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Selection of optimal Product Lifecycle Management components based on AHP Methodologies

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Abstract— Adopting right PLM components and making proper strategy investment decisions enlarge business benefits. Evaluation and selection of PLM components require analyzing the PLM functionalities. These functionalities could be extracted from the company PLM maturity and PLM benefits, based on its capabilities in terms of specific features such as technology, information, management, organization, sustainability, etc. In this paper we propose a framework called TIFOS (TechnoWare, InforWare, FunctionWare, OrgaWare, SustainWare) to collect these main PLM components. The paper also provides a development approach based on the Analytical Hierarchy Process (AHP) method to better handle these components. AHP is a multi-criteria, multi-objectives decision-making method that employs pair-wise comparison matrix among the criteria to obtain optimal alternatives.

Keywords—TIFOS Framework; PLM maturity model; AHP methodology; PLM components; business benefits

I. INTRODUCTION

Product Lifecycle management (PLM) has appeared since 1990s with the aim of improving several engineering aspects of an enterprise. It enables the collaborative creation, management, dissemination, and use of product definition and process operation across the extended enterprise from market concept to product retirement (Amann et al, 2002). PLM has several benefits, such as: help the business to deliver more innovative products and services in a shorter time (Stark, 2005), build a consistent and secure repository of product data to make sure the supply chain could run in a flexible way, with better coordination and responsiveness (Hill, Sidney, 2012). This paper focuses on the benefits that PLM can bring to decision-making in taking advantage of maturity analysis effectiveness.

Several PLM maturity models have been proposed to evaluate the capabilities, abilities and competencies level of PLM approaches. For instance, PDM (Product Data Management) maturity models (Stark, 2005) define the activities that a company needs to carry out at each stage, and

define a generic five-step process per stage, related to the as-is situation and to-be situation of the studied company. CPI (Collaborative Product Innovation) maturity model (Sharma, 2005) proposes three unique stages of CPI based on collaborative maturity. Batenburg (Batenburg, 2006) developed a PLM framework to assess and guide PLM implementations. Sääksvuori model (sääksvuori & Immonen, 2008) determines the maturity of a large international corporation for a corporate-wide PLM development program, and develops business and PLM related issues such as processes or information. Other PLM maturity works include Silventoinen work (Silventoinen et al. 2010), PLMIG model (PLM Maturity Reference Manual, 2007) and Business Process Maturity Model (Van looy et al, 2012). From these maturity works, we can get several PLM maturity dimensions and PLM functionalities. In general, the functionalities of PLM are related to the technology and information technology, standards, organization, environmental impact, management, innovation, etc.

This work extends an existing TIFO framework to TIFOS and collects fifteen PLM components based on TIFOS framework.

The aim is to choose the right PLM components in TIFOS framework according to the company business profits, in getting the criteria, obtaining the pairwise comparison and determining the relative important PLM components. This complex decision making issue could be approached by the AHP method that represents a decision problem as hierarchy levels.

The AHP was developed and popularized by Prof. Saaty in the late 1970s in the USA. It consists in structuring multiple choice criteria into a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining an overall ranking of the alternatives. In our paper, this has been conceptualized as a hierarchical composition of ‘Goals’, ‘Criteria’, ‘Sub-criteria’ and ‘Alternatives’.

The remainder of this paper is structured as follows: section 2 gives the definition of TIFOS framework and the main PLM components; section 3 focuses on the detailed criteria of TIFOS framework and details the AHP steps to get the right PLM components in TIFOS framework; section 4 concludes our work.

II. TIFOS FRAMEWORK

From Sharif perspective (Sharif 1995, 1997), technology can be classified into four components: TechnoWare, HumanWare, OrgaWare and InforWare:

- **TechnoWare:** contains components, equipment (manual and powered), vehicles, machinery, IT and other facilities;
- **HumanWare:** describes the skills to comprehend and use the job related components, the problem solving capacity; the ability to mobilize, to setup and utilize technology components; to innovative; and have the motivation to improve the work performance;
- **OrgaWare:** consists in organizational techniques, work assignments, education, and experience-based work facilitation; and has the means for using and controlling factors of production, systems analysis, organization of products, processes, and components.
- **InforWare:** contains documents or knowledge records that reflect facts and formulas (design parameters, standards), principles of physical and social phenomena; computer software; technical information; theories and state-of-the-art knowledge for innovation.

From Vengugopalan et al. perspective (Vengugopalan et al, 2008), the functionalities of PLM tools are classified into four major categories based on TIFO Framework (TechnoWare, InfoWare, FunctionWare, and OrgaWare). They mixed the initial HumanWare with the OrgaWare components (organization, process, management, people, abilities/skills, culture, teaming, satisfaction, framework and practices) and added a new FunctionWare component:

- **FunctionWare:** depth and breadth of functionalities;

Vengugopalan work focuses on is limited to product design phase. But it is more significant to make an extension to consider PLM sustainability, knowing that PLM systems have the abilities for knowledge sharing, product improvement, and organization innovation. Therefore, we extend TIFO framework into TIFOS and add a new component called sustainWare. The content of SustainWare is:

- **SustainWare:** reducing waste and pollution; designing eco-friendly products; using new materials and supply chain; minimizing damage to environment and human; consuming low energy.

After getting TIFOS framework, fifteen PLM main components were studied in this paper. These components are: People, Measurement (Jochem et al, 2011), Product management (Eigner, Martin et al, 2011), Techniques and Practices (Niemi, Petri et al, 2009), Collaborative development (Bukhsh et al, 2012), business management (Rohloff, Michael. 2011), Strategy and Supervision (Burlton, Roger. 2010), PLM applications (Batenburg et al., 2005, 2006), Organizational Interoperability (Kwak, 2000, Maier et al, 2012), PDM (Simonsson, Johnson, 2007), Financial Management, metrics maintenance (Simonsson, Johnson, 2007), Process

Management (Reijers, 2003; Trkman, Peter, 2010; Röglinger et al, 2012), new products and skills, and Product data.

III. METHODOLOGY

In order to analyze features of TIFOS framework, we give the detail criteria of TIFOS in sub-section A. These criteria can be divided into sub-criteria. Different PLM components will contain several functionalities in each TIFOS framework. Sub-section B, constructs the TIFOS decision-making model to help companies to select the right PLM components. Sub-section C, defines the business profits by determining the criteria of business profits and figuring out the more suitable PLM components based on different company profits.

A. TIFOS Criteria

The content of TIFOS framework is large. It contains technologies, organization, functionalities, information, and sustainability viewpoint of PLM. Each part of PLM component impacts the others. Each component needs collaboration and cooperation to make sure PLM runs smoothly. The criteria of TIFOS are shown in Table I.

TABLE I. CRITERIA OF TIFOS FRAMEWORK

TIFOS Framework and Related Criteria	
TechnoWare	Collaboration and System tools
	Enterprise Application, Machinery
	CAD/CAM/CAPP/ERP
	Hardware and Software integration
	Innovative ideas and collaboration works
	Customization, flexibility and information security
	Internet technologies
InforWare	Document management and data collection
	Measurement and information analysis
	Automation information of daily work assignment
	Work plan changes based on market information
	Workflow management information supply
	Information of employees capabilities
	Standards and rules consistency
	Enhanced project and program management
Information on requirements (manpower, products)	
FunctionWare	PDM/PLM software and hardware
	Configuration management of functionalities
	Notifications and alerts
	Visualization management
	Bill of material management
	Broadened opportunities in market
OrgaWare	Employees management
	Training management
	Standards of application platform
	Social corporate responsibility
	Regulatory compliance
	Innovation awareness
SustainWare	Emission reduction (carbon footprint)
	Low energy consumption
	Life cycle assessment (LCA)

	Cost effective materials and supply chain
	Green PLM awareness and innovation

B. Construction of TIFOS decision-making model based on AHP methodology

The conception of AHP is to provide a scientific method to assist in solving goal-oriented decision problems. Two main parts are studied in this work: figuring out which PLM tool can cover more functionalities in TIFOS Framework; defining business profits and acquiring which PLM component need to be improved.

AHP hierarchy is shown in figure 1. The objective is to choose PLM components in TIFOS framework represented by O1(TechnoWare), O2(InforWare), O3(FunctionWare), O4(OrgaWare) and O5(SustainWare). The factors of O1-O5 can be selected from Table 1. Competing alternatives come from PLM components (T1-T15), (limited in the examples given in this paper to T9).

We first determine the priorities of each PLM component based on decision criteria. Priorities for each criterion are calculated from their importance in reaching the goal. The priorities are then combined throughout the hierarchy to get an overall priority for each component. The component with the highest priority will be the best alternative, and the ratios of PLM components' priorities indicate their relative importance to the goal. The decision process is described in depth in the following steps:

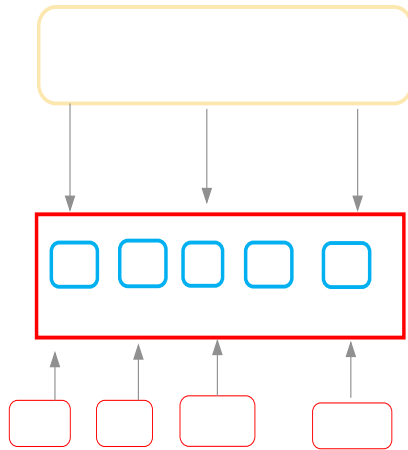


Figure 1. AHP hierarchy towards selection of PLM components

Step 1. Developing the fundamental objective hierarchy. Grouping the related criteria. Structuring the hierarchy.

Step 2. Constructing the pairwise comparisons matrix. In our example, we start from comparing the alternatives with their importance to each of the criteria. Then we compare the criteria with respect to their importance to the goal. There are nine alternatives (T1-T9): PLM application (T1), PDM (T2), Techniques and Practices (T3), Organizational Interoperability (T4), Financial Management (T5), Product Management (T6), Process Management (T7), Measurement

(T8), and Product Data (T9). Comparing each one to the others (T1vs.T2, T1vs.T3, etc.), making five pairwise comparisons related to each criterion. The AHP fundamental Scale of assigning the weights is given in Table II.

Step 3: The first calculation step starts from comparing pairs of PLM components related to O1. Using AHP fundamental scale (Table II), we assign the weights. Tables III-VII give an example of calculation of the parameters. Using the same method we can get a comparison matrix related to each criterion. The following steps give the calculation methodology of the different parameters:

- (1). Calculation: add all the elements of each column and get sum1;
- (2). Normalization: all the elements in each column of the matrix (M1) are divided by its respective column sum (Sum1) and entered in the new matrix (K).
- (3). Sum of each row is calculated for the matrix K and entered into Sum2;
- (4). Priorities (M2) are obtained by dividing Sum2 with the number of elements in (n is equal to the trace of the comparisons matrix); M3 is the product of matrix M1 and matrix M2;
- (5). M4 is given by the ratio (M3/M2);
- (6). CI (consistency Index) is calculated by the equation $(k-n)/(n-1)$;
- (7). RI is the random index. $RI=1.98*(n-2)/n$;
- (8). CR (Consistency Ratio) is calculated by CR/CI ;

Step 4: Analysis of the consistency of judgments. The value of CR as the end sign of calculation, CR should be less than or equal to 0.10. This is chosen as consistency condition. If it is not so, the whole process needs to be repeated, till the condition $CR \leq 0.10$ is satisfied;

Step 5: Evaluation of the criteria with respect to the corresponding importance in reaching the goal. Once again, getting the result by pairwise comparisons. To get this comparison data requires much discussion among decision makers. Table VIII gives an example.

Step 6: Determination of global weights, following the principle of hierarchical composition. In order to determine the importance of each objective, corresponding to goal, the final step is to get and apply the principle of the hierarchical composition. The local weights of each criterion adding up the results of the corresponding higher-level components weight obtained in step 3. Proceeding from top to bottom, the local weights of all criteria of hierarchy are gradually evolved into global weights. The calculation equation is:

$$W_j = \sum_{i=1}^n w_i a_{ij} \forall i \in (1,2,\dots,n) \forall j \in (1,2,\dots,m) \quad (1)$$

Where, w_j is the priority value of the alternative j; W_i is the priority value of criteria i; a_{ij} is the priority value of the alternative j related to criteria i. M is the number of alternatives and n is the number of criteria. Table IX gives an example of result.

TABLE II. METHOD TO GET PAIR-WISE COMPARISON MATRIX

Value	Interpretation
1	i and j have the same importance
3	i is little more important than j
5	i is considerably important than j
7	i is far important than j
9	i is absolutely more important than j
1/3	i is little less important than j
1/5	i is considerably less important than j
1/7	i is far less important than j
1/9	i is absolutely less important than j
2,4,6,8	Intermediate values, when a compromise is necessary.

TABLE III. PAIRWISE COMPARISON MATRIX FOR O1

	M1	M2	M3	M4	M5	M6	M7	M8	M9	SUM2	M2	M1*M2	M3/M2	CI	CR
T1	1	2	2	2	2	2	2	5	3	1.8036	0.2004	1.9487	9.7239	0.0862	0.056
T2	0.5	1	2	2	2	2	2	3	3	1.4694	0.1633	1.6088	9.8539		
T3	0.5	0.5	1	2	2	2	2	5	5	1.3860	0.1540	1.5185	9.8599		
T4	0.5	0.5	0.5	1	2	2	2	5	5	1.2061	0.1340	1.3075	9.7502		
T5	0.5	0.5	0.5	0.2	1	2	2	5	3	0.9498	0.1055	1.0258	9.7202		
T6	0.5	0.5	0.5	0.5	0.5	1	2	3	3	0.7923	0.0890	0.8488	9.6419		
T7	0.5	0.5	0.5	0.5	0.5	0.5	1	5	3	0.7388	0.0821	0.7991	9.7352		
T8	0.2	0.33	0.2	0.5	0.2	0.33	0.2	1	2	0.3440	0.0382	0.3654	9.5596		
T9	0.33	0.33	0.2	0.2	0.33	0.33	0.33	0.5	1	0.3099	0.0344	0.3221	9.3555		
SUM1	4.83	6.16	7.40	8.90	10.5	12.16	13.83	32.50	28			M3	M4		

TABLE IV. PAIRWISE COMPARISON MATRIX FOR O2

	M1	M2	M3	M4	M5	M6	M7	M8	M9	SUM2	M2	M1*M2	M3/M2	CI	CR
T1	1	5	2	2	2	5	2	4	8	2.1067	0.2341	2.4607	10.5123	0.150	0.09*
T2	0.2	1	1/3	1/3	1/3	2	1/3	1/3	1/3	2.1067	0.0379	0.3667	9.6793		
T3	0.5	3	1	2	5	7	5	5	5	2.1067	0.2230	2.4448	10.9614		
T4	0.5	3	0.5	1	5	7	5	5	5	2.1067	0.1937	2.1396	11.0466		
T5	0.5	3	0.2	0.2	1	3	1/3	1/3	1/3	2.1067	0.0567	0.5185	9.1488		
T6	0.2	0.5	0.14	0.14	0.33	1	1/5	1/3	1/3	0.2123	0.0236	0.2307	9.7790		
T7	0.5	3	0.2	0.2	3	5	1	2	2	0.8563	0.0951	0.9690	10.1840		
T8	0.25	3	0.2	0.2	3	3	0.5	1	3	0.6863	0.0763	0.7991	10.4779		
T9	0.125	3	0.2	0.2	3	3	0.5	0.33	1	0.5367	0.0596	0.5994	10.0524		
SUM1	3.775	24	4.77	6.27	22.66	36	148	18.33	25			M3	M4		

TABLE V. PAIRWISE COMPARISON MATRIX FOR O3

	M1	M2	M3	M4	M5	M6	M7	M8	M9	SUM2	M2	M1*M2	M3/M2	CI	CR
T1	1	2	2	2	3	3	3	6	3	2.0519	0.2280	2.3428	10.2761	0.1240	0.0805
T2	0.5	1	3	2	5	3	5	2	3	1.7291	0.1921	1.9806	10.3089		
T3	0.5	0.33	1	1/3	2	3	2	2	2	0.8669	0.0963	0.9844	10.2193		
T4	0.5	0.5	3	1	5	7	5	2	3	1.6611	0.1846	1.9046	10.3193		
T5	0.33	0.2	0.5	0.2	1	2	2	1/3	4	0.6268	0.0696	0.6806	9.7738		
T6	0.33	0.33	0.33	0.14	0.5	1	2	1/3	2	0.4604	0.0512	0.4877	9.5331		
T7	0.33	0.2	0.5	0.2	0.5	0.5	1	1/3	1/3	0.3181	0.0353	0.3421	9.6803		
T8	0.17	0.5	0.5	0.5	3	3	3	1	2	0.8154	0.0906	0.9388	10.3622		
T9	0.33	0.33	0.5	0.33	0.2	0.5	3	0.5	1	0.4704	0.0523	0.4943	9.4564		
SUM1	3.99	5.39	11.3	6.70	20	23	26	14.50	20.3			M3	M4		

TABLE VI. PAIRWISE COMPARISON MATRIX FOR O4

	M1	M2	M3	M4	M5	M6	M7	M8	M9	SUM2	M2	M1*M2	M3/M2	CI	CR
T1	1	1/5	1/5	1/5	1/5	1/3	1/5	2	1/5	0.2872	0.0319	0.2981	9.3411	0.1143	0.0742
T2	5	1	2	2	3	2	3	2	2	1.800	0.2000	1.9938	9.9695		
T3	5	0.5	1	2	3	3	5	5	2	1.7038	0.1982	2.0348	10.2665		
T4	5	0.5	0.5	1	3	3	5	5	2	1.5408	0.1712	1.7645	10.3067		
T5	5	0.5	0.33	0.33	1	2	2	2	1/5	0.7448	0.0828	0.8150	9.8484		
T6	3	0.33	0.33	0.33	0.5	1	2	2	1/5	0.5614	0.0624	0.6134	9.8333		
T7	5	0.5	0.2	0.2	0.5	0.5	1	2	1/3	0.5550	0.0617	0.5912	9.5870		
T8	0.5	0.33	0.2	0.2	0.5	0.5	0.5	1	1/3	0.3214	0.0397	0.3470	9.7174		
T9	5	0.5	0.5	0.5	5	5	3	3	1	1.4057	0.1562	1.6182	10.3606		
SUM1	34.5	4.36	5.26	6.76	15.7	18.3	20.7	25	8.266			M3	M4		

TABLE VII. PAIRWISE COMPARISON MATRIX FOR O5

	M1	M2	M3	M4	M5	M6	M7	M8	M9	SUM2	M2	M1*M2	M3/M2	CI	CR
T1	1	5	5	5	5	5	5	0.5	5	2.6718	0.2969	3.3712	11.3587	0.1143	0.0742
T2	0.2	1	2	2	2	3	2	3	2	1.0952	0.1217	1.4833	12.1894		
T3	0.2	0.5	1	2	3	3	5	5	2	1.1927	0.1325	1.6418	12.3888		
T4	0.2	0.5	0.5	1	3	3	5	5	2	1.0565	0.1174	1.4582	12.4215		
T5	0.2	0.5	0.33	0.33	1	2	2	2	1/5	0.4875	0.0508	0.6234	12.2620		
T6	0.2	0.33	0.33	0.33	0.5	1	2	2	1/5	0.3711	0.0412	0.5360	12.9995		
T7	0.2	0.5	0.2	0.2	0.5	0.5	1	2	1/3	0.3148	0.0350	0.4828	13.8059		
T8	5	0.33	0.2	0.2	0.5	0.5	0.5	1	1/3	0.8827	0.0981	1.7716	18.0631		
T9	0.2	0.5	0.5	0.5	5	5	3	3	1	0.9877	0.1064	1.2111	11.3813		
SUM1	7.4	9.16	10.06	11.56	20.5	23	25.5	23.5	13.06			M3	M4		

TABLE VIII. PAIRWISE COMPARISON MATRIX OF OBJECTIVES IN THE GOAL

Goal	O1	O2	O3	O4	O5	M2	M1*M2	M3/M2=M4	CI	CR
O1	1	2	4	6	2	0.3953	2.3662	5.9851	0.0104	0.0105
O2	0.50	1	2	5	5	0.2703	1.7052	6.3076		
O3	0.25	0.50	1	2	4	0.1448	0.9009	6.2227		
O4	0.17	0.20	0.50	1	6	0.1180	0.7409	6.2794		
O5	0.5	0.2	0.25	0.17	1	0.07	0.3795	5.3051		
SUM1	1.92	3.70	7.50	14	25			M3		

TABLE IX. GLOBAL WEIGHTS AND RANKING RESULTS

	O1	O2	O3	O4	O5	Overall Weight	Rank
W _i	0.3953	0.2703	0.1448	0.1180	0.07	W _j	
T1	0.2004	0.2341	0.2280	0.0319	0.2969	0.2005	1
T2	0.1633	0.0379	0.1921	0.2000	0.1217	0.1347	4
T3	0.1540	0.2230	0.0963	0.1982	0.1325	0.1677	2
T4	0.1340	0.1937	0.1846	0.1712	0.1174	0.1604	3
T5	0.1055	0.0567	0.0696	0.0828	0.0508	0.0804	5
T6	0.0850	0.0236	0.0512	0.0624	0.0412	0.0558	7
T7	0.0821	0.0951	0.0353	0.0617	0.0350	0.073	6
T8	0.0382	0.0763	0.0906	0.0357	0.0981	0.0599	8
T9	0.0344	0.0596	0.0523	0.1562	0.1064	0.063	9

C. Analysis of business profits based on AHP methodology

The next step is to gain in terms of business profits. The strategy proposes to help the company to choose the suitable components when business profits are defined. The AHP steps are described in part B. Construction of the pairwise comparison matrix of each objective and the goal, then, calculation of the local and global weights, in order to gain a higher consistency (CR Consistency Ratio and CI Consistency Index will be examined during the whole process). To allow business gaining more profits, time-to-market should be reduced, high quality of products and services should be reached, higher competing abilities should be achieved, etc. In our example, we divide business profits into 6 aspects (Table X).

TABLE X. BUSINESS MAIN GOALS AND CORRESPONDING CRITERIA

Business profits	Reduce time-to-market
	Manage all the information of the product Lifecycle
	High quality products/services at lower cost in a shorter time
	Competing in the global market
	Meet demands of industrial partnership and relationship with other business objectives
	Managing the evolution of product configuration

TABLE XI. TIME-TO-MARKET CRITERIA

Reduce time-to-market	Access to information of different business sectors
	Traceability of the product
	On-line publication of information
	Sharing of information between different departments
	Higher performance documentation and accuracy

TABLE XII. INFORMATION MANAGEMENT CRITERIA

Manage all the information of the product Lifecycle	Data storage
	Traceability of product information
	Bill of Materials
	Innovation information collection

TABLE XIII. QUALITY-COST-TIME CRITERIA

High quality products/services at lower cost in a shorter time	Lower cost of ownership
	Compliance with customer requirements in shorter time
	Effectiveness of right-to-market strategy

TABLE XIV. COMPETING IN GLOBAL MARKET

Competing in the global market	Faster delivery of new products to market
	Better business decision and strategy
	Flexibility and agility to respond swiftly to changing market pressures and competition
	Efficiency of after-sale service
	Reduction of errors when dealing with all kind of issues

TABLE XV. INDUSTRIAL PARTNERSHIP

Ability to meet demands of industrial partnership and relationship with other business objectives	Ability of sharing and exchanging product information internally
	Engineering innovation for business decisions
	Quick change response
	Flexibility to rapidly respond to market changes

TABLE XVI. PRODUCT CONFIGURATION

Management of the evolution of product configuration	Product model evolution Effectiveness of the innovation strategy
	Use of compatible components
	Ability to smoothly structure and share product information between departments

Tables XI--XVI gives the detail of each business profits criteria. Figure 2 highlights the use of the AHP method within the goal of getting global business profits. The related criteria are given in table X, (figure 2 represents only four of them). This part also arranges these criteria as a second hierarchy, adopting their features as sub-criteria.

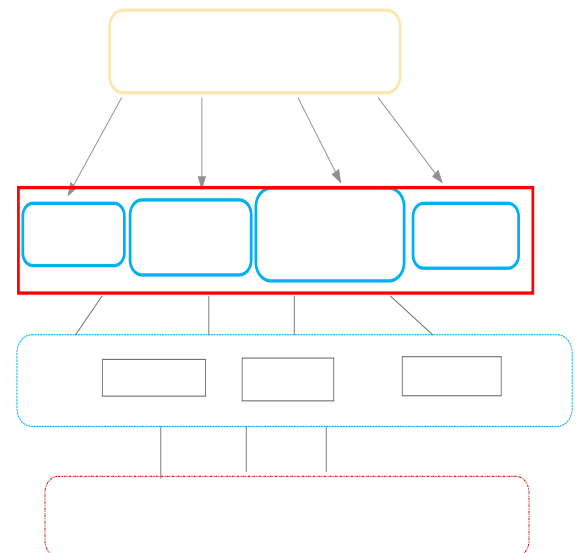


Figure 2. Structure chart for the business benefits goal

IV. CONCLUSION

The scope and functionalities of PLM is large and continuously expanding. It is quite difficult to give accurate range and content of PLM components and measure capabilities among competing PLM components. Business has different aims as well when adopting PLM components; hence it is important to know the business goals and expected benefits when selecting PLM components. By studying TIFO framework and adding sustainability functionalities such as reduction of environmental impacts, improvement of eco-friendly products, regulation compliance and innovation leads us to propose the TIFOS framework. To obtain optimal PLM solutions we based our work on an AHP methodology, using a weighting process in competing alternatives via pair-wise comparison matrices.

As perspective, we aim to extend this work in considering the uncertainty of the collected information. This leads us to use a specific Fuzzy AHP method to enhance the analysis of the TIFOS framework and results.

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