PLM Maturity Evaluation and Prediction Based on a Maturity Assessment and Fuzzy Sets Theory

Haiqing Zhang, Aicha Sekhari, Yacine Ouzrout, Abdelaziz Bouras

PLM Maturity Evaluation and Prediction Based on a Maturity Assessment and Fuzzy Sets Theory

Haiqing Zhang[*], Aicha Sekhari[*], Yacine Ouzrout[*], Abdelaziz Bouras[†*]

***** DISP laboratory, University Lumière Lyon 2, France, 160 Bd de l'Université 69676 Bron Cedex

† Computer Science Department - Qatar University, ictQATAR, Box. 2731, Doha, Qatar

haizhang@mail.univ-lyon2.fr

{yacine.ouzrout, aicha.sekhari}@univ-lyon2.fr

abdelaziz.bouras@qu.edu.qa

Abstract: Companies adopt PLM maturity models to evaluate PLM implementation and recognize relative positions in PLM selection to better harness PLM benefits. However, the majority traditional PLM maturity models are relative time-consuming and energy-consuming. This work focuses on proposing a fuzzy extended PCMA (**P**LM **C**omponents **M**aturity **A**ssessment) maturity model to brightly evaluate the gradual process of PLM maturity accompaniment with time changes, which aims to reduce the efforts spent on maturity evaluation. The proposed PCMA uses triangular fuzzy elements to express maturity levels that can solve vague and complexity issues in PLM evaluation. The proposed fuzzy PCMA is tested by two Chinese firms. The first evaluation uses PCMA maturity model to obtain the maturity levels for a Chengdu company in 2010. The PLM maturity for this company from 2011 to 2013 is conducted by the fuzzy extended PCMA maturity model through inputting the KPIs' value. Fuzzy extended PCMA is also used to predict the maturity level for a Shanghai company. A comparison of the results obtained by fuzzy extended PCMA model and the real-life situation verify the effectiveness of the proposed model.

Keywords: PLM maturity model, Triangular fuzzy elements, Key performance indicators, PLM maturity evaluation, PLM components maturity assessment (PCMA)

1. Introduction

Product Lifecycle Management (PLM) manages a company's product from its early conception stages to the final disposal stages. PLM drives cost reductions, facilitates reducing lead time, and improves product quality [1, 13]. To pave the way toward obtaining the true benefits of PLM, the users should have a clear understanding of PLM definition, PLM components, PLM functionalities, and the relative position of PLM implementation. To address full PLM functionalities, Vengugopalan et al.'s work [2] decomposes the functionalities of PLM into four major dimensions based on the TIFO Framework (TechnoWare, InfoWare, FunctionWare, and OrgaWare). Vengugopalan et al.'s work focuses on the functionalities in beginning of life phase and middle of life phase. The functionalities in the end of life phase, in terms of: DFE (Design for Environment), TRIZ (Theory of Inventive Problem Resolution), and LCA (Life Cycle Assessment), need to be integrated and collaborated with PLM to satisfy performance requirements. Thus zhang et al. [3-4] extends the TIFO framework into TIFOS framework by adding a new dimension called SustainWare in consideration of sustainability.

Several basic components construct PLM functionalities. Stark et al. [5] state that PLM is a holistic approach and PLM contains nine PLM components, which consist of products, data, applications, processes, people, work methods, and equipment. Abramovici et al. [6] define five PLM levels, and each PLM level has several concrete PLM components that can have interdependencies with other components. Fifteen different types of PLM components in TIFOS framework is collected and described by zhang et al.[3], which include 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. This work will adopt these fifteen PLM components to analyze PLM implementation.

Many companies start to enlarge investment of PLM to reap PLM benefits. Decision-makers have yet to clarify PLM adoption and implementation, because of PLM being large and complex. Measuring PLM components adoption, running condition, and maturity situation, can reflex implementation of PLM and provide guidelines for decision-makers in a company. This work aims to solve the following research questions:

1. *How companies can **self-evaluate** a PLM implemented situation and **recognize the gradual process** of PLM adaptation in present and future years?*
2. *How to guide companies to **automatically evaluate a PLM implemented situation based on the existing value** instead of setting new values for exhausted evaluation criteria to measure maturity level every year?*

To solve the two questions we study literature works as well as experimental research. In literature studies, PLM maturity models [1, 7-12] identify different maturity growth stages that can evaluate PLM adoption; but these maturity models are still weaker to aid companies in self-evaluation PLM and to recognize the gradual process of PLM accompaniment through time changes. Most of the PLM maturity models define several maturity levels and describe the differences between each level by using linguistic terms. The linguistic terms have a feature of uncertainty and vagueness, which makes the decision-makers, not able to input accurate values for each maturity level. The third research question is:

3. *How can companies **maximally keep and express decision-makers' intentions,** while evaluating PLM implementation by using PLM maturity models?*

A fuzzy extended PCMA maturity model is proposed to be able to resolve these research questions. This model is used to evaluate and predict the gradual process of PLM maturity by using the first year's evaluation results and the KPIs values to reduce the efforts spent on PLM evaluation. The proposed maturity model is examined by a structured survey. The experimental research is conducted to validate the survey and the fuzzy extended PCMA maturity model. The survey was conducted in two Chinese firms in 2013. The work is structured as follows: section 2 gives the literature view of PLM maturity models and fuzzy sets theory; section 3 describes the running mechanism of PCMA maturity model; section 4 proposes a fuzzy extended PCMA maturity model to automatically evaluate PLM maturity; section 5 examines the proposed fuzzy extended PCMA by two case studies; section 6 concludes our work.

2. State of the art

2.1 PLM maturity models

PLM maturity models provide guidelines to PLM implementation for any given company. CMMI (Capability Maturity Model Integration) [7-9] has the potential to significantly improve the organization's profitability, because it has the abilities to evaluate an organization's maturity and process area capability. CMMI defines multiple process areas, and provides the goals for each level of implementation. Yet it has not proposed **a roadmap to implementation or identification of key process improvement areas**. A company usually needs to prepare lots of documents to suit CMMI assessment in China. These prepared documents are specially used for one-time assessments. Strategies have not been given to analyze the weaker items obtained from the assessments, which makes the companies cannot receive the true benefits of maturity assessments. Besides the whole assessment process is quite time-consuming and energy-consuming. Stark [1] proposes a PDM (product data management) maturity model with four stages of evaluation, and defines the activities that a company needs to carry out at each stage. Batenburg [10] develops a PLM framework to assess and guide PLM implementations for organizations in terms of five dimensions: Strategy and policy, Monitoring and control, Organisation and processes, People and culture, and Information technology. Henk and Kees [11] apply Batenburg model in 20 companies to analyze PLM implementation of these companies. Sääksvuori Model [12] determines the maturity of a large international corporation for a corporate-wide PLM development program and develops business and PLM related issues. Yet, it should be mentioned that most of these maturity models are qualitative analysis, which cannot give a satisfactory impression of companies' relative position, and cannot solve research questions mentioned in introduction.

2.2 Applying fuzzy sets theory to describe maturity levels

Maturity models adopt linguistic terms to express the content of maturity levels. The linguistic terms have to be changed into numbers to make the maturity results easier understand. Crisp numbers cannot precisely express maturity results due to complex and vague features of linguistic terms. Fuzzy set theory is proposed by Zadeh [14] and this theory is a revolutionary way of solving the vagueness issues. Fuzzy sets theory allows objects to exist in more than one set. The membership function is proposed to demonstrate how much degree of an element belongs in a set, which means that the associated membership function of an object is multivalued. Fuzzy triangular elements and the corresponding membership function of fuzzy sets theory is used to express performance evaluation of maturity levels, because the advantages of fuzzy triangular numbers in fuzzy sets [15].

3. The running mechanism of PCMA Maturity Model

The goal of PCMA maturity model is to measure and monitor PLM dimensions. Key performance indicators (KPIs) are used to help define concrete actions in evaluation [16-17]. PCMA provides a holistic assessment for PLM dimensions based on a comprehensive set of KPIs in each maturity level. These KPIs are defined by the authors in collaboration with representatives from partner companies. We derive five dimensions based on TIFOS framework which are called 'TechnoWare', 'InforWare', 'FunctionWare', 'orgaWare' and 'SustainWare'. Fifteen PLM components are proposed based on the five dimensions. The

maturity level of each PLM component is explained by linguistic terms in PCMA maturity model. This work determines the corresponding KPIs for each maturity level in PCMA and calculates the final maturity score based on these KPIs.

An example of outcome of PLM maturity evaluation is shown in Table 1. The evaluation concerns a PLM dimension called 'FunctionWare' in TIFOS framework. Five maturity levels are defined, based on 'standard' scale in PLMIG [19] and CMMI scale [7-9]. The maturity score on each KPI is represented by a black rectangle. The maturity level of this dimension of the company is determined by the average score of all related KPIs. The relative weights among each KPI will be discussed in the future.

Table 1. PLM components and corresponding key performance indicators

PLM dimensions	PCMA maturity	KPIs	**Levels**				
			Ad-hoc	*Repeatable*	*Defined*	*managed*	*Optimized*
D1: TechnoWare	The detail explanation of maturity levels for each component	D1_K1: %of new products		■			
		D1_K2: Produce accurate products			■		
		D1_K3: Running cycle time				■	
		D1_K4: Installation Planning costs			■		
		D1_K5: Clear Product Innovation Strategy					■

Several components consist of 'FunctionWare' dimension. Product data management (PDM) is a set of functionalities which can fulfill the practical activities and provide technology solutions. Therefore, PDM is considered as one component of 'FunctionWare'. The maturity levels and maturity level contents for PDM are shown in table 2. We outline part of the KPIs for the 'PDM' based on three categories in terms of 'cost', 'time', and 'quality' in Table 2. More categories including 'complexity' and 'distributivity' will be studied in the future. Maturity levels, indicators for PDM maturity, and KPIs have numerous mapping relationships in Table 2. Similarly, we can obtain the maturity score of every PLM dimension.

Table 2. PCMA Maturity Level and Corresponding Content

Maturity Levels	PCMA maturity level content for PDM component	KPIs
1 *ad-hoc*	• The activity of product data management is done with expediency • Nobody is responsible for product data management • Documentation is at the lowest point to satisfy operational needs • PDM system and the corresponding processes have deficiencies	***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 ***Time*** 1. Acceptance necessary time:
2 *Repeatable*	• The activity is defined and managed, but it is repetitious • Documentation and record is carefully studied • Mutual actions are finished in processes and departments • PDM systems are involved and used in the proper places. • No effort has been made to consider about recycling	

3 *Defined*	• The activity is formalized and supported by standards • Documentation and record is studied and shared • Personal actions and mutual actions are carried out efficiently • PDM systems are easily implemented • Environmental awareness occurs	2. Average number of training hours per employee 3. Average time for data change version 4. Average time for data creation ***Quality*** 1. Data Accuracy Ratio 2. Data Duplication Ratio 3. Potential same data (data cleaning)
4 *managed*	• Activities run smoothly • PDM systems cooperate with other enterprise systems • The products run efficiently and are effective • Progressively eliminates errors and failures	
5 *optimized*	• The activity runs optimally • PDM system helps company make improved decisions • Best practices and innovative ideas are documented, archived and concretely re-used. • Research and Development service continuously improve the products	

A survey is conducted to obtain the values of KPIs. Four KPIs from cost category are selected, a detail description for each KPI is given, and the related questions are proposed to deduce the value of the KPIs in Table 3.

Table 3. Maturity description of PDM and the corresponding key performance indicators

KPIs	Description	Questions
1. Average Data storage cost	Measure of all data storage/ number of documents (categories)	How much you pay for information storage (including hardware and software)?
		How many documents you have to manage?
		How much memory 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 you used more than 30 minutes per day?
3. Average Document finding time-to-cost	How many time it takes for users to find it in seconds/minutes	How long 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 you spend to use these documents (including printing, creating the .pdf, ...)

4. Fuzzy extended PCMA maturity model

Fuzzy sets is adapted to address PLM maturity levels to better express decision-makers' intentions in PLM maturity evaluation. Five out of nine level fundamental scales of judgments are described via the triangular fuzzy numbers to express the relative difference among maturity levels in Table 4. The triangular fuzzy numbers is made up of a triple of numbers (L, M, U), including the medium value (M) of

the membership function μ(x), the lower (L) and the upper (U) bounds which limit the range of the maturity evaluation.

Table 4. PCMA maturity levels and the corresponding fuzzy scale

Maturity levels	*Ad-hoc*			*Repeatable*			*Defined*			*managed*			*optimized*		
Fuzzy Scale	*L*	*M*	*U*	*L*	*M*	*U*	*L*	*M*	*U*	*L*	*M*	*U*	*L*	*M*	*U*
	0	*0.1*	*0.3*	*0.1*	*0.3*	*0.5*	*0.3*	*0.5*	*0.7*	*0.5*	*0.7*	*0.9*	0.7	0.9	1

PCMA maturity model in section 3 is used to do the first evaluation. The companies need to spend time, costs and human resources to evaluate PLM. To answer the first and the second research questions, a strategy should be proposed to help companies to predict the gradual process of PLM in the following years to reduce the amount of efforts that spend on evaluation PLM. A real case is analyzed for a swimming industry in China. The maturity situation of PDM in 2010 is gotten by PCMA and the values of KPIs from 2011to 2013 is obtained from the company, which is shown in Table 5.

Table 5. Primary data of KPIs and initial maturity level

KPIs	2013	2012	2011	2010	Maturity Level (2010)
1. Average Data management cost	3.0-4.0(range)	2.8-4.2(range)	8.0-10.0(range)	35-40(range)	*Defined* [0.3,0.5,0.7]
2. Average Document using frequency per day	10	7	5	2	*Repeatable* [0.1,0.3,0.5]
3. Average Document finding time-to-cost	*managed*	*managed*	*managed*	*managed*	*managed* [0.5,0.7,0.9]
4. Average using cost per document	10 RMB	40/7RMB	6 RMB	5 RMB	*Defined* [0.3,0.5,0.7]

A fuzzy extended PCMA maturity model is proposed to calculate the maturity levels from 2011 to 2013 by adopting the data in Table 5. Set $C\_K_i^{j-year}$ is the i KPI (K_i) in the j year (K^{j_year}) for a specific category(C); let $C\_M_i^{j-year}$ represents the maturity value (M_i) of the i KPI in the j year (M^{j_year}) for a specific category(C). Then the ratio between two maturity levels in two selected years (j year and x year) can be gotten from the ratio of the j year to the x year for the same KPI. The formula to get the maturity level in x year is shown in the following:

$$\frac{C\_M_i^{x-year}}{C\_M_i^{j-year}} = f(k_i) \bullet \frac{C\_K_i^{x-year}}{C\_K_i^{j-year}} \quad \textbf{(1)}$$

To be more precise, the formula (1) can be replaced by formula (2):

$$C\_M_i^{x-year} = f(k_i) \bullet \frac{C\_K_i^{x-year}}{C\_K_i^{j-year}} \bullet C\_M_i^{j-year} \quad \textbf{(2)}$$

This formula represents the maturity level in the x year that can be deduced from the maturity level in the j year. The ratio between the j year and the x year for the i KPI in C category determines the changing trend and the varying degree of the maturity level in j year.

"$f(k_i)$" is the coefficient and the signal that express the influence degree of the changing value and the changing range. The value of $f(k_i)$ is given based on the real-life problem. For instance, we select the first KPI value in 2010 and 2013 in Table 5. The maturity level in 2013 for the first KPI in cost category is calculated by formula (2) in the following:

$$Cost\_M_1^{(2013)\_year} = f(k_i) \bullet \frac{Cost\_K_1^{(2013)\_year}}{Cost\_K_1^{(2010)\_year}} \bullet Cost\_M_1^{(2013)\_year} = f(k_1) \bullet \frac{[3,4]}{[35,40]} \bullet [0.3, 0.5, 0.7] \quad \textbf{(3)}$$

The sign $f(k_i)$ shows that formula (3) need to do numerical calculation and the value of $f(k_i)$ equals to 1 in this case based on the information given by the company. Then the way to obtain the maturity level is arithmetic operation. The average data management cost range is from 3 to 4 in 2013, the lowest value in formula (3) is the lowest value of the range: (3/40)*0.3=0.06; the middle value is the average value of the possible middle numbers: (((3/35+3/40)+(4/35+4/40))*0.5)/4=0.046875; the upper value is the largest value of the range: 4/35*0.7=0.08. Then formula (3) is changed into formula (4), which indicates the maturity level is '*Ad-hoc*' in 2013.

$$Cost\_M_1^{(2013)\_year} = 1 \bullet [0.0225,\ 0.046875,\ 0.08] = [0.0225,\ 0.046875,\ 0.08] \quad \textbf{(4)}$$

The second example is the second KPI value in 2010 and 2013 in Table 5. The maturity level in 2013 for the second KPI in cost category is calculated by formula (2) in the following:

$$Cost\_M_2^{(2013)\_year} = f(k_i) \bullet \frac{Cost\_K_2^{(2013)\_year}}{Cost\_K_2^{(2010)\_year}} \bullet Cost\_M_2^{(2013)\_year} = f(k_2) \bullet \frac{10}{2} \bullet [0.1, 0.3, 0.5] \quad \textbf{(5)}$$

The sign $f(k_i)$ shows that formula (5) needs to do range calculation. Every increase 'four' of 'Average Document using frequency per day' from the year 2010, then the maturity level will go to the next higher level based on the information from the company. The extent of changing the maturity level in formula (5) is calculated in formula (6):

$$f(k_2) \bullet \frac{10}{2} = (10-2)/4 = 2 \quad \textbf{(6)}$$

The maturity in 2013 is increased two times of 'four', then it go to the second higher maturity level: [0.5,0.7,0.9]. The maturity levels for the cost category in four KPIs from 2011 to 2013 are calculated by formula (2). The maturity level of cost for each year is the average value of the maturity value in total KPIs.

5 Case studies

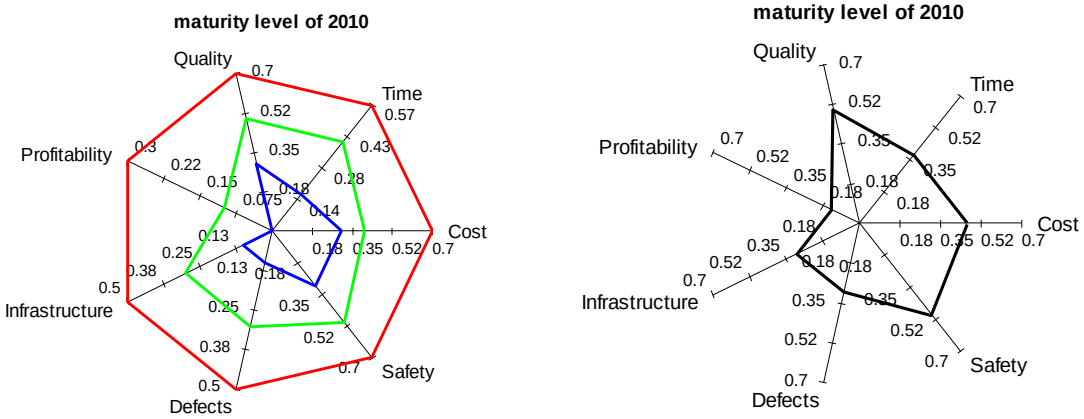
This section concerns two parts: using fuzzy extended PCMA maturity model to predict maturity scores in different years; studying the effectiveness of the proposed fuzzy extended PCMA maturity model by comparing the predict maturity scores with maturity model evaluation scores. Experimental data and important information have been collected by interviewing the managers of two Chinese companies.

The first case study is related to a swimming industry in Chengdu (China) studied from 2010 to 2013.We calculate the final maturity score per each category including cost, time, quality, safety, defects, infrastructure, and profitability. The results can be seen in the radar chart (left figure 1) showing the level of achievement for each category. The maturity level for each category is combined by three parts: lower value (blue line), middle value (green line), and upper value (red line). For instance, the maturity value of cost in 2010 is: (0.3, 0.4, 0.7), which is read from blue line, green line, and red line respectively. The

overall product data management maturity (right figure 1) can be obtained by the signed distance defuzzification method [18] that calculating the average score of the lower value, middle value, and upper value.

To examine the effectiveness of fuzzy extended PCMA maturity model, we evaluate maturity level for product data management in seven categories by using PCMA maturity model (right figure 2) and compare with the results which have been gotten from the proposed fuzzy extended PCMA model (left figure 2). The comparing results show that the maturity levels for two models are the same. More data is studied to evaluate the maturity levels of this company; similarly, results of maturity level in 2012 and 2013can be obtained by the proposed model. The maturity evaluation shows that the introduced software and hardware in 2010 is getting out-of-date. The average time consuming and the quality of PDM is decreasing year by year; this company starts needing more energy to organize the documents in 2013, because of the safety of PDM is decreasing and the defects of PDM is increasing. The maturity analysis reveals that this company should improve PDM or introduce new PDM to satisfy the requirements of document management.

The second case study is to predict the maturity level in a company in which the industry control field is located in Shanghai, China. This company bought Aopeng PDM in 2007, the expected lifespan of this software is 10 years. But the company has to invest new software to satisfy the new requirements after five years later. Therefore, the company bought Windchill at 2012, in which using permission is two years, which means the company needs to make a decision of which software should be invested in 2014. The general maturity level (Figure 3) shows that the new introduced PDM is acceptable in 2013 except the 'quality category' is relatively lower than the other categories.



.

Fig. 1. Maturity Score for product data management in seven dimensions in 2010

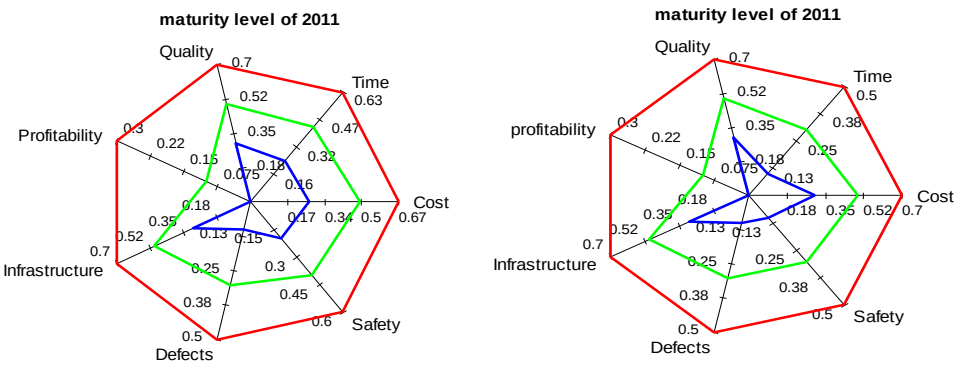


Fig. 2. Maturity levels comparison for fuzzy extended PCMA maturity model and PCMA maturity model in 2011

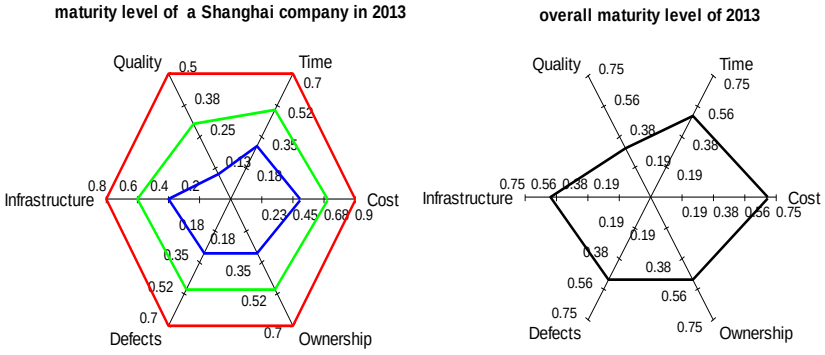


Fig. 3. Maturity Score for product data management in seven dimensions in 2013 for a Shanghai company

6. Conclusion and Future Work

This work analyzes PLM components that can fulfill PLM functionalities. To better handle PLM implementation, a PCMA maturity model is used to evaluate the maturity of PLM components. PCMA maturity model first gives the maturity level, then proposes the detail description of each maturity level, and collects the corresponding KPIs based on the content of each maturity level; finally obtaining the values of KPIs through a survey. A fuzzy extended PCMA maturity model is proposed to reduce the energy that spends on maturity evaluation. This model builds the relationship between the ratio for a pair of maturity levels and the ratio for the corresponding KPIs in two selected years in formula 2. A coefficient in formula 2 can determine how to get the changing degree and changing range for an unknown maturity level. The comparison results show that the proposed model can be used in real-life cases and can efficiently reduce the use of human resources, time, and expense in maturity evaluation.

The restriction of the proposed model is that the selected years must be in the same stage of the company. The results of the proposed model should be recalculated when the company has significant decisions changes. The future work will use more realistic data to examine the effectiveness of the proposed fuzzy extended PCMA maturity model. The realistic data that extracted from social media are diversity and complexity. Therefore, strategies will be given to demystify Big Data based on data structures (structured data, semi-structured data and non-structured data) that enhancing the credibility of the proposed PLM maturity model.

References

1. Stark, J. 2005. Product Lifecycle Management – 21st Century Paradigm for Product Realization, Berlin, Decision Engineering Series, Springer.
2. Vengugopalan, S.R., et al. 2008. Application of AHP for PLM Tools Selection. Product Lifecycle Management: Fostering the culture of innovation. PLM-SP4, pp.111-125.
3. Zhang, H., Ouzrout, Y., Bouras, A., Mazza, A., Savino, M.M., 2013. PLM Components Selection Based on a Maturity Assessment and AHP Methodology, in: Product Lifecycle Management for Society, IFIP Advances in Information and Communication Technology. Springer Berlin Heidelberg, pp. 439–448.

4. Zhang, H., Ouzrout, Y., Bouras, A., Della Selva, V., Savino, M.M., 2013. Selection of product lifecycle management components based on AHP methodologies, in: Advanced Logistics and Transport (ICALT), 2013 International Conference on. pp. 523–528.
5. Stark, John, 2011. 'Product Lifecycle Management', in Product Lifecycle Management (London: Springer London), pp. 1–16.
6. Abramovici, M., etc., 2012. Decision Support Framework for PLM Harmonization Projects within Industrial Companies, in: Product Lifecycle Management. Towards Knowledge-Rich Enterprises. Springer, pp. 535–546.
7. Alfaraj, H.M., Qin, S., 2011. Operationalising CMMI: integrating CMMI and CoBIT perspective. Journal of Engineering, Design and Technology 9, 323–335.
8. Team, C.P., 2010. CMMI for Development. Version 1.3 (CMU/SEI-2010-TR-033). Software Engineering Institute, Carnegie Mellon University.
9. Chrissis, M.B., Konrad, M., Shrum, S., 2011. CMMI for Development®: Guidelines for Process Integration and Product Improvement, Published Mar 10, 2011 by Addison-Wesley Professional. Part of the SEI Series in Software Engineering series.
10. Batenburg, R., Helms, R.W., Versendaal, J., 2006. PLM roadmap: stepwise PLM implementation based on the concepts of maturity and alignment. International Journal of Product Lifecycle Management 1, 333–351.
11. Pels, H. J., & Simons, K. 2008. PLM maturity assessment. The 14th International Conference on Concurrent Enterprising: Concurrent Innovation: a New Wave of Innovation in Collaborative Networks, Lisbon, Portugal, June (pp. 23-25).
12. Sääksvuori, A., & Immonen, A. 2008. Product lifecycle management [electronic resource]. Springer.
13. Stark, J., 2011. Product Lifecycle Management, in: Product Lifecycle Management, Decision Engineering. Springer London, pp. 1–16.
14. Zadeh, L. A. 1973. Outline of a new approach to the analysis of complex systems and decision processes. Systems, Man and Cybernetics, IEEE Transactions on, (1), 28-44.
15. Zhang, H., Sekhari, A., Ouzrout, Y., & Bouras, A. 2014. Optimal Inconsistency Repairing of Pairwise Comparison Matrices Using Integrated Linear Programming and Eigenvector Methods. Journal of Mathematical Problems in Engineering. In press.
16. Rohloff, M., 2009. Case Study and Maturity Model for Business Process Management Implementation, in: Dayal, U., Eder, J., Koehler, J., Reijers, H. (Eds.), Business Process Management, Lecture Notes in Computer Science. Springer Berlin Heidelberg, pp. 128–142.
17. Wetzstein, B., Ma, Z., Leymann, F., 2008. Towards Measuring Key Performance Indicators of Semantic Business Processes, in: Abramowicz, W., Fensel, D. (Eds.), Business Information Systems, Lecture Notes in Business Information Processing. Springer Berlin Heidelberg, pp. 227–238.
18. Chou, S.-Y., Chang, Y.-H. & Shen, C.-Y. 2008. A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes. European Journal of Operational Research 189, pp.132–145.
19. PLMIG (2007) 'PLM Maturity Reference Manual (Version 1.0)', PLM Interest Group, 19 March 2007, 50 pages.