Journal of KONBiN 5 (8) 2008
ISSN 1895-8281

DOI 10.2478/v10040-008-0109-4

KNOWLEDGE-BASED COLLABORATIVE LEAN MANUFACTURING MANAGEMENT (KBCLMM) SYSTEM

SYSTEM ZESPOŁOWEGO ZARZĄDZANIA PRODUKCJĄ, OBNIŻAJĄCY NAKŁADY, OPARTY NA BAZIE WIEDZY

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Abstract: The objective of this research paper is to demonstrate the application of hybrid Knowledge-Based System, Gauging Absences of Pre-Requisites (GAP), and Analytic Hierarchy Process (AHP) approaches for selecting the improvement programs for Collaborative Lean Manufacturing Management (CLMM) System. In this research, a generic Knowledge-Based System is developed to measure the level of CLMM adoption in automotive manufacturers compared to the ideal system. Using the embedded GAP and AHP technique, the key lean manufacturing improvement programs can be prioritised by using both qualitative and quantitative criteria. The analysis covers the planning stage of the KBCLMM. The utilisation of the approach is demonstrated with an illustrative example.

Keywords: Analytic Hierarchy Process (AHP), lean manufacturing, Knowledge-Based System (KBS), Gauging Absences of Pre-Requisites (GAP).

Streszczenie: Celem niniejszej pracy badawczej jest przedstawienie rozmaitych sposobów wyboru programów poprawy wydajności dla systemu Zespołowego Zarządzania Produkcją obniżającego nakłady (CLMM), opartego na Bazach Wiedzy. Omawiane sposoby, to Pomiar Niedostępności Warunków Wstępnych (Gauging Absences of Pre-Requisites - GAP) oraz Analityczne Procesy Hierarchiczne (Analytic Hierarchy Process - AHP). W ramach prezentowanej pracy badawczej opracowano generyczny System Oparty na Bazie Wiedzy pozwalający na pomiar przydatności systemu CLMM w zakładzie produkcyjnym przemysłu samochodowego w porównaniu z systemem idealnym. Dzięki zastosowaniu wbudowanych technik GAP oraz AHP można optymalizować kluczowe programy zarządzania produkcją, określając priorytety za pomocą kryteriów ilościowych, jak i jakościowych. Analiza obejmuje również etap planowania systemu KBCLMM. Wykorzystanie każdego sposobu jest przedstawione za pomocą poglądowego przykładu.

Słowa kluczowe: Analityczny Proces Hierarchiczny (AHP), zarządzanie obniżające nakłady, Systemy Baz Wiedzy (KBS), Pomiar Niedostępności Warunków Wstępnych (Gauging Absences of Pre-Requisites - GAP)

1. Introduction

Lean manufacturing is a management philosophy that focuses on producing the highest value product on time (Liker and Yu, 2000). The highest value of products is achieved by identifying and eliminating wastes (all non-value-added activities) through continuous improvement which result in greater productivity, shorter delivery times, cost reduction, improved quality, increased customer satisfaction and higher profit (Schroer, 2004, Dolcemascolo, 2006).

A new concept called Collaborative Lean Manufacturing Management (CLMM) can be implemented for any car manufacturer to improve their lean manufacturing processes (Nawawi et al., 2007). In the CLMM chain, all members in the automotive manufacturing chain must work together towards common objectives in order to make lean manufacturing achievable in the collaborative environment.

This paper proposes the integration of a decision making tool, Analytic Hierarchy Process (AHP), with the hybrid Knowledge based (KB)/ Gauging Absences of Pre-Requisites (GAP). The detail of this hybrid system is described in the following sections.

2. Hybrid Knowledge-Based System and GAP Analysis

The planning stage is the basis for developing CLMM. In the planning stage there are two major sets of information that need to be considered: *Collaborative Business* and *Lean Manufacturing* perspectives as shown in Fig. 1.

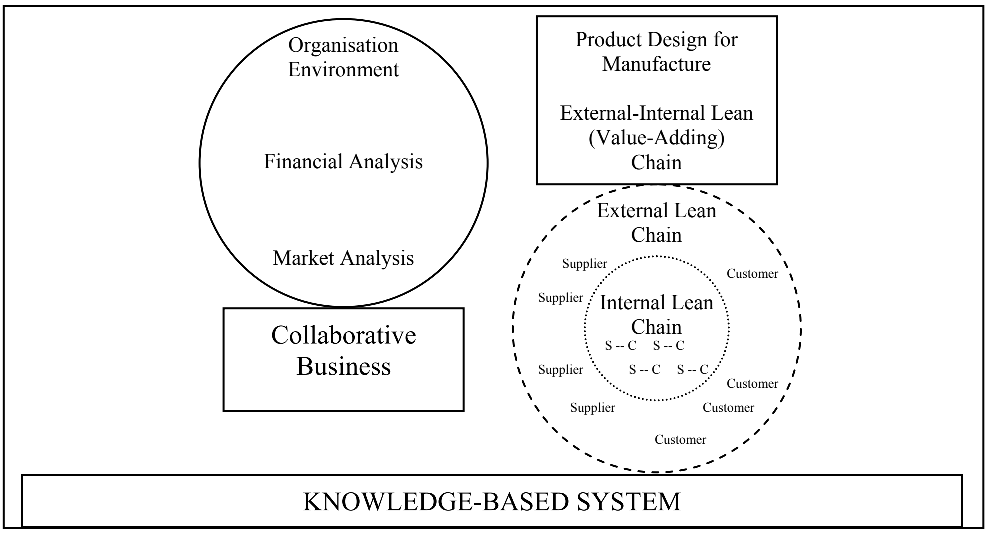

Fig. 1 Planning Stage of Conceptual Model for CLMM

The function for the first part of Planning Stage, *Collaborative Business* is for gathering general information about the organisations environment, financial and market status. Organisation environment determines the particular environment the company is operating in. The information needed in this module are size of company, annual sales turnover, number of employees, age of company, position of company in automotive chain, competitors, suppliers, customers, and investment in CLMM activities. In CLMM, the position of a company in the supply chain is required to determine its suppliers and customers, since emphasis in not only within the organisation (internal), but also between organisations (external) (Womack and Jones, 2003).

In the second part of Planning Stage, *Lean Manufacturing Chain* component refers to connections between any two value-adding activities inside and across organisations. Activity in any process can be allocated as value-adding or non-value adding. In lean manufacturing, non-value adding activity is considered as a waste and must be eliminated. *Lean Manufacturing Chain* can be divided into three subcomponents, *Internal Chain*, *External Chain*, and *Product Design for Manufacture*. In the *Internal Lean Chain*, operators of the next process are the customers, and suppliers (current process) are committed to supply parts which are good in quality at the right time and right quantity. Customer satisfaction and supplier commitment are two major elements which contribute to the success of the internal lean chain. In the *External Lean Chain*, suppliers are considered as partners (Monden, 1998) instead of outsiders. Suppliers are well informed about the demand and planning of the organisation and sometimes invited to involve in the product development and process design. The *Product Design for Manufacture* is developed with objectives of gathering product design information and analysing the product design process which covers from the conceptual design to the full launch of new products.

The utilisation of a knowledge-based (KB) approach is a basis for CLMM system development. In this study, the production rule-based type of KBS is used to structure the knowledge and information that is gathered and compiled from literature and interactive session with users. By using selected KB shell software, all modules are developed independently and finally linked each other in the integrated KBCLMM system. The example of rule-base for *Internal Lean Chain* sub-module in the *Lean Manufacturing Perspective* module used for deducing this condition is listed as follows.

IF *the organisation have kaizen team which regularly conduct kaizen event to improve the process* (**Yes**: GP; **No**: BP, **PC1**)
AND *the kaizen event is always documented* (**Yes**: GP; **No**: BP, **PC1**)
AND *the kaizen event is documented and presented to top management* (**Yes**: GP; **No**: BP, **PC1**)
AND *the kaizen event is always presented to staff of operations* (**Yes**: GP; **No**: BP, **PC1**)

AND *the kaizen event is always presented to staff of planning* (**Yes**: GP; **No**: BP, **PC3**)
AND *the kaizen event is always presented to staff of purchasing* (**Yes**: GP; **No**: BP, **PC4**)
AND *the kaizen event is always presented to staff of financial* (**Yes**: GP; **No**: BP, **PC4**)
AND *the kaizen event is always presented to staff of administration* (**Yes**: GP; **No**: BP, **PC1**)
AND *the organisation implements cellular layout as part of internal continuous improvement* (**Yes**: GP; **No**: BP, **PC1**)
AND *the organisation implements pull production as part of internal continuous improvement* (**Yes**: GP; **No**: BP, **PC1**)
AND *the organisation implements Kanban control as part of internal continuous improvement* (**Yes**: GP; **No**: BP, **PC1**)
AND *the organisation implements set-up time reduction as part of internal continuous improvement* (**Yes**: GP; **No**: BP, **PC1**)
THEN *the organisation commitment to kaizen events and internal continuous improvement is good*
OR *the organisation needs to improve the kaizen event and internal continuous improvement activities*

In this study, a technique known as Gauging Absences of Pre-requisites (GAP) analysis is used to assess the gap between the organisation's actual environment and an ideal one, resulting in knowledge of the desirable pre-requisites for an effective implementation (Udin, 2004).

Table 1. Problem Categories and Description of GAP Analysis Technique

Category Code	Description
PC1	This indicates a serious problem, which should be resolved immediately. If resolved, it is quite likely to provide real benefits.
PC2	This indicates a serious problem, which is likely to have pre-requisites and is better dealt with as part of an appropriate and logical improvement and implementation plan.
PC3	This is not a serious problem and can be dealt with now. If resolved, it is likely to produce short-term benefits.
PC4	This is not a serious problem. Although it could be dealt with now, it is unlikely to produce short-term benefits. Therefore, it should only be dealt with if it is a pre-requisite for other things.
PC5	This is not really a Good or Bad point itself. The questions associated with this category are primarily asked to identify certain situations in the environment, which depends on subsequent questions and hence may reveal other problems.

An explanation facility is also provided in the system in order to assist the users in understanding the questions. Many of the questions are used with the GAP Analysis and are indicated by either *Good Point* (GP) code or *Bad Point* (BP) with problem categories code (PC1 to PC5). The description of the code is as described by (Udin, 2004) and as shown in Table 1. By answering the questions, the missing pre-requisites of the manufacturer position in relative to the benchmark can be identified through the number of *Bad Points* and its PC number.

3. AHP System in KBCLMM

First developed and introduced by Saaty in 1970s (Saaty, 2001), AHP deals with complex, unstructured and multi-attribute decision problems. The application of AHP is widely accepted in various areas such as operation management, manufacturing, economics, business, and information technology (Render et al., 2006). With its ability to mimic human opinions in structuring a complex and multi-attribute problem, AHP has significantly improved the performance of the decision-making process in organisations. Razmi et. al. (2000) stress that the AHP is a powerful tool, which can be used to deal with multi-attribute and complex problems particularly in selecting and prioritising an alternative for improvement purposes. AHP has the capability to weight the alternatives and make a comparison amongst the alternatives before the optimum solution can be suggested. The AHP structure for *Lean Manufacturing Perspective* has been developed and is shown in Fig. 2.

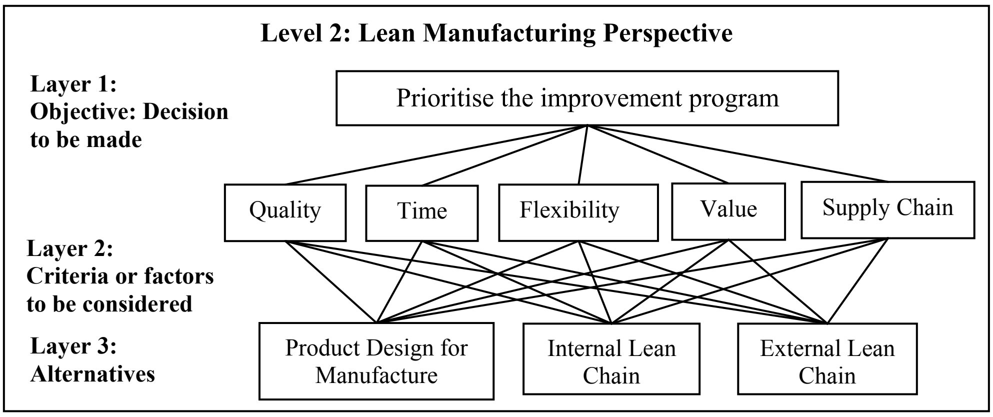

Fig. 2 The AHP Structure for *Lean Manufacturing Perspective* of KBCLMM

Layer 1 is the focus, which sets the objective of the structure, which is to prioritise and select the most needed improvement program for the *Lean Manufacturing Perspective* activities. Layer 2 of the hierarchy consists of *Quality*, *Time, Flexibility, Value* and *Supply Chain* which are the factors or criteria that influenced the selection of the improvement programs. Finally in Layer 3, there are alternatives that should be prioritised and improved within the organisation to reflect the readiness of the organisation to implement the improvement programs for *Lean Manufacturing Perspective*. This level consists of *Product Design for Manufacture (PDfM), Internal Lean Chain (ILC),* and *External Lean Chain (ELC).*

The needs for these alternatives are assessed based on the criteria in Layer 2 through series of questions in KBCLMM and GAP analysis (Nawawi et al., 2008).

In this paper, only the *Lean Manufacturing Perspective (LMP)* and its three sub-modules (*PDfM*, *ILC* and *ELC*) will be illustrated in detail. The comparisons or pair-wise comparisons (term used in AHP analysis) start from this level. The data for these comparisons is transferred directly from the process of GAP analysis embedded in the KBCLMM Model.

For each of this sub-module, there are another two or three elements that can be taken to improve that particular CLMM activity. Fig. 3 shows the improvement initiative elements for *PDfM* sub-module. The elements are *Conceptual Design, Design Tools for Analysis* or *Product Development.*

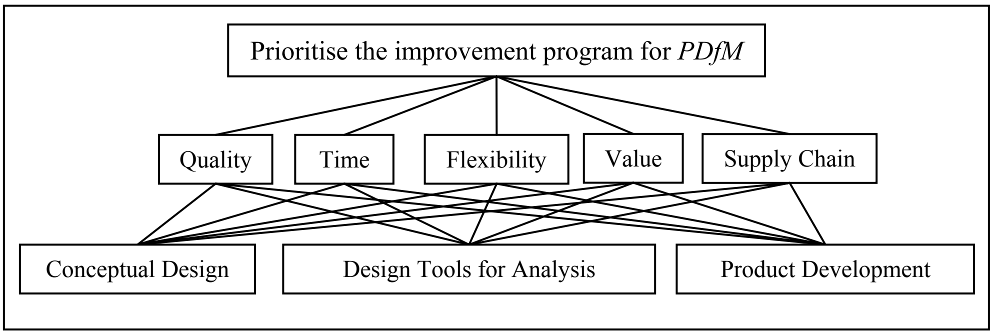

Fig. 3 The AHP Structure for *PDfM* sub-module of *Lean Manufacturing Perspective*

Based on GAP analysis in the first paper, for each of this sub-module, AHP decides which of these elements (*Conceptual Design, Design Tools for Analysis* or *Product Development*) should be in priority of improvement to increase company competitiveness for *PDfM.*

This is also the case for *Internal Lean Chain (ILC)* and *External Lean Chain (ELC)* sub-modules. Figures 4 and 5 show the improvement initiative elements for these sub-modules. As shown in Figure 4, AHP decides which of these elements (*Internal Continuous Improvement* or *Internal Process Control*) should be in priority of improvement to increase company competitiveness for *ILC. For ELC,* AHP decides which of these elements (*Integration with Suppliers* or *Integration with Customers*) should be in priority of improvement to increase company competitiveness as shown in Figure 5.

At the same time, the AHP Model also decides which one of these three factors (*PDfM*, *ILC* and *ELC*) should be in priority of improvement to increase company competitiveness for *Lean Manufacturing Perspective.* This module is designed in order to determine the most suitable improvement priorities of company competitiveness for a given circumstance based on the interactive user's answers for each sub-module.

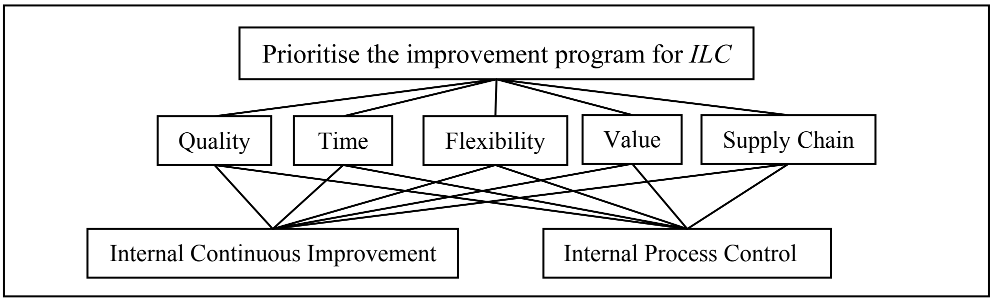

Fig. 4 The AHP Structure for *ILC* sub-module of *Lean Manufacturing Perspective*

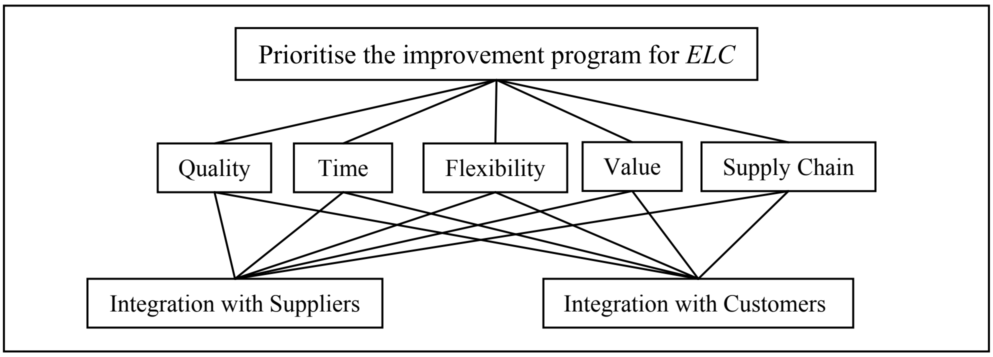

Fig. 5 The AHP Structure for *ELC* sub-module of *Lean Manufacturing Perspective*

The combination between the GAP Analysis and the AHP approach needs a transferred process of scale. It has been explained that in the GAP analysis there are five *Problem Categories* for each performance condition assessed, while the AHP approach provides nine *Intensity of Importance* to be implemented for the each sub-module level. The process is given in detail by (Wibisono, 2003) and (Udin, 2004).

3. Results

In order to evaluate the system performance and consistency, the KBCLMM model for the second part of the planning stage has been validated using industrial data. An automotive manufacturer in Malaysia is selected and interview was conducted with key personnel of the company for this purpose. The summarised results for each sub-module are shown in Table 2.

Table 2. Summarised GAP Analysis Results of *Lean Manufacturing* Perspective

Level 2: **Lean Manufacturing Perspective**	**No of Questions**	**GAP Analysis**						
		GP	BP	Problem Category				
				1	2	3	4	5
Product Design for Manufacture (PDfM)								
Conceptual Design	49	42	7	0	0	0	7	0
Design Tools for Analysis	19	19	0	0	0	0	0	0
Product Development	16	14	2	2	0	0	0	0
Total	**84**	**75**	**9**	**2**	**0**	**0**	**7**	**0**
Internal Lean Chain (ILC)								
Internal Continuous Improvement	31	28	3	1	0	0	2	0
Internal Process Control	18	13	5	5	0	0	0	0
Total	**49**	**41**	**8**	**6**	**0**	**0**	**2**	**0**
External Lean Chain (ELC)								
Integration with Suppliers	24	18	6	4	1	1	0	0
Integration with Customers	8	6	2	1	0	0	0	1
Total	**32**	**24**	**8**	**5**	**1**	**1**	**0**	**1**
Grand Total	**165**	**140**	**25**	**13**	**1**	**1**	**9**	**1**

Table 2 shows the summarised GAP Analysis Results of *Lean Manufacturing Perspective*. It contains the total number of 165 questions that have been asked, the number of *Good Points* (GP) and the number of *Bad Points* (BP), along with their Problem Categories. In the GAP Analysis, only BP are categorised into Problem Categories, with the aim of identifying the missing pre-requisites that are needed in order to implement CLMM successfully.

In the *Product Design for Manufacture* (*PDfM*) module, the KBCLMM has identified many problems at *Conceptual Design* with seven from nine *Bad Points* being exactly there. However, all the problems are not serious problems since all of them are under PC4 whereas for *Product Development*, there are two PC1. In the *Internal Lean Chain* (*ILC*) module, the System has found five PC1 at *Internal Process Control*, which indicates the area needs immediate improvement. In the *External Lean Chain* (*ELC*) module, the KBCLMM has discovered that the major problem area is at *Integration with Suppliers* with six *Problem Categories* (four PC1, one PC2, and one PC3) out of eight *Bad Points*.

Based on the results of the GAP analysis for Level 2, the KBCLMM model then processes the results using the AHP approach to determine which aspect should be in priority of improvement and how the weight of priority between *PDfM*, *ILC* and *ELC* should be determined. Tables 1-3 depict the priority vector values for each of elements in each of the sub-modules, and Table 4 shows the priority vector values for *PDfM*, *ILC* and *ELC* based on the results of the GAP analysis.

Table 3. AHP Analysis with priority vector for *PDfM* sub-module

Aspect	**Conceptual Design**	**Design Tools for Analysis**	**Product Development**	**Priority Vector**
Conceptual Design	1	1	½	0.2680
Design Tools for Analysis	1	1	½	0.1946
Product Development	2	2	1	**0.5374**

Table 3 shows that the priority vector for *Conceptual Design* is 0.2680, *Design Tools for Analysis* is 0.1946, and *Product Development* is 0.5374. It means that based on the GAP analysis and AHP process embedded in the system, for *PDfM*, the company should place its improvement priority firstly on the *Product Development*.

Table 4. AHP Analysis with priority vector for *ILC* sub-module

Aspect	**Internal Continuous Improvement**	**Internal Process Control**	**Priority Vector**
Internal Continuous Improvement	1	1/3	0.2500
Internal Process Control	3	1	**0.7500**

Table 4 shows that the priority vector for *Internal Continuous Improvement* is 0.25 and for *Internal Process Control* is 0.75. This means the company should place its improvement priority firstly on the *Internal Process Control* compared to *Internal Continuous Improvement* aspect.

Table 5. AHP Analysis with priority vector for *ELC* sub-module

Aspect	**Integration with Suppliers**	**Integration with Customers**	**Priority Vector**
Integration with Suppliers	1	2	**0.6667**
Integration with Customers	½	1	0.3333

Table 5 shows that the priority vector for *Integration with Suppliers* is 0.6667 and for *Integration with Customers* is 0.3333. This means the company should place its improvement priority firstly on *Integration with Suppliers* compared to *Integration with Customers*.

Finally, the same AHP process is then carried out at a higher level for *PDfM*, *ILC* and *ELC*. Table 4 shows that the priority vector for *PDfM* is 0.1638, for *ILC* is 0.2973, and for *ELC* is 0.5390. Based on the GAP analysis and AHP process embedded in the system, the company should place its improvement priority firstly on *ELC*, then *ILC* and lastly *PDfM*. The similar procedures of performance assessment are conducted for the other levels.

Table 6. AHP Analysis with priority vector for *Lean Manufacturing Perspective* of KBCLMM

Aspect	Product Design for Manufacture (PDfM)	Internal Lean Chain (ILC)	External Lean Chain (ELC)	Priority Vector
Product Design for Manufacture (PDfM)	1	½	⅓	0.1638
Internal Lean Chain (ILC)	2	1	½	0.2973
External Lean Chain (ELC)	3	2	1	**0.5390**

Based on the results from Tables 3-6, Table 7 provides the summary of the AHP Priority Vectors for each of the modules and sub-modules.

From Table 7, it can be seen that the KBCLMM System suggests that the company should focus firstly to improve the *External Lean Chain (ELC)* activity because of the highest Priority Vector of 0.5390. In the *ELC* itself, the company should place its improvement priority on the *Integration with Suppliers* elements (with Priority Vector of 0.6667).

Table 7. Summary of AHP Results for *Lean Manufacturing Perspective* of KBCLMM

Level 2: Lean Manufacturing Perspective			
Module	**Priority Vector**	**Sub-module**	**Priority Vector**
Product Design for Manufacture (PDfM)	0.1638	Conceptual Design	0.2680
		Design Tools for Analysis	0.1946
		Product Development	**0.5374**
Internal Lean Chain (ILC)	0.2973	Internal Continuous Improvement	0.2500
		Internal Process Control	**0.7500**
External Lean Chain (ELC)	**0.5390**	Integration with Suppliers	**0.6667**
		Integration with Customers	0.3333

It can also be seen in Table 7 that the following suggestions by the KBCLMM System. The company then should focus to improve *Internal Lean Chain (ILC)* activity (with Priority Vector of 0.2973) before committing the improvement program for *Product Design for Manufacture (PDfM)* activity (with Priority Vector of 0.1638). In the *ILC* activity, the company needs to focus more on *Internal Process Control* aspect (with Priority Vector of 0.75) compared to *Internal Continuous Improvement* aspect (with Priority Vector of 0.25). Lastly, in the *PDfM* activity, the company needs to focus more on *Product Development* aspect (with Priority Vector of 0.5374) compared to both *Conceptual Design* (with Priority Vector of 0.2680) and *Design Tools for Analysis* aspects (with Priority Vectors of 0.1946).

4. Conclusion

This paper has described an application of hybrid (KB, GAP, and AHP approach) methodology to improve the collaborative lean manufacturing activities. The AHP structure for *Lean Manufacturing Perspective* of KBCLMM model consisting of three layers was developed to serve the purpose. There are alternatives of improvement programs identified i.e. *Product Design for Manufacture (PDfM), Internal Lean Chain (ILC),* and *External Lean Chain (ELC).* For each of these alternatives, there are two or three sub alternatives that need to be prioritised for that particular improvement alternative. In the examples based on the industrial information given for *Lean Manufacturing Perspective* module, the company should focus more to improve the *PDfM* activity, and in the *PDfM* activity itself, the company should place its improvement priority firstly on the *Conceptual Design* and *Product Development* elements. By incorporating the GAP and AHP analysis technique, the KBCLMM system assists users to easily understand the position of their organisation and what programs should be taken first to optimise the improvement process.

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