A hybrid KB-AHP-GAP analysis for the performance measurement system in a manufacturing environment

Part 2: The Detailed PMS System

D. Wibisono

Abstract

This paper presents on designing and managing performance of a manufacturing unit from the corporate level to the shop floor level. A Hybrid Knowledge Based (KB) Analytic Hierarchy Process (AHP) Gauging Absence of Pre-requisite (GAP) analysis of Performance Measurement System (PMS) Model is developed that considers five levels of company performance: *Business Perspective, Customer Perspective, Manufacturing Competitive Priorities Perspective, Internal Process Perspective, and Resource & Method Availability Perspective*. The research validation was confined to four industry sectors: aircraft component manufacturing, electronics manufacturing, computer and office equipment manufacturing and telecommunication products manufacturing. The results of the validation exercise indicate that the present Hybrid PMS Model is a suitable decision-making tool to assist the practitioners of PMS and provides consistent and detailed results.

Key words: Performance Measurement System, Knowledge Based, Analytic Hierarchy Process, GAP analysis, Manufacturing

1. The Hybrid PMS Model Strategic Level

In the Strategic Level, three modules that will be assessed are Company Environment, Business Perspective and Customer Perspective, shown in the Figure 1. From Figure 1, it can be seen that in Level 0 Company Environment Module, the information needed are type of industry, number of employee, age of company, age of industry, competitors and business life cycle stage. The Company Environment Module is the starting point of the KBPMS Model and is used to identify the existing condition of the company and its operating environment. The KB system processes the user's company details through the rule-base to categorise the company based on the technology implemented (high, medium, low), number of employees (big, medium, small), competition (high, medium, low) and business life cycles (growth, sustain, harvest).The information from the Company Environment Module, including the result of the KB process (e.g. classification of the company),

will then be used in the next module to positioning company in which the performancestandards have to be applied (e.g. a high-technology industry has a higher performance standard of quality compared to low-technology industry). The necessary information is then stored in the Information Base and the next module (Business Perspective Module) is loaded. The Level 1- Business Perspective Module is related to the procedures for measuring company performance in terms of financial ratios and market share. The assessing of financial performance in this module is based on the Income Statement and Balance Sheet of company for three years in which four financial ratios that are Leverage, Liquidity, Profitability and Returns on Investment are then calculated. The conclusion of financial performance is drawn, based on the benchmarking from literature. In this module, market share is measured based on the percentage of business received from customers domestically and globally.

Figure 1 Hybrid PMS Model - Strategic Level

Referring again to the Figure 1, the *Customer Perspective Module consists of three Sub-modules namely Customer Satisfaction (CS), Customer Loyalty (CL) and Customer Acquisition (CA). Structure of the Customer Perspective Module shows*, in Figure 2. It can be seen that the KB system firstly assess the company concerns on the CS. The KB system will then assess the CL and the CA in a similar manner. Based on the assessment of CS, CL and CA, the KB system, using the AHP approach embedded in the model, then determines what improvement priority should be taken by the company. It should be noted that the CS Sub-module has been covered in great detail in this section, to show the breadth and depth of the Hybrid PMS Model and its Knowledge Base. Subsequent sub-modules (CL, CA) and modules for levels 3, 4 and 5 in the Operational Level (Section 2) will not be covered in the same level of detail, due to brevity reasons.

From Figure 2, it can also be seen that there are two types of question implemented in the *Customer Perspective Module*: general and specific. The general type of questions is relating to *company commitment, company programmes and programmes achievement in the last three years. The specific questions such as communication- (in the Company Commitment), programmes content (in the Company Programmes) and detail of programmes achievement (in the Programmes Achievement)* appear within the specific aspects of the Hybrid PMS Model.

Relating to the management commitment on the CS, not only are the top management being *assessed* in the CS Sub-module but also Sales/ Marketing, Product Design and Production Management, as shown in Figure 3. An example of rule-base for assessing the Production Management *commitment* is listed below (only few rules are given)

IF   *Production Management is responsible for establishing performance indicators on CS (Good Point)*

AND   *is not responsible for determining key benchmarks & competitors on CS (Problem Category 1)*

AND   *is responsible for determining data source of Customer Satisfaction relatives to its competitors (Good Point)*

AND   *is not responsible for developing employees' capabilities on implementation of CS programmes in production department (Problem Category 1)*

AND   *is responsible for preparing production facilities related to CS programmes (Good Point)*

AND   *is responsible for monitoring CS programmes on shop floor implementation (Good Point)*

THEN   *Production Management commitment on CS achieves 4 Good Points and 2 Problem Category 1*
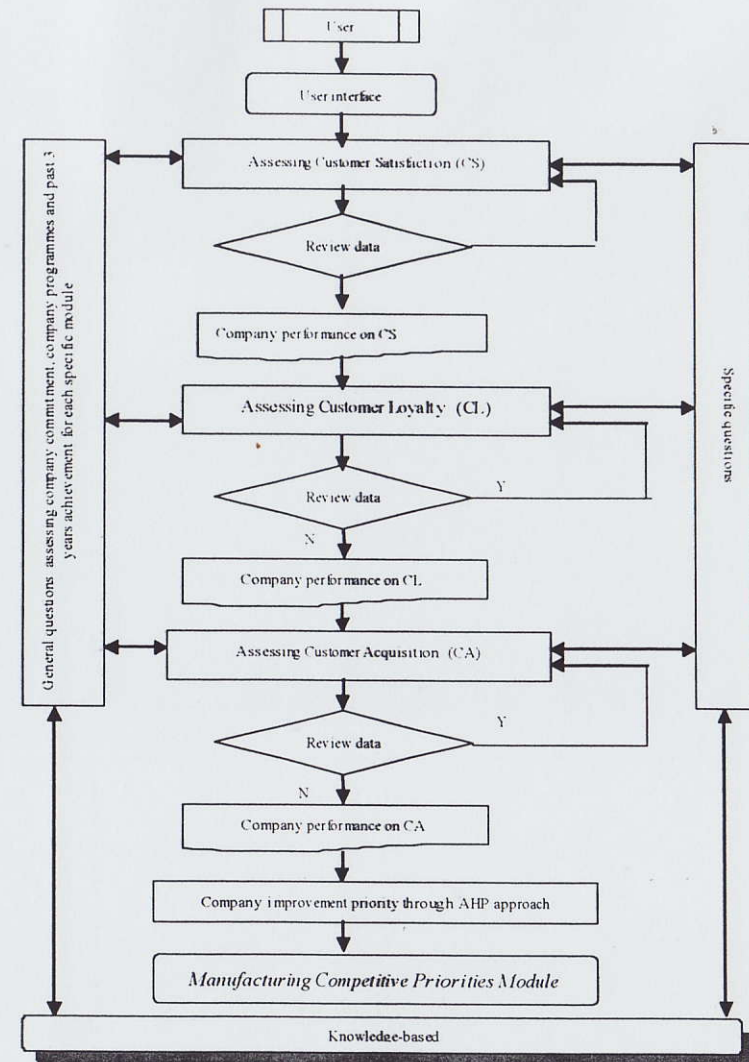

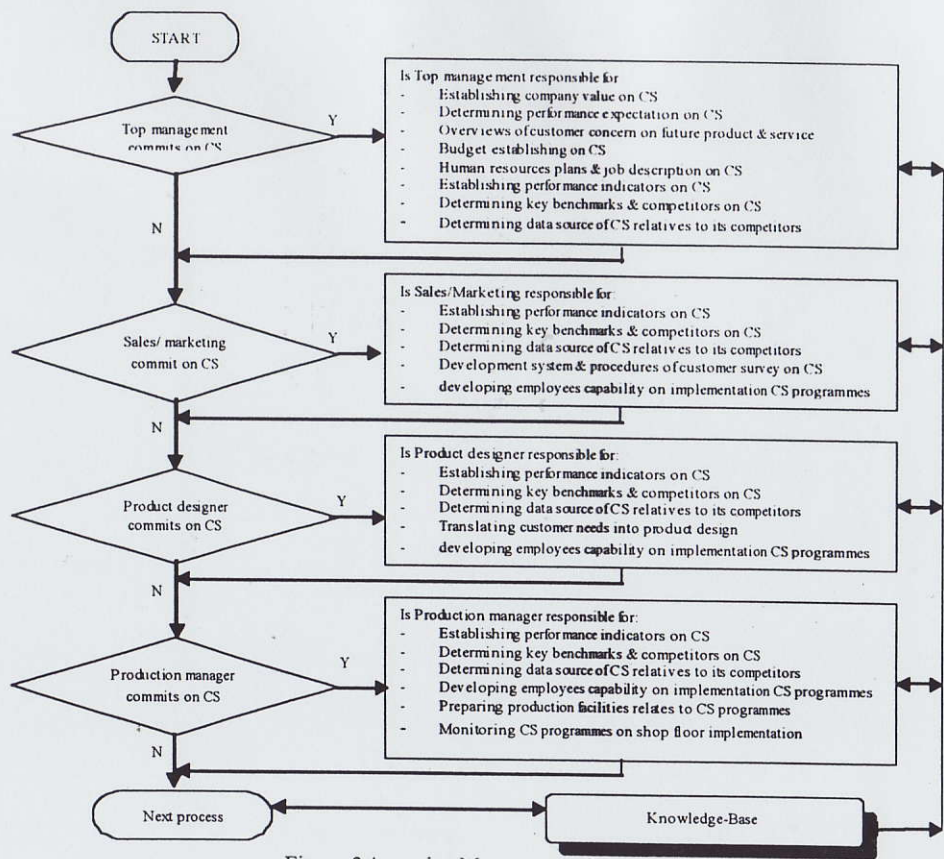Figure 2 Structure of the *Customer Perspective Module*

Figure 3 Assessing Management Commitment on CS

Figure 4 Structure of KB for CS *Programmes* Content

The structure of assessing *CS programmes* content can be seen in Figure 4. From Figure 4, it can be seen that the *programmes content* relates to the existence of CS programmes on quality of product, quality of service, safety and value for money which the procedures to assess this aspect is conducted through the rules-base as the previous explained.

The assessment of company *programmes achievement* on CS in the last three years basically refers to the achievement of program content stated in the above section.

In summary, in the CS sub-module output, the number of questions for each aspect and the *Problem Category* can be shown in Table 1.
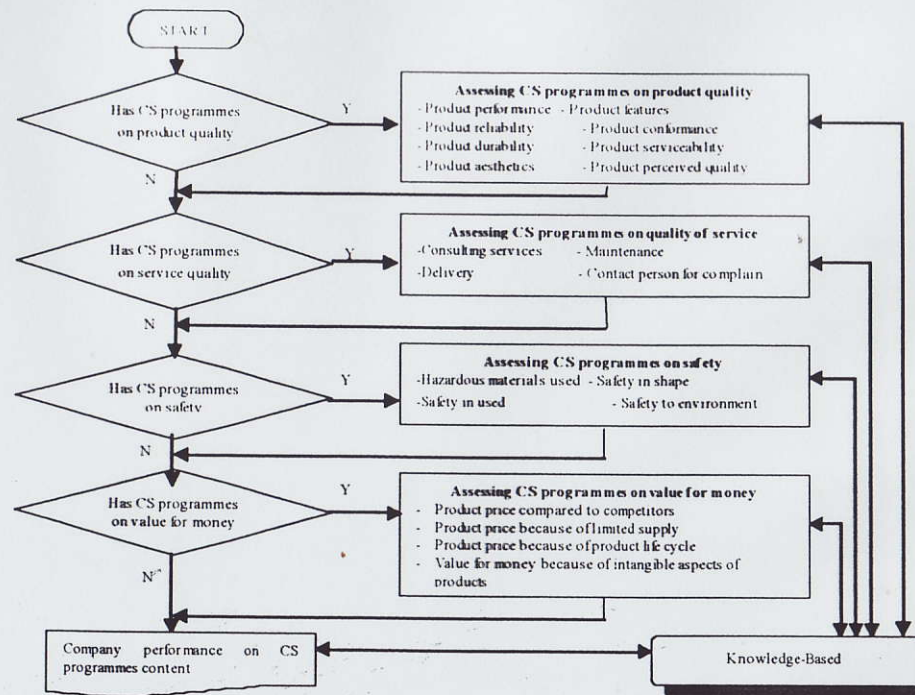
Aspect		Number of questions	Potential Problem Category (from direct answer)				
			1	2	3	4	5
Commitment	Top management on CS	10	10	0	0	0	0
	Sales/ marketing on CS	5	5	0	0	0	0
	Product designers on CS	4	4	0	0	0	0
	Production management on CS	6	6	0	0	0	0
	Communication of CS to employees	6	3	5	0	0	0
Programmes	Content of CS programmes	25	10	15	0	0	0
	Employee participation on CS programmes development	18	2	4	3	0	9
	Project manager existence & reliability	23	10	1	0	0	12
	CS programmes reliability	30					
Programmes achievement	Product quality	24	24	24	24	24	0
	Service of quality	12	12	12	12	12	0
	Safety	9	9	9	9	9	0
	Value for money	12	12	12	12	12	0
TOTAL		184	107	82	60	57	21

Table 1 Questions and *Problem Category* for CS sub-module

Based on the input data from CS, CL and CA sub-modules, the KBPMS Model then determines the improvement priority that has to be undertaken by the company to improve its competitiveness for the *Customer Perspective* Level. The process of transferring from the *Problem Category* to the *Intensity of Importance* of Saaty (1980) for the AHP approach has been explained in the Paper Part 1.

2. The Hybrid PMS Model Operational Level

The three modules that are assessed in the operational level include *Manufacturing Competitive Priorities Perspective, Internal Process Perspective and Resource & Method Availability Perspective*, shown in Figure 5.
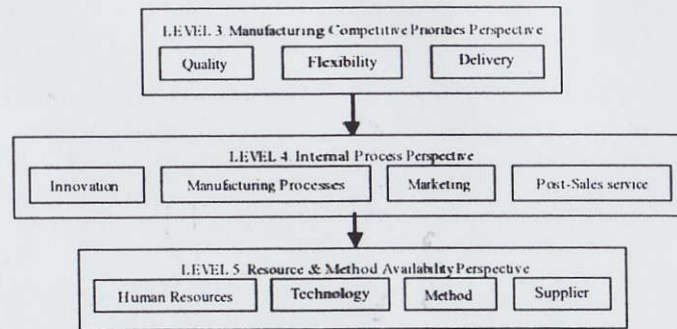

Figure 4 Hybrid PMS Model – Operational Level

Figure 4 shows the *Manufacturing Competitive Priorities Module* consists of three sub-modules that will be assessed: *Quality, Flexibility and Delivery*. The KB systems assess the company commitment on *Quality - Flexibility - On-time delivery*, the existence of programmes, the employee participation on the programmes development, the existence and reliability of project manager, the reliability of the programmes and the statistic of the programmes achievement in the last three years through similar procedures with those for the Customer Satisfaction Sub-module in the context of Quality-Flexibility-On-time delivery.

Referring to Figure 4, in the *Internal Process Perspective Module*, four sub-modules that will be assessed are *Innovation, Manufacturing Processes, Marketing and Post-Sales Service*. Figure 4 also shows the Resource & Method Availability Module that consists of four sub-modules namely *Human Resources, Technology, Method and Supplier* that will be assessed in the Hybrid PMS Model. Again, the structure of the KB system of those sub-modules follows the general patterns of question illustrated in the section 1.

3. A Case Study

The next stage after developing the Hybrid PMS Model is the testing, verification and validation of the Model. Validation of a KB system involves the validation of the knowledge (rules and conditions) incorporated into the system and the correct use of the knowledge to solve a problem (Hussain, 1998; Razmi, 1998). Real information is obtained from four Indonesian manufacturing companies. The validation process of the Model is based on interviews, questions and input/information. The input/information (answers to questions and input data) provided by each person in each company is their own data (based on their current and previous data, past experiences and judgement). The knowledge contained in the model is also tested and verified (through user feedback during the system testing). The profile of the companies for the verification and validation processes is listed in Table 2.

Description	A	B	C	D
Core Business	Electrical machinery	Communication equipment	Aeroplane part	Computer, office machinery
Number of employee	1,250	1,100	1,600	2,000
Turnover	£ 10,000,000	£ 30,000,000	£ 50,000,000	£ 8,000,000
Products	Broad castings, Transmission, IT, Signalling, Defence electronics, Energy & power electronic	Telephone, Communication network & component	CNC, maintenance Machine/ tools re-calibration	IC, Semiconductor
Number of plants	1	1	1	1
Markets	Indonesia	Indonesia	Indonesia, USA, Spain, German, British, Japan	Indonesia Singapore

Table 2 Summary of Company Profile for KBPMS Model Validation

As mentioned in Section 1, the *Company Environment Module* is the starting point of the KBPMS Model and is used to identify the existing condition of the company and its operating environment. The *Company Environment Module* is tested and verified for the accuracy of the information entry and knowledge. The user tested the behaviour of the KBPMS system regarding the KNOWLEDGE (RULE-BASE) contained in the Module. The Model performs a check in detecting any possible incorrect input. The general information provided in the *Company Environment Module* will then be exported to the next module (Financial & Market Share Module).

Since the data input for the *Company Environment Module* is mostly raw and general information needed for the subsequent modules, hence there is no crucial issue in this module regarding the company performance itself, rather the KB mechanism implemented in the system is to process these data for the other modules.

The Business Perspective Module is the first level of the KBPMS Model that is to be used as starting point to analyse the company competitiveness. Based on the data of Income Statement and Balance Sheet, the KB system uses its internal rules to produce the output shown in Table 3, which presents examples of various financial ratios of company A in terms of *leverage, liquidity, profitability and Return on Investment (ROI)*.

Description	Last year		2 Years ago		3 Years ago		Trend
	Ratio	Category	Ratio	Category	Ratio	Category	
Leverage ratio							
Debt ratio	0.95	Fair	0.98	Fair	0.89	Fair	Fluctuated
Times Interest Earned	10.28	N/A	9.59	N/A	3.72	N/A	Improved continuously
Liquidity ratio							
Net Working Capital to Total Assets	0.43	N/A	0.27	N/A	0.07	N/A	Improved continuously
Current ratio	2.88	Excess idle cash	1.97	Good	1.15	Good	Improved continuously
Quick ratio	1.03	Good	1.11	Good	0.58	Fair	Fluctuated
Cash ratio	0.37	Bad	0.46	Bad	0.31	Bad	Fluctuated
Interval measures	72.13	Fair	366.47	Good	286.53	Good	Fluctuated
Profitability ratio							
Sales to Total Assets	1.38	Good	0.51	Bad	0.45	Bad	Fluctuated
Sales to Net Working capital	5.43	N/A	1.99	N/A	1.75	N/A	Improved continuously
Net Profit Margin	16.92	Good	28.30	Good	9.96	Good	Fluctuated
Inventory Turnover	4.12	Good	1.23	Good	1.09	Good	Improved continuously
Average Collection Period	218.92	Bad	218.92	Bad	218.92	Bad	Steady
Return on Total Assets	23.37	N/A	14.32	N/A	4.44	N/A	Improved continuously
Return on Equity	3211.81	Good	2195.79	Good	494.53	Good	Fluctuated
ROI	24.5485	Good	14.6560	Good	4.6117	Fair	Improved continuously

Table 3 Example of Financial Performance for Company A

The user validates the reliability of Customer Perspective Module through interactive questions implemented sequentially in the system. In each sub-module, the KB system presents the results of GAP analysis, which consists of the number of question asked, the Good Points and the Problem Categories that are faced by the company.

After processing all three sub-modules (CS-CL-CA) sequentially, the KB system applies the AHP methodology to these three sub-modules, as highlighted in the previous section. Table 4 shows the summary of GAP analysis provided by the Hybrid PMS Model related to CS, CL and CA.

Sub-Module	Aspect	Sub-aspect	Number of questions	Good Points Total	Problem Category Achieved Total	Problem Category Achieved 1	2	3	4
Customer satisfaction (CS)	Commitment	Top management	10	9	1	1	0	0	1
		Sales/marketing	5	0	5	5	0	0	0
		Production designers	4	0	4	4	0	0	0
		Production management	4	0	4	4	0	0	0
	Programmes	Communications	6	2	4	4	0	0	0
		Content	6	4	2	2	0	0	0
		Employees participation	25	20	5	5	4	0	0
		Project manager	18	9	12	12	0	0	0
		Reliability	30	14	16	3	9	3	1
		Product quality	24	0	24	24	24	0	0
		Service quality	12	0	12	12	12	0	0
		Safety	9	0	9	9	0	0	0
		Value for money	12	0	12	12	0	0	0
	TOTAL		**184**	**69**	**115**	**77**	**13**	**3**	**1**
Customer Loyalty (CL)	Commitment	Top management	6	1	5	5	5	0	0
	Programmes	Content	7	6	1	1	3	0	0
		Budget allocation	3	3	0	3	0	0	0
		Employees participation	18	9	9	9	0	0	0
		Project manager	23	4	19	6	0	0	0
		Reliability	18	10	8	9	1	1	0
	Programmes achievement	Existing CL achievement	12	3	9	3	0	0	0
	TOTAL		**87**	**33**	**54**	**26**	**6**	**1**	**0**
Customer Acquisition (CA)	Commitment	Top management	6	2	4	2	2	0	0
	Programmes	Content	7	3	4	0	0	0	0
		Budget allocation	3	3	0	0	0	0	0
		Employees participation	18	3	15	1	3	2	0
		Project manager	23	0	23	10	1	1	0
		Reliability	16	9	7	4	3	0	0
	Programmes achievement	Existing CA achievement	6	2	4	4	3	0	0
	TOTAL		**79**	**22**	**57**	**21**	**12**	**3**	**0**
GRANDTOTAL			**350**	**124**	**226**	**124**	**31**	**7**	**0**

Table 4 An Example Summary of GAP Analysis for *Customer Perspectives Module* for Company A

From 184 questions of CS, the company achieves 69 *Good Point* and 115 *Problem Category* (PC) that consists of 77 PC 1, 13 PC 2, 3 PC 3, 1 PC 4 and 21 PC5. In the sub-module *Commitment*, Company A has a good commitment for top management but very poor for sales/ marketing, production designers and production management, indicating that the commitment from top management is not being implemented lower down. The lack of commitment from this middle management has further impact on the programmes achievement (again very poor results), for *customer satisfaction*. From this table it can be seen that the *Customer Satisfaction* for product quality, service quality, safety and value for money are all very poor with the total Problem Category 1 for these four aspects being 115 out of 184. This is a tremendously negative performance for Company A and drastic actions are needed.

For the *Customer Loyalty* (CL) aspect, from a total of 87 questions, the company achievement is 33 Good Points and 54 *Problem Categories* (PC) consisting of 26 PC 1, 6 PC 2, 1 PC 3, 0 PC 4 and 21 PC 5, again indicating very poor performance.

Finally, for the Customer Acquisition (CA) aspect, from 79 questions asked, Company A achieves 22 *Good Points* and 57 *Problem Category* consisting of 21 PC 1, 12 PC 2, 3 PC 3, 0 PC 4 and 21 PC 5.

Based on the results of the GAP analysis, the Hybrid PMS 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 CS, CL and CA should be determined. Table 5 shows an example of the *Priority Vector* for CS, CL and CA based on the result of the GAP analysis shown in Table 4.

Aspect	Customer Satisfaction	Customer Loyalty	Customer Acquisition	Priority Vector
Customer Satisfaction	1	2	2	0.500
Customer Loyalty	½	1	1	0.250
Customer Acquisition	½	1	1	0.250

Table 5 *Priority Vector* for *Customer Perspective*

The Table 5 shows that the Priority Vector for CS is 0.500, for the CL and CA are both 0.250. It means that based on the GAP analysis and AHP process embedded in the system, the company should place its improvement priority firstly on the CS as two times compared to CL and CA aspect, and improvement for CL and CA as a similar priority. The similar procedures of performance assessment are conducted for the *Manufacturing Competitive Priorities Module, Internal Processes Module and Resource & Method Availability Module.*

The process of verification and validation of Hybrid PMS Model through the other three manufacturing companies is conducted in a similar manner as has been explained for the Company A. Tables 6 and 7 show the summary results for the GAP analysis and the AHP analysis (in terms of *Priority Vector*). It needs to be reiterated that the GAP analysis provides the priorities actions needed internal to each sub-module (in terms of *Problem Categories*) where the AHP output

provides the prioritised actions between the sub-modules.

Table 6 shows the content findings by the Hybrid PMS Model for the four companies, indicating that the present performance of these companies is distant from the benchmark standards contained in the model. The results indicate for each company where it needs to focus for each of the sub-module.

Table 7 provides a summary of the AHP analysis and shows, relatively, which issues to be tackled initially. The bold figures show the priorities for each major perspective. Hence in the *Customer Perspective*, for Company A the priority is deemed to be CS (over CL and CA), for Company B it is all tree, for Company C it is CS and for Company D it is CL. Similar observations can be coped out for the other perspectives, to determine the key actions required at the sub-module. Thus the Hybrid PMS Model has not only provided the details of where the performance can be improved, but it has also provided an in-depth and prioritised decision-making tool for the practitioners.

Table 6 Summary of Hybrid PMS Model Validation Results for GAP Analysis

Note: CS = Customer satisfaction, CL = Customer Loyalty, CA = Customer Acquisition, PSS = Post Sales Service, HR = Human Resource

Module	Sub-Module	Company A	Company B	Company C	Company D
Customer Perspective	CS	0.500	0.333	0.500	0.200
	CL	0.250	0.333	0.250	0.400
	CA	0.250	0.333	0.250	0.400
	TOTAL	1.00	1.00	1.00	1.00
Manufacturing Competitive Priorities Perspective	Quality	0.250	0.260	0.200	0.600
	Flexibility	0.500	0.410	0.400	0.199
	Delivery	0.250	0.330	0.400	0.199
	TOTAL	1.00	1.00	1.00	1.00
Internal Process Perspective	Innovation	0.173	0.124	0.144	0.289
	Man Process	0.399	0.237	0.391	0.247
	Marketing	0.069	0.071	0.319	0.176
	PSS	0.359	0.567	0.144	0.288
	TOTAL	1.00	1.00	1.00	1.00
Resource & Method Availability Perspective	HR	0.244	0.234	0.250	0.304
	Technology	0.099	0.198	0.250	0.277
	Method	0.219	0.284	0.250	0.304
	Supplier	0.437	0.284	0.250	0.113
	TOTAL	1.00	1.00	1.00	1.00

Table 7 Summary of Hybrid PMS Model Validation Results for AHP (Priority Vector) Analysis

4. Conclusion

The design of PMS is a complicated process as it involves many performance variables and formula. Using a hybrid (Knowledge Based, GAP analysis and AHP approach) methodology, the PMS model consisting five performance levels was developed to serve the purpose. The hypothesis of this research was to show that the application of KB systems was a viable PMS methodology to improve company competitiveness based on the financial and non-financial variables and both based on the qualitative and quantitative assessment processes. This has been shown to be a valid hypothesis, whereby the development and the subsequent application of the Hybrid PMS model in four industrial applications have identified key areas of performance improvements. In the validation processes based on the industrial information, the Hybrid PMS model can determine accurately (for every level) which performance variables should be tackled for improvement by the company.

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