(Capability Maturity Model Integration)* **[7, 9-12]** for instance aims to improve the usability of maturity models by integrating several maturity models into one framework. The detail maturity levels and key process areas of CMMI are shown in **Table 1**. PDM *(Product Data Management)* maturity models **[1]** define the activities that a company needs to carry out at each stage and define a generic five-step process per stage, which is related to the as-is situation and to-be situation of the studied company. CPI *(Collaborative Product Innovation)* maturity model **[2]** proposes three unique stages of CPI based on the collaborative maturity of People, Processes, and Data. Batenburg **[3]** developed a PLM framework which is supported by a PLM maturity and alignment model to assess and guide PLM implementations. Sääksvuori Model **[4]** determines the maturity of a large international corporation for a corporate-wide PLM development program and develops business and PLM related issues. This model is a one-dimensional maturity model, which mixes different organizational aspects into one general dimension. Bensiek & Kuehn model **[5]** focuses on virtual engineering and aims to evaluate performance and improvement in SMEs. This model proposes a step by step improvement strategy to SMEs based on specialized SMEs requirements. Other PLM maturity models include PLMIG **[6]**, PCMA model **[14]**, and BPMM **[8]**. Next, in **Table 2** we discuss and compare five important works according to several aspects *(aim area, target users, etc.)*.

After studying these PLM maturity models, we can conclude as follows:

- Assess As-Is PLM implementation: most of these PLM maturity models have been applied to assess the As-Is situation of a company.
- Demand strategies to achieve To-Be PLM implementation: these models have not proposed strategies on how to go to the To-Be level.
- Relative importance of dimensions to the overall PLM maturity level: fewer works have discussed how to allocate structural weights of different dimensions to balance different business needs.

Our previous works **[13-15]** focused on proposing strategies to help companies achieve To-Be PLM implementation, and figure out the relative importance of PLM dimensions. This work will give a detailed description of PLM Components Maturity Model *(PCMA)* and will study the As-Is situation of the PLM components in section 1**.**

B) Maturity dimensions based on TIFOS framework

To better handle PLM functionalities which have been adopted in a company, our previous work proposed TIFOS framework **[14, 15]**. In **Figure 1**, the PLM functionalities are categorized into five dimensions based on Technoware, Inforware, Functionware, Orgaware, and Sustainware *(TIFOS)*. For example, the functionality of product data management in Functionware is to handle tons of information and data related to products.

Fifteen PLM components have been proposed based on these functionalities. These fifteen PLM components are maturity dimensions: techniques & practices, PLM software & applications, strategy & supervision, quality management, business management, maintenance management, BOM management, PDM, financial management, people, distributed collaboration management, workflow & process management, eco-friendly & innovation, life cycle assessment and green conception.

C) Decision Methodology of fuzzy analytic hierarchy process

The research questions are as follows: 1).which PLM component is the relatively weak one; and 2).which PLM component should be improved the first time. To solve these issues, we need to define the objective, the corresponding criteria, and the alternatives, and then calculate the relative weights of each alternative to achieve the objective. It is a typical multi-criteria decision making issue. Therefore, we study multi-criteria decision making methodologies.

CMMI Maturity Levels	Focus	Key Process Areas
1. Initial	Basic project management	Requirements management; Project planning; Project monitoring and control; Supplier agreement management; Process and product quality assurance; Configuration management.
2. Repeatable		
3. Defined	Process standardization	Requirements development; Technical solution; Product integration; Verification; Validation; Organizational process focus; Organizational process definition; Organizational training; Risk management; Decision analysis and resolution.
4. Quantitative	Quantitative management	Organizational process performance; Quantitative project management;
5.Optimizing	Continuous process improvement	Organizational innovation and deployment; Causal analysis and resolution.

TABLE 1. *CMMI Maturity Levels and Key Process Areas*

Maturity Models	CMMI [7,9-12]	Batenburg model [3]	PLMIG model [6]	Sääksvuori & Immonen model [4]	Bensiek& Kuehn model [5]
Aim area	Process Improvement	PLM	PLM	PLM	Virtual engineering
Target users	Managers/ Clients	Managers	Managers/ clients	Managers	SMEs
Distribute	Open	Open	Restricted	Open	Open
Dimensions	CMMI: various process areas (See **Table 1**).				
	Batenburg model: 5 dimensions (strategy and policy, management and control, organization and processes, people and culture and information technology).				
	PLMIG model: 5 dimensions (dat a, people, processes, technology and knowledge).				
	Sääksvuori & Immonen model: 1 dimension (PLM generic maturity).				
	Bensiek & Kuehn model: 5 action fields (data management, re-use, documentation, product analysis, culture).				
Levels (short descriptions)	5 levels	4 levels	5 levels	5 levels	4 levels
Benefits	CMMI: separates organizational functions, sets process improvement goals and priorities, provides guidance for quality processes, and provides a point of reference for appraising current processes.				
	Batenburg model: Balance between dimensions, easier to understand and apply, provides benchmark data to other maturity models.				
	PLMIG model: Gives advice dvices to next steps, identifies gaps among levels, coordinates between different dimensions.				
	Sääksvuori & Immonen model: Defines criteria for reaching each level requirements, evolves from level 1 to level 5 while PLM maturity grows.				
	Bensiek& Kuehn model: Offers a step by step performance improvement to SMEs, application can be finished in short time.				
Restrictions	CMMI: SMEs less likely to benefit from CMMI, time consuming questionnaires, CMMI deals with which processes should be implemented, but not so much with how processes can be implemented.				
	Batenburg model: focuses on improvement towards inter-organizational level.				
	PLMIG model: application areas quite narrow.				
	Sääksvuori & Immonen model: should be refined by more elaborated PLM maturity assessment framework such as Batenburg model.				
	Bensiek & Kuehn model: application areas quite narrow.				

TABLE 2. *Comparison of Some PLM Maturity Models*

The obtained data about PLM components have uncertainty and fuzzy features , which can be solved by triangular fuzzy numbers. A number of methods have been developed to handle fuzzy triangular numbers. Van Laarhoven & Pedrycz **[16]** suggest a fuzzy logarithmic least squares method to obtain the fuzzy weights from a triangular fuzzy comparison matrix. Buckley **[17]** utilizes the geometric mean method to calculate fuzzy weights. Chang **[18]** proposes an extent analysis method, which derives crisp weights for fuzzy comparison matrices. Xu **[19]** provides a fuzzy least squares priority method *(LSM)*. Csutora & Buckley **[20]** propose a Lambda-Max method, which is the direct fuzzification of the well-known λ-max method. Mikhailov **[21]** develops a fuzzy preference programming method, which also derives crisp weights from fuzzy comparison matrices. Srdjevic **[22]** proposes a multi-criteria approach for combining prioritization methods within the AHP, including additive normalization, eigenvector, weighted least-squares, logarithmic least-squares, logarithmic goal programming and fuzzy preference programming *(FPP)*. Wang et al. **[23]** presents a modified fuzzy logarithmic least square method. Yu & Cheng **[24]** develop a multiple objective programming approach for the ANP to obtain all local priorities for crisp or interval judgments at one time, even in an inconsistent

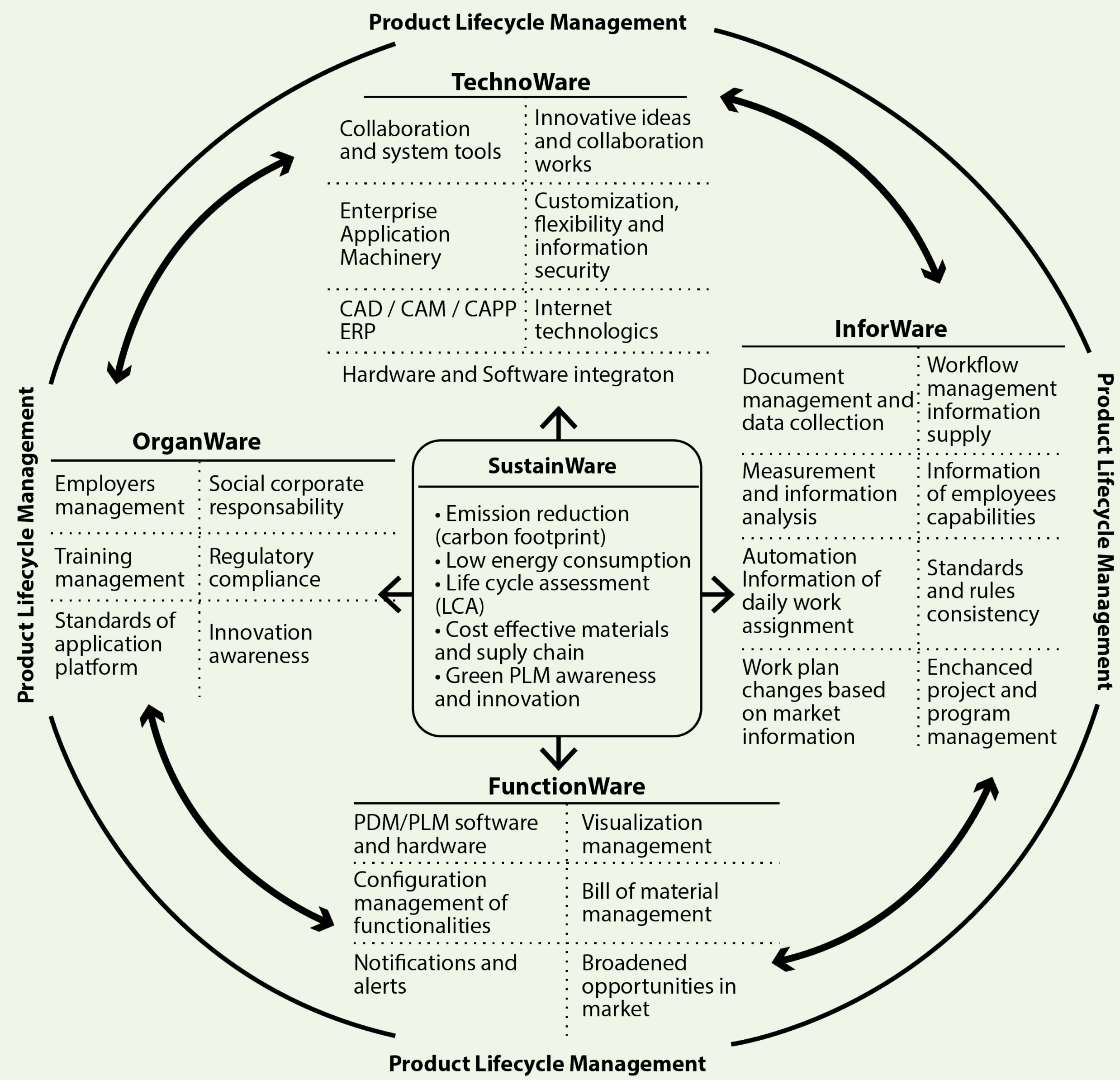

FIGURE 1. *TIFOS Framework and Categorized PLM functionalities*

situation. Huo et al. **[25]** propose a new parametric prioritization method to determine a priority vectors in AHP.

FPP method **[21]**, as a reasonable and effective means, is adopted in this study. This method can obtain more precise weights of alternatives and can acquire the consistency ratios of fuzzy pairwise comparison matrices without an additional study, and the local weights can be easily solved by Matlab. Besides, FPP method solves the various shortcomings of different fuzzy AHP methodologies **[26]**.

This paper is structured as follows: PLM components maturity model are proposed in section 1, and the maturity situation of PLM components in a swimming industry are also studied. In section 2, FAHP methodology is adopted to rank the weights of PLM componentsand help a company make investment decisions . In section 3, five different PLM models which contain different PLM components are discussed. Section 4 proposes a PLM components monitoring framework by combining a PLM maturity model and FAHP methodology. Section 5 concludes our work.

1. The proposed PLM Components Maturity Assessment Model

PLM Components Maturity Assessment model *(PCMA)* **[14]** considered viewpoints of different maturity models and analyzed key performance indicators of PLM components. This maturity model follows the principle structure of CMMI by using the same maturity levels and structured questionnaires. CMMI defined process maturity is developed incrementally from one level to the next level and it does not allow skipping levels. This limitation of CMMI will result in misleading interpretations for small and middle enterprises *(SMEs)*. PCMA model concerns the limitation and provides a clear gap among each level. Our previous work gives detailed information of fifteen components in each maturity level in which the maturity is assessed separately, and the items of maturity level descriptions are outlined in **Table 3**.

We give an example in **Table 4** for how to evaluate the PLM components maturity level by using PCMA model. Two PLM components *(C1 and C2)* are selected in Technoware, several KPIs *(C1_K1 to C1_K5)* are selected for each component, and an evaluator can put the value of each level. The maturity level is gotten by calculating the average value of all KPIs' value which belong to a specific PLM component.

The issue is how to make the industries understand KPIs which are proposed and get the accuracy value of these KPIs. The solution is to categorize these KPIs by considering their contribution to return on investment. The categories are cost, time, quality, defects, safety, integrity, and ownership. We give an example in **Table 5**. The component of product data management is selected, and takes the 'cost' category as an example. Four KPIs are proposed based on 'cost' category, and then the detailed content is explained for each KPI, and specific questions are proposed based on the contents. These specific questions can help the companies obtain the exact value of each KPI.

Table 6 gives an example of calculations in the final maturity level of the product data management based on the information proposed in **Table 3**, **Table 4**, and **Table 5**. The data is from a swimming industry, which is located in Chengdu *(south of China)*. This company focuses on three categories: cost, time, and quality. KPIs are proposed based on these three categories. Questions are made to help the company obtain the values of these KPIs. Maturity level is attained based on KPIs. The final maturity level is the average score of all KPIs, and product data management is level 2 for this company. The maturity level of all PLM components for this swimming industry is shown in **Figure 2**.

2. PLM components selection based on FAHP methodology

Adopt fuzzy triangular numbers to express linguistic terms

We can get the As-Is situation by using the maturity model PCMA, then the issue is how to help company to improve the expected To-Be situation by proposing specific strategies.

Define the maturity level of PCMA from level 1 to level 5 as: very low, low, middle, high, and very high.

Then define the value range for each level. The Linguistic terms *(very low, etc.)* can better explain the uncertainty of each level. The membership function of triangular fuzzy numbers is used to express linguistic terms and has the feature of piece-wise continuous and strictly monotone. The definition and membership function from 'very low' to 'very high' is shown in **Table 7**. **Figure 3** is used to describe the structure of membership function. The aim to set a range for each level is to help questionnaire responders when they do not know the exact value of the corresponding KPIs.

FPP Methodology calculation steps

FPP is an approach which can guarantee the preservation of the preference intensities and provide a well interpretive consistency index. The steps of this methodology are as follows:

Step 1. Develop the fundamental objective hierarchy. Group the related criteria, and structure the hierarchy in **Figure 4**. The objective is to find the optimal PLM component to invest based on several criteria *(cost, time, urgent, and expected income)*. The alternatives are PLM components. It is not necessary for a company to own all fifteen components. This study just focuses on the specific situation of a company.

Step 2. Construct the fuzzy pairwise comparisons matrix based on **Table 7** and **Figure 3**. In our work, we start by comparing the alternatives with their importance to each of the criteria. Then we compare the criteria with respect to their importance to the goal. The equation expression of fuzzy pairwise comparison matrix is:

$$\tilde{A} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \qquad (1)$$

Where a_{ij} is a triangular fuzzy number to show the decision-maker's preference of i over j, and $a_{ij} = 1/a_{ji}$. The value of each variable follows **Table 7**. Take 'Product data management' and 'configuration management' as an example, the first level comparison from 'criteria' to 'objective' for these two PLM components is:

$$\tilde{A}_{goal} = \begin{pmatrix} Goal & Cost & Time & Urgent & Income \\ Cost & equal & VH & L & M \\ Time & 1/VH & equal & VL & M \\ Urgent & 1/L & 1/VL & equal & M \\ Income & 1/M & 1/M & 1/M & equal \end{pmatrix} \qquad (2)$$

Maturity Levels	Our Work (Items for PLM components Maturity Levels)
1 Ad-hoc	• The activity is done with expediency • Nobody is responsible for PLM • Documentation is at the lowest point to satisfy operational needs • PLM software system and processes have deficiencies
2 Managed	• The activity is defined and managed, but it is repetitious • Documentation and records are carefully studied • Mutual actions are finished in processes and departments • PLM systems are involved and used in the proper places • No effort has been made to consider recycling
3 Defined	• The activity is formalized and supported by standards • Documentation and records are studied and shared • Personal actions and mutual actions are carried out efficiently • PLM systems are easily implemented • There is environmental awareness
4 Quantitatively managed	• Activities run smoothly • PLM systems cooperate with other enterprise systems • The products run efficiently and are effective • Progressively eliminates errors and failures
5 Optimized	• The activity runs optimally • PLM system helps company make improved decisions • Best practices and innovative ideas are considered

TABLE 3. *PCMA Maturity Level and Corresponding Content*

TIFOS Framework	PLM Components	KPIs	Levels				
			1	2	3	4	5
TechnoWare	C1: Techniques & Practices	C1_K1: % of new products		•			
		C1_K2: Produce products accuracy			•		
		C1_K3: Running cycle time				•	
	C2: PLM software & Applications	C1_K4: Installation Planning costs			•		
		C1_K5: % of Waste...			•		

TABLE 4. *PLM components and corresponding key performance indicators*

	Product Data Management			
	KPIs	Description	Questions	Value
Cost	1. Average Data storage cost	Measure of all data storage/number of documents (categories)	How much do you pay for information storage (including hardware and software)?	
			How many documents do you have to manage?	
			How much memory do you need to manage information? (GB)	
	2. Average Document using frequency per day	Number of document using frequency/number of all documents using frequency	How many documents do you use? More than 30 minutes per day?	
	3. Average Document finding time-to-cost	How long it takes for users to find it in seconds/minutes	How much time do you spend to find the documents you use every day?	
	4. Average using cost per document	Average cost for printing and creating the .pdf per document	How much do you spend to use these documents (including printing, creating the .pdf)	

TABLE 5. *Product Data Management component and its' corresponding key performance indicators*

	Product Data Management				
Categories	**KPIs**				**Level**
KPIs for cost	1. Average Data storage cost	2. Average Document using frequency per day	3. Average Document finding time-to-cost	4. Average using cost per document	4
KPIs for Time	1.Acceptance necessary time:	2.Average number of training hours per employee	3.Average time for data change version	4.Average time for data creation	2
KPIs for Quality	1. Data Accuracy Ratio	2. Data Duplication Ratio	3. Potential same data (data cleaning)	-	2
Final Level	-	-	-	-	2

TABLE 6. *Product Data Management component and its' maturity level*

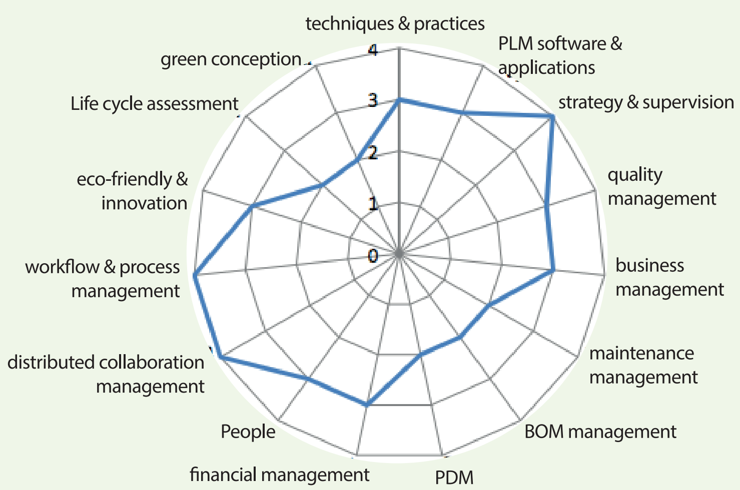

FIGURE 2. *Maturity Level for fifteen PLM components in a swimming industry*

Fuzzy numbers	Definition	Membership function
0.1	Very Low (VL)	(0, 0.1, 0.3)
0.3	Low (L)	(0.1, 0.3, 0.5)
0.5	Middle (M)	(0.3, 0.5, 0.7)
0.7	High (H)	(0.5, 0.7, 0.9)
0.9	Very High (VH)	(0.7, 0.9, 1)

TABLE 7. *Definition and membership function of fuzzy scale*

The value of $\tilde{A}_{goal}$ can be defined by **Table 6**

$$\tilde{A}_{goal} = \begin{pmatrix} \hat{1} & 0.9 & 0.3 & 0.5 \\ 1/0.9 & \hat{1} & 0.1 & 0.5 \\ 1/0.3 & 1/0.1 & \hat{1} & 0.5 \\ 1/0.5 & 1/0.5 & 1/0.5 & \hat{1} \end{pmatrix} \quad (3)$$

On the basis of fuzzy triangular numbers definition, the exact value of $\tilde{A}_{goal}$ is:

$$\tilde{A}_{goal} = \begin{pmatrix} (1,1,1) & (0.7,\ 0.9,\ 1) & (0.1,\ 0.3,\ 0.5) & (0.3,\ 0.5,\ 0.7) \\ (1,1.1,1.42) & (1,1,1) & (0,\ 0.1,\ 0.3) & (0.3,\ 0.5,\ 0.7) \\ (2,3.3,10) & (3.3,10,100) & (1,1,1) & (0.3,\ 0.5,\ 0.7) \\ (1.42,2,3.3) & (1.42,2,3.3) & (1.42,2,3.3) & (1,1,1) \end{pmatrix} \quad (4)$$

Step 3. Derive a crisp priority vector w = *(w1,w2, …, wn)*^{T} by using FPP. The problem is to derive a crisp priority vector w = *(w1,w2, …, wn)*^{T}, and the priority ratios w_i/w_j are approximately within the scopes of the initial fuzzy judgments, or equivalently.

$$l_{ij}(\alpha) \lesssim \frac{wi}{wj} \lesssim u_{ij}(\alpha) \quad (5)$$

Where the symbol '$\lesssim$' denotes the statement "fuzzy less or equal to".α means decision maker's preference *(α-cut)*, and $l_{ij}(\alpha), u_{ij}(\alpha)$ is the lower and upper bound of fuzzy triangular numbers.

For instance, the priority ratios w_i/w_j can be the ratios between 'product data management'/'configuration management'.

Step 4. Propose Membership function to measure the ratio in equation 5. Each crisp priority vector w satisfies the double-side inequality with some degree, which can be measured by a membership function, linear with respect to the unknown ratio w_i/w_j.

$$\mu_{ij}\left(\frac{w_i}{w_j}\right) = \begin{cases} \dfrac{\dfrac{w_i}{w_j} - l_{ij}}{m_{ij} - l_{ij}}, & \dfrac{w_i}{w_j} \le m_{ij} \\ \dfrac{-\dfrac{w_i}{w_j} + u_{ij}}{-m_{ij} + u_{ij}}, & \dfrac{w_i}{w_j} \ge m_{ij} \end{cases} \quad (6)$$

The membership function takes the following values:

$$\mu_{ij}\left(\frac{w_i}{w_j}\right) \in [0,1],\ if\ l_{ij} \le \frac{w_i}{w_j} \le u_{ij} \quad (7)$$

$$\mu_{ij}\left(\frac{w_i}{w_j}\right) \in (-\infty,0),\ if\ \frac{w_i}{w_j} < l_{ij}\ or\ \frac{w_i}{w_j} > u_{ij} \quad (8)$$

It takes the maximum value of 1 when

$$\frac{w_i}{w_j} = m_{ij} \quad (9)$$

For example, this membership function can mean the ratio function of 'product data management/configuration management'.

Step 5. Propose two assumptions to obtain the optimal crisp priority vector. For example, it means finding the optimal value of 'product data management/configuration management'. The solution to the prioritization problem by the FPP method is based on two main assumptions. The first one requires the existence of non-empty fuzzy feasible area P on the *(n-1)* dimensional simplex Q^{n-1}:

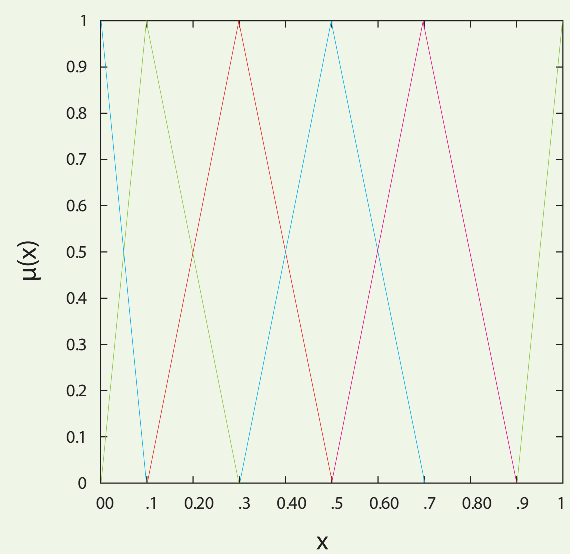

FIGURE 3. *Structure of Fuzzy triangular numbers*

$$Q^{n-1} = \{w_i \mid \sum_{i=1}^{n} w_i = 1, w_i > 0\} \quad (10)$$

The membership function of the fuzzy feasible area P is given by:

$$\mu_p(w) = \min_{ij}\{\mu_{ij}(w) \mid i = 1,2,\ldots,n-1,\ j = 2,3,\ldots,n,\ j > i\} \quad (11)$$

The second assumption of the FPP method specifies a selection rule, which determines a priority vector, having the highest degree of membership in the aggregated membership function. It can easily be proved that μp*(w)* is a convex set, so there is always a priority vector $w^* \in Q^{n-1}$ that has a maximum degree of membership.

$$\lambda^* = \mu_p(w^*) = \max_{w \in Q^{n-1}} \min\{\mu_{ij}(w)\} \quad (12)$$

Step 6. Transform the problem into a bilinear program based on the rule of Bellman and Zadeh **[27]**. The equation is as follows:

$$\begin{aligned}
&\max \lambda \\
&s.t. \\
&(m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \le 0; \\
&(u_{ij} - m_{ij})\lambda w_j + w_i - u_{ij} w_j \le 0; \\
&\textstyle\sum_{k=1}^{n} w_k = 1; \\
&w_k > 0, \\
&i = 1,\ldots,n-1,\ j = 2,\ldots,n,\ j > i,\ k = 1,\ldots,n
\end{aligned} \quad (13)$$

Implementation in real-word cases

The data was selected in a swimming industry from January to July. The reason this company was selected is because security and sustainability are the first issues to be considered in China. Take three widely used PLM components as the alternatives, which are: product data management *(C1)*, new product development *(C2)*, and configuration management *(C3)*. The goal is to help the manager make the decision of which component should be first invested in. The criteria are cost to invest, time to invest, urgent to invest, and the expected income after invest.

This company is a small and mid-sized enterprise. They need to update the product data management to afford the increasing information, at the same time, new security software investments should be made to protect the customers' safety, and configuration management should be updated to configure new requirements. Four pair-wise comparison matrixes are established based on four criteria. The aim of these matrixes is to find the optimal components to balance the cost, time, urgent need, and expected income. The weights which are obtained from these matrixes are called local weights. After that, build a global matrix to determine the relative weights of cost, time, urgent, and income to obtain the global weights. The final weights are gotten by combining local weights and global weights.

Next, we build a fuzzy comparison pairwise matrix to obtain the local weights and global weights. **Table 8** gives the data of fuzzy comparison matrix based on 'cost' criterion. **Table 9** shows the comparison from criteria to global goal. Apply FPP steps in section 3.2 to obtain the final weights of three components in **Table 10**. 'Product data management' is the optimal component for investment based on the final weights.

3. New swift of PLM models in smes

In the market, many companies adopt on-premise PLM model which includes various PLM components. But the on-premise model is too heavy for small and middle enterprises *(SME)*. The cost of an on-premise PLM model is expensive and many functionalities of this model are useless for SMEs. In order to help SMEs to implement well-planned PLM systems, the swift on-premise PLM mode vendors for 'as SaaS', 'in the cloud', 'in-a-box' and 'out-of-the-box' compromise the shortcomings of the on-premise mode. Work should be done to discover how advantageous these new modes are to SMEs by analyzing key performance indicators. Firstly, we will discuss what the PLM modes are.

The detail information of five PLM models is as follows:

- On premise, hosted in your company, which is the traditional PLM system.
- PLM-in-the-cloud appears because on-premise PLM model cannot efficiently share product data with stakeholders.
- As SaaS (Software-as-a-Service) in rental mode and hosted in the Cloud. This mode has an overlapping between cloud computing. Cloud computing can refer to several different service types, including Application/Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS).
- PLM-in-a-box is to implement and host multiple PLM instances in one Box. The idea regards corporate wide PLM implementations with multiple business units and sites.
- PLM-out-of-the-box typically refers to software that users install and immediately start using, with full access to all program functions and features. PLM-out-of-the-box is extended to a solution that seamlessly integrates one system (e.g., ERP) with another system (e.g., CAD).

In the future the PLM components which are needed in a company will be analyzed, studying the PLM components in these five PLM models, and figure out which type of PLM model is the optimal option for a specific company.

4. A framework to Monitor PLM maturity level

In this section, we propose a PLM component monitoring framework *(***Figure 5***)* to monitor the situation of

Cost	C1	C2	C3
C1	Equal	H	VH
C2	1/H	Equal	H
C3	1/VH	1/H	Equal

TABLE 8. *Fuzzy comparison pairwise matrix for getting local weight*

	Cost	Time	Urgent	Income
Cost	Equal	VH	L	M
Time	1/VH	Equal	VL	M
Urgent	1/L	1/VL	Equal	M
Income	1/M	1/M	1/M	Equal

TABLE 9. *Fuzzy comparison pairwise matrix for getting global weight*

	C1	C2	C3	Global weight
Cost	0.6286	0.2854	0.1014	0.1857
Time	0.5058	0.3230	0.1676	0.1296
Urgent	0.3378	0.4305	0.2317	0.3823
Income	0.2485	0.4251	0.3264	0.2845
Final weight	0.3821	0.3804	0.2220	

TABLE 10. *Local weights and global weights*

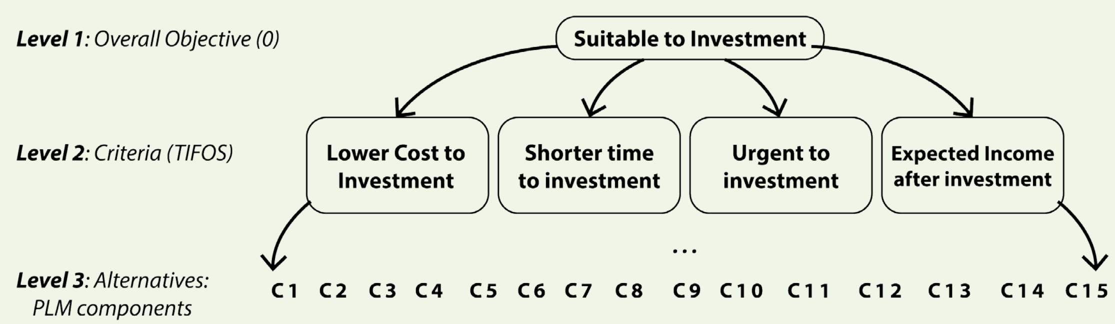

FIGURE 4. *FAHP hierarchy towards of PLM components selection*

PLM components. This framework is combined in section 1, section 2, and section 3.

In this framework, we adopted PCMA model to evaluate the as-is maturity situation of PLM components. Next, various KPIs are studied in order to help propose the strategies regarding the PLM component that should be selected to invest in. Then, the FPP methodology is used to determine the relative considerable PLM component. After that, a detailed report will be generated for PLM components' current maturity level, and the weights obtained of all PLM components to determine the optimal selection. Based on the optimal selection, the maturity situation of a company will achieve a higher level after a specific PLM component has been improved. Then, the PLM components that should be used in a specific company are determined, the suitable PLM models to be invested in this company are based on cost, quality, time, etc. Finally, the feedback loop in **Figure 5** indicates that it is required to re-assess the PLM maturity with a certain frequency, say every six months or once in a year. By doing so we can measure whether the PLM components are on track in reaching the new maturity level, and the adopted PLM model is the optimal option in terms of cost, time, quality, etc.

5. Conclusion

Studying the features and functionalities of PLM is essential for companies and researchers. In many companies failures are due to the lack of a clear understanding of what PLM is. Our work studies the PLM maturity models and functionalities of PLM in order to find a solution for this issue. We group all PLM components into TIFOS framework based on PLM functionalities, and propose PCMA maturity model to evaluate the strength and weakness of PLM components.

This work focuses on helping the SMEs to choose the right PLM model together with the right PLM components at the right time by applying PLM components monitoring framework in section 5. A case study in a Chengdu swimming industry shows that PLM components in Sustainware and Functionware is relatively weak. This company has a tough decision to make about which component should be first invested in: 'product data management', 'new product development', and 'configuration management'. Decision results are obtained by developing FPP methodology. 'Product data management' is the optimal choice when compared with other components in terms of lower cost, shorter time, quality, and expected income.

Key performance indicators of PLM models will be further studied. The next step of this work will focus on measurement experiments of PLM models in SMEs by using KPIs.

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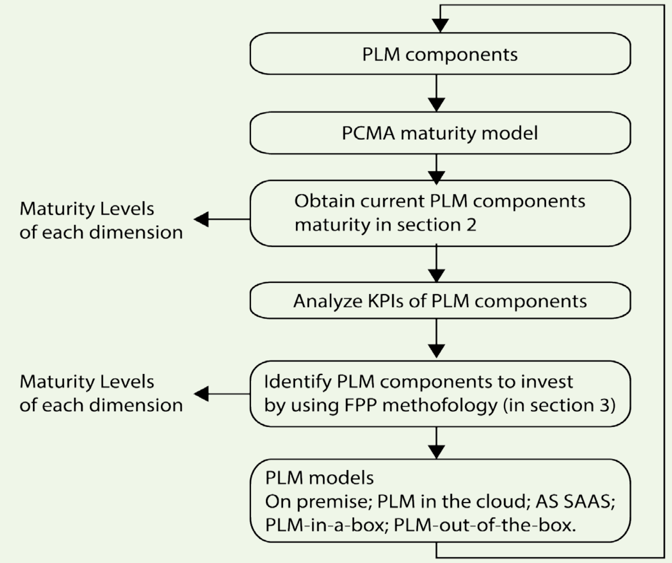

FIGURE 5. *PLM components monitoring framework*

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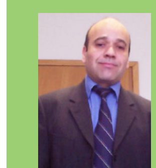

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