UNSYS digital

International Journal of Robotics and Mechatronics

Performance Measurement System for a Manufacturing Environment: KB/GAP/AHP Approach

Dermawan Wibisono[†] and M. Khurshid Khan[‡]

[†]School of Business and Management, Institut Teknologi Bandung, Indonesia

[‡]School of Engineering, Faculty of Engineering and Informatics, University of Bradford, United Kingdom

***Abstract*—**Designing and implementing Performance Measurement System (PMS) is an integral part of management control systems. This paper presents an original and novel approach to designing and benchmarking of PMSs for a manufacturing environment through a hybrid framework which overcomes the shortcomings of earlier models. A detailed review was taken of previous models and their limitations were identified. The present hybrid PMS model seeks to improve the earlier research models by the following novel approach: implementation of a Knowledge Based (KB) expert system, Gauging Absences of Pre-requisite (GAP) analysis and Analytic Hierarchy Process (AHP) methodology in an integrated KBPMS. The paper has shown that the present hybrid (KB-AHP-GAP) approach to developing a KBPMS model is a realistic methodology. The combination of the KB-AHP-GAP approach allows detailed benchmarking of the PMS existing within a manufacturing organisation. Furthermore, this approach can assist in identifying and prioritising the key decisions that need to be actioned to overcome the existing PMS shortcomings.

***Keywords*—**Performance Measurement System (PMS), Knowledge Based (KB), expert systems, GAP analysis, Analytic Hierarchy Process (AHP).

I. Introduction

MANUFACTURERS, more than ever before, are realising that the need for accurate and comprehensive information about their performance activities is of crucial importance. This is because as [1], [2], [3], [5], [6], and [7] have indicated, to be classified as World Class Manufacturers (WCM), manufacturing organisations need to have a number of critical ingredients; one such ingredient is that of an appropriate Performance Measurement System (PMS). Throughout the 1990s, various novel frameworks have been derived, to aid manufacturing organisations to select and implement measures, such as SMART [8], Performance for World Class Manufacturing (PWCM) [9], Vital Signs [10], Balanced Scorecard(BSC) [11] and the Prism [12]. However, as [13] have observed, research in the area of performance measurement has not produced solid findings and this remains a challenge. [14] support this argument through their research findings which show that some 90% of managers fail to implement and deliver their organisation's strategies by the performance measurement applied. They argue that this failure is mainly due to the business performance itself being a multi-faceted concept that needs a different type of PMS. Furthermore, methods for developing and implementing detailed measures, adapted to the environment of a specific company, are seldom described in detail. This paper presents a novel hybrid KBPMS system based on a KB, GAP, AHP approach and which contains over 2000 KB rules.

Corresponding author: Khurshid Khan (e-mail: m.k.khan@bradford.ac.uk).
This paper was submitted on November 28, 2015; revised on December 20, 2015; and accepted on December 27, 2015.

II. Conceptual Framework of a PMS

The previous section has surveyed a number of PMS frameworks, introduced their benefits and also limitations. Compared to the previous frameworks**,** the proposed KBPMS model in this study is new in a number of key ways through the use of an interactive methodology in terms of the KB systems as a decision making tool. The implementation of GAP analysis together with the AHP approach in an integrated KBPMS model covers all organisational levels and provides exact analysis of the present PMS against a benchmark.

In developing a PMS, previous researchers start by identifying the characteristic of 'reliable' measurement systems, for which some provide the characteristics explicitly, whilst others imply them by criticising financial performance measurement [see for example: [15], [16], [17], [18] and [19]]. Even though there are some differences in terminology and scope of the characteristics proposed by these studies, they can be condensed into the set of general principles as summarised below. These principles are taken as the basic thinking for developing the PMS in this study:

a. A PMS should relate performance of the shop floor to manufacturing strategy.
b. A PMS should consist of a set of well-defined and measurable criteria. Even though the previous studies implemented a wide range of variables, there is general agreement regarding how to choose the 'appropriate' variables as summarised below:

- The chosen performance variables must be easily understood and must represent the system they try to measure.
- The 'KISS' (Keep It Simple Stupid) principle should be applied.
- In choosing performance variables, care should be taken to avoid two particular problems: 'false alarm' and 'gap'. [20] define the term 'false alarm' to be the use of the wrong measure to motivate managers so they spend time improving something that has few positive consequences for the company, and perhaps even some harmful consequences. The term 'gap' refers to a failure to include a necessary measure, so that something important for the company stays neglected.

c. The standard of performance for each criterion is very important. It should be complemented by procedures to compare actual performance achieved to standards provided.
d. A PMS should foster improvement rather than just monitor performance.
e. A PMS should provide information on a timely basis. The aim should be to provide feedback as close to the event as possible.

Referring to these principles of developing a PMS and considering steps of designing a PMS, there are three main important stages that have been considered in the development of the KBPMS Model: *Basic Information, Core of Performance Measurement*, and *Mechanism of Performance Measurement.* Within these three features of the conceptual model, the KB expert system is used as the main foundation, as depicted in the **Figure 1**, and described in detail in the following sections.

A. Stage 1

From **Figure 1**, it can be seen that in *The Basic Information* stage there are three important sets of information that need to be considered: *Company Environment Information, Financial and Market Information* and *Product Information*. The aim of the *Company Environment Information* is for positioning the area in which the company currently competes. The reasons for considering company *Financial and Market Information* is that financial performance indicates how the company is presently being run in terms of efficiency and effectiveness [11]. While *Market Share* reflects how competitive the company's products and services are, it also provides an indication of customer satisfaction in comparison to that of competitors [21]. Since the *Product Information* is a backbone of manufacturing competitiveness, the information about the products that the company is manufacturing and selling is absolutely crucial. For all intents and purposes, it is this aspect of the company that the customer receives (be it a tangible or intangible product).

B. Stage 2

In the *Core of Performance Measurement* aspect there are several important pieces of information that need to be considered such as: company statements, performance variables, linkage among performance variables, weight of each variable relative to the company's performance and performance standards of each variable.

Since company statements such as company *strategy, vision, mission,* and *objectives* determine the future direction, it is therefore important to explore whether the company not only has these statements but also communicates them to all employees at all levels. All company statements should become a 'compass' for guidance in determining performance variables. This is based on the argument that all performance variables used in the PMS have to be aligned with the company strategies, vision, mission, and objectives [11].

From **Figure 1** it can also be seen that there are four different groups of manufacturing company performance variables related to the management responsibility: *Customer Perspective*, *Manufacturing Competitive Priority*, *Internal Process* and *Resource & Method Availability*. Each of these four groups consists of several performance variables. The most critical aspect in this stage is in determining which performance variables are most appropriate to the company. Within the manufacturing environment, managers can make the manufacturing function a competitive weapon by outstanding accomplishment of one or more of the measures of manufacturing performance. However managers need to know: *What must we be especially good at: quality, lead times, cycle time, productivity, delivery, product flexibility, volume flexibility, minimum changing schedules, rework levels or other measures?* Choosing just a single variable will misrepresent the overall factory performance, while using all the possible variables may represent the real performance but would be very complex. In many cases, performance against some variables may be adequately represented by the measurement of others [22]. It is impossible to measure every aspect of the plant because measurement systems incur real costs, both obvious and hidden. Therefore choosing several key variables that most represent performance is a critical step in developing performance measurement variables.

Referring again to **Figure 1**, the AHP is embedded in the system for determining quantitative and qualitative linkage patterns among performance variables in the *Customer Perspective, Manufacturing Competitive Priorities, Internal Process* and *Resource and Method Availability*. These linkages are important to determine the cause and effect between performance variables in the different levels and to know the improvement priority that should be taken among performance variables in the same level. The details of the AHP mechanism will be discussed in Section 5.

The essence of Benchmarking is to encourage continuous learning and to lift organisations to higher competitive levels. Benchmarking is not a means of winning at any cost, but is a legitimate, systematic, overt and ethical process of bringing about effective competitiveness [23]. It is concerned more with finding out about ideas on managing processes and therefore achieving superior performance rather than with gathering sensitive information on cost, pricing, and effectiveness.

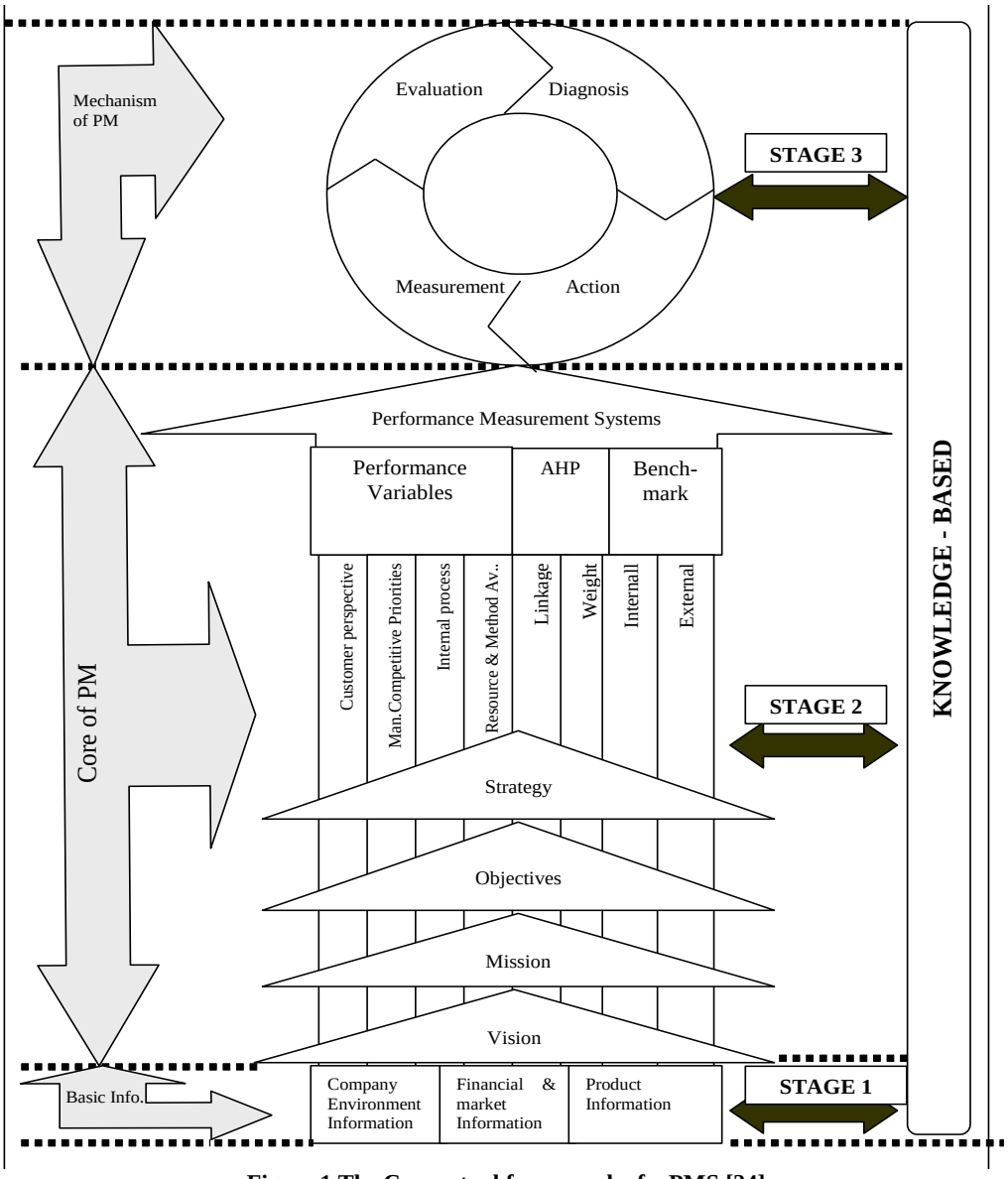

Figure 1 The Conceptual framework of a PMS [24]

C. Stage 3

Referring finally to **Figure 1**, *the Mechanism of Performance Measurement aspect* consists of four main steps: *Measurement, Evaluation, Diagnosis* and *Action. Performance Measurement* has been implemented in the factory level for most manufacturing companies. However, *Performance Measurement* often seems to have become a routine activity, without any determined strategy for the required follow up action. The results of performance measurement tends to give an insight where the actual performance is worse than expected.

It does not give an insight into why the actual performance differs from the expected nor does it inform how one can improve the actual performance. It is clear that performance measurement does not automatically give an answer to the question, "how good the actual performance is", neither does it give suggestions for where performance improvements are possible [26]. Performance measurement thus, is a starting point for further analysis.

Performance Evaluation is the assessment of a possible situation in comparison with plans and or standards previously set as a target. There are two ways in which to set a performance target: internal and external standards. The first target could be to monitor internal competitiveness in term of continuous improvement. The most important thing in deciding an internal target is that it should be realistic and challenging; if there is no drive for improvement, people will not easily think about ways to improve their performance [22]. The internal benchmark could be conducted based on comparisons to the best previous performance, the technical standard, the other departments in the company, the average in a certain period or the last period of performance. The external target is based on the benchmarking of best practice in a similar industry, industry

benchmarking or current competitors. This target is crucial since implementation based merely on internal targets can be meaningless if, over time, the competitors are getting further ahead.

Performance Diagnosis is defined as the process of finding causes of performance deviations and explaining the achieved performance. Diagnosing the performance is important because to some extent, management often claims to know the causes for performance deviations [25]. They can give numerous explanations for the observed gap between actual performance and the performance target. According to [26], the danger of qualitative explanations regarding the deviation of performance is that it is possible that the assumed causes are not all the causes that explain the observed performance gap. In this case, there are other causes that have not been determined yet. For this reason, it is important to have knowledge of the linkage among different performance variables. Secondly, if the result of the diagnosis is that the assumed causes were the right ones, one can use this information to reinforce the intuition. Thirdly, due to all kinds of changes on the shop floor or its environment, there is the danger that problems are solved only by using the past experience to find possible causes, whereas new factors may have arisen.

Action plan is concerned with identifying actions that need to take place if performance proves to be either satisfactory or unsatisfactory. There are two different aspects for the improvement of actions: strategic and technical [27]. The strategic aspect is more concerned with decision making in the higher level of management and in the long-term policy, especially in the policy of improvement resources. For example if it is found that inadequate resources are rendering the company to be uncompetitive, the need for new resource capabilities is intense.

III. Conceptual Model of Hybrid KBPMS

The hybrid PMS Framework introduced in Section 2 can also be visualised from a strategic and operational structure, as depicted in **Figure 2**. This **Figure 2** is a clearer interpretation of how the hybrid PMS framework has been actually developed as a hybrid KBPMS expert system model, and reflects the strategic and operational structure of a typical organisation. Of course there are links between performance measures at one level with those at other levels. Company performance on the *Business Perspective* (Level 1), for example, is influenced by performance on the *Customer Perspective* (Level 2). Performance of Level 2 is influenced by performance in the Level 3. The bottom link of company performance is Level 5

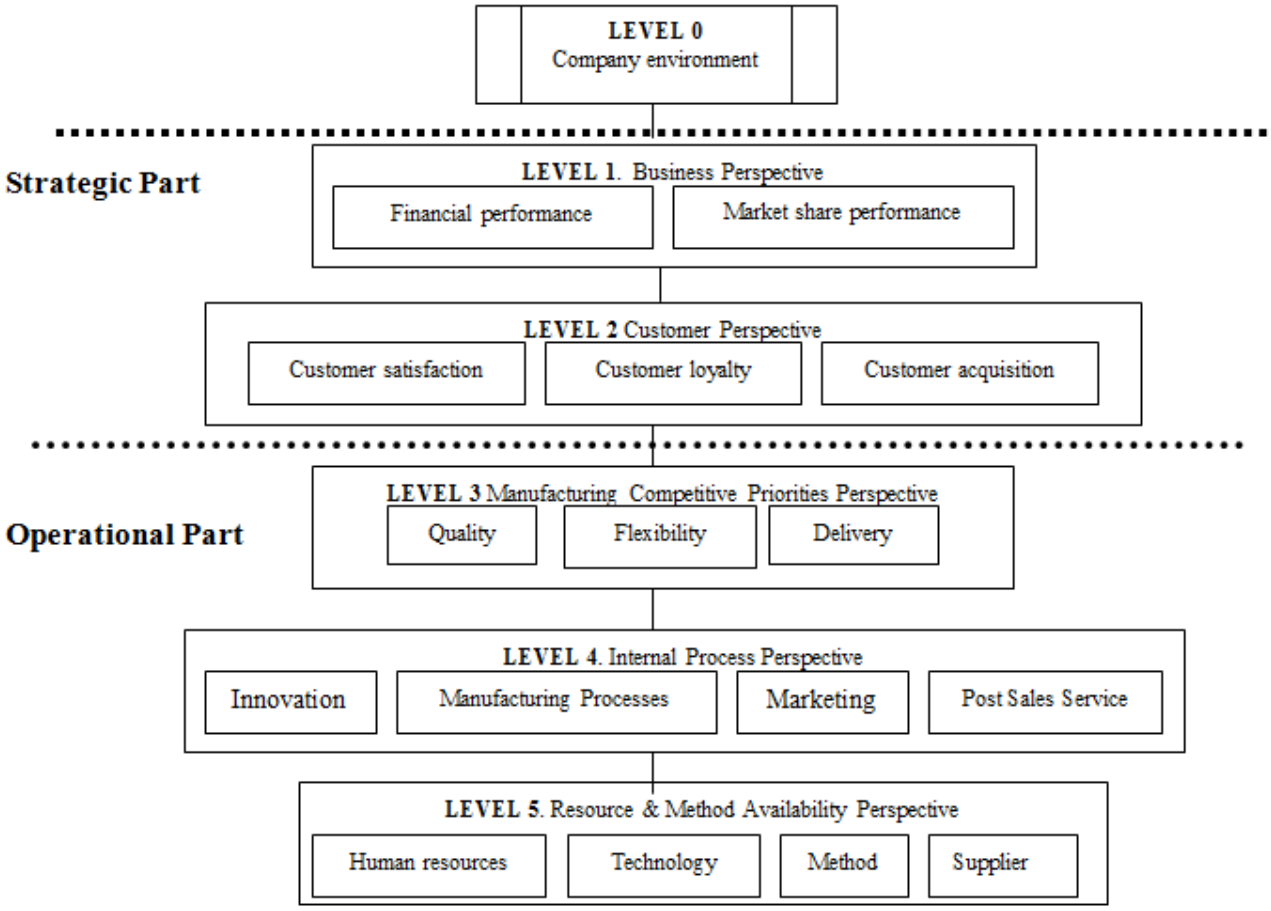

Figure 2 Showing the Hybrid KBPMS model framework [25]

(*Resource and Method Availability Perspective*). It can be seen that the company's profitability is influenced by customer loyalty, whilst the customer loyalty itself will be increased if, for example, the customers always receive the product on-time. On-time delivery only could be guaranteed by the achievement of production on schedule that needs to be supported by qualified and trained employees. Thus there is inter-relation (across and below) of factors that affect the performance of a company which need to be taken into account in the KBPMS model. The following descriptions are referring to Figure 2.

A. Level 0 – Company Environment

The *Company Environment Module* (Level 0) determines the particular environment the company is operating in. Since different company environments need different performance standards and different improvement strategies, it is therefore a crucial stage to identify and map the company's environment to ensure the performance diagnosis is valid, reliable and factual. The information needed in this module is: *type of industry*, *number of employees*, *age of company*, *age of industry*, *competitors* and *business life cycle.*

The industry information is needed to classify a manufacturing company into a certain group of appropriate benchmarks based on the product produced. This classification is based on the reasoning that a certain type of industry has its own competitive priorities and special performance standards. This information is the starting point for mapping the current status or condition relative to the competitors so that the improvement programmes can be determined. Business life cycle influences the company in determining its manufacturing strategy.

B. Level 1 - Business Perspective

This level covers the first strategic part of the KBPMS model. Financial and market share objectives serve as the focus of all businesses in the world. Maximisation of profit, maximisation of the return on capital employed, maximisation of shareholders' wealth, survival and growth are some of the most important objectives of the company to survive. It is therefore, crucial to consider these business parameters in any PMS. In the KBPMS Model, *The Business Perspective Module* assesses a company's financial performance and market share through specific performance criteria. The financial performance and market share serve as the focus for the objectives and measures of other perspectives.

C. Level 2 - Customer Perspective

This level covers the second strategic part of the KBPMS model. In the past, companies could concentrate on their internal capabilities, emphasising product performance and technology innovation. However companies are also now moving their focus externally, to customers and competitors. If business units are to achieve long-run superior financial performance, they must create and deliver products and services that are valued by customers'. The three most important performance measures in the company's perspectives are customer satisfaction, customer loyalty and customer acquisition. The *Customer Perspective* in the KBPMS model will diagnose customer satisfaction, customer loyalty and customer acquisition as a key measure of external performance measurement.

D. Level 3 - Manufacturing Competitive Priorities Perspective

This level covers the first operational part of the KBPMS model. *Manufacturing Competitive Priorities Perspective* is a measuring system developed to support managers in decision making with regards to their performance attainment against the three competitive variables: quality, flexibility and delivery. These three are chosen as the key variables of manufacturing competitiveness based on the extensive literature reviews. The previous researchers ([1], [2], [3], and [4]) state clearly that there is correlation between these three performance variables and the company's competitiveness. The importance of quality, flexibility and delivery in determining manufacturing competitiveness has been very well documented.

E. Level 4 - Internal Process Perspectives

This level covers the second operational part of the KBPMS model. Internal processes have been a focus of a company's improvement in competitiveness for a long time. Even traditional PMS systems usually focus on controlling and improving existing departments which are separated not only from the measurement activities of other departments but also have no relationship with the other programmes [14]. Since an internal process represents the effectiveness and efficiency of internal manufacturing performance, it is therefore important to manage the performance rigorously. Four of the most important performance parameters in the *Internal Process Perspective* that will be assessed are *Innovation*, *Manufacturing Process*, *Marketing* and *After Sales Service*, with each aspect consisting of several performance sub-variables.

F. Level 5 - Resource and Method Availability Perspective

This level covers the third operational part of the KBPMS model. Organisations must also invest in their infrastructure: people, systems and procedures if they are to achieve ambitious long-term financial growth objectives. In the proposed KBPMS Model this infrastructure is named as *Resource and Method Availability Perspective.* There are four main categories of resources and methods in manufacturing that will be assessed: *Human Resource*, *Technology*, *Method* and *Suppliers*, within which there are a number of sub categories.

The above section has described in detail the KBMPS model and its structure. The following sections describe the GAP and AHP aspects, which are imbedded in the hybrid KBPMS.

IV. GAUGING ABSENCES OF PRE-REQUISITES (GAP)

GAP analysis is used to determine the disparity between the essential or desirable prerequisites and what actually exists in an organisation. This analysis is to identify likely problem areas, which must be addressed by the management if an effective implementation is to be achieved. The mechanism of GAP analysis is conducted through the responses of the user to

the questions provided in the KBPMS Model. The problems highlighted for each negative reply is categorised under the following headings in descending order of importance ([27] and [28]).

Category 1: This indicates a serious problem which should and can be resolved in the short-term, and the resolution of the problem is quite likely to provide real short-term benefits

Category 2: This indicates a serious problem which is likely to have pre-requisites, and is thus better dealt with as part of an appropriate and logical improvement and implementation plan

Category 3: This is not a serious problem, but can be dealt with now. If resolved, it is likely to yield short-term benefits

Category 4: This is not a serious problem. Although it could be dealt with now, it is unlikely to yield short-term benefits. Therefore, it should only be dealt with if it is a pre-requisite for other things

Category 5: 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, upon subsequent probing by succeeding questions, may well reveal problems.

The computer based GAP analysis system has been designed to provide a number of user friendly facilities to maximise the ease with which the computerised Knowledge-Base can be created in the first place and used subsequently. The main facilities in the system, from the view point of an end user are as follows.

Explanation to the question

This facility is a very important part of the KBPMS model, in that contains additional knowledge to assist the user in not only understanding the question, but also to help them in terms of the possible answers (and thus avoiding any 'fuzziness'). While the questions are phrased as unambiguously as possible, certain questions may include terms which the user may not understand at first glance. Any misinterpretation of the question could lead to an incorrect answer and, eventually, wrong diagnosis by the GAP analysis system. The explanation also provides an indication of good practice.

V. Analytic Hierarchy Process (AHP)

Selection of the most suitable improvement priorities is a multi-attribute and complex problem. It requires the development of a tool to address both qualitative and quantitative parameters. The AHP is one of the most powerful tools employed to deal with these kinds of problems [27]. The application of the AHP not only provides the tool to weight the factors, but also it confirms the correctness and integrity of the comparison of the factors made by the user.

AHP has been applied to several decision problems [25] e.g. investment appraisal, human resource evaluation, project selection and vendor rating. However, little attention has been given so far for the application of the AHP to performance measurement [25]. The step of implementing AHP in this model follows the guidance given by [28]. However the following gives an outline of the process.

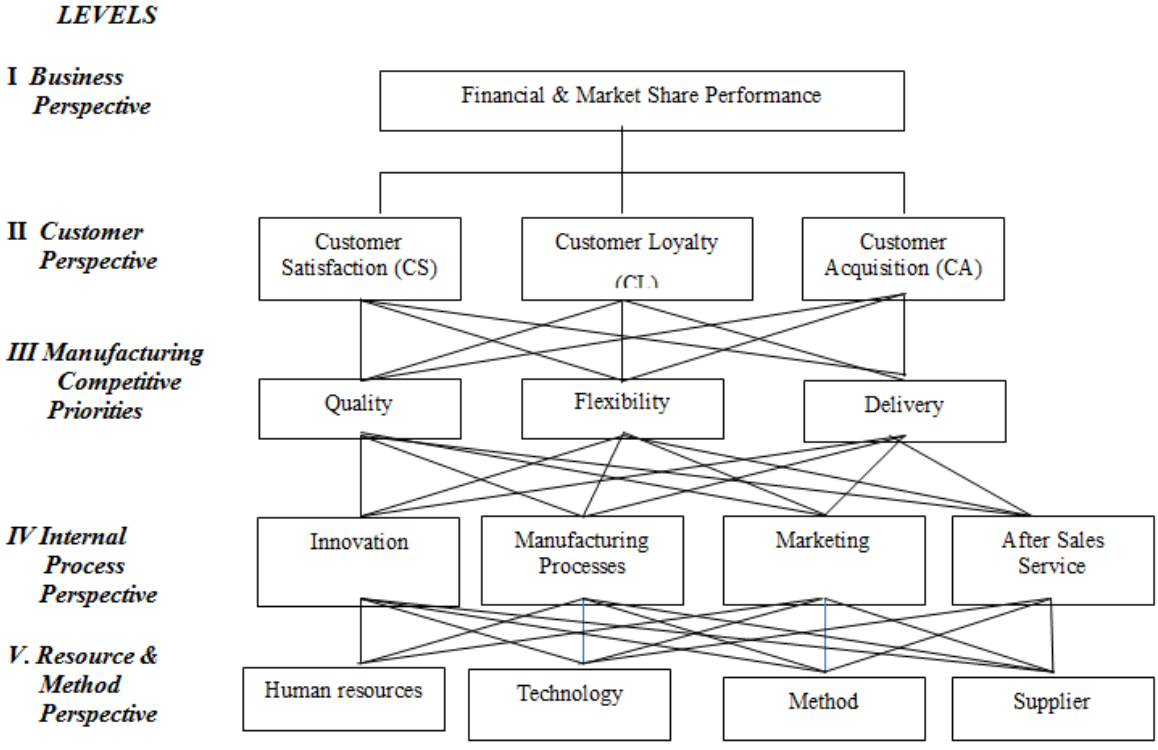

Figure 3 Showing the AHP Structure for KBPMS Model [25]

- State the problem
- Identify criteria that influence the behaviour of the problem
- Structure a hierarchy of the criteria, sub-criteria, properties of alternatives and the alternatives themselves.
- Prioritise the primary criteria with respect to their impact on the overall objective called the focus.
- State the question for pairwise comparison clearly above each matrix.
- Prioritise the sub-criteria with respect to the criteria
- Enter pair-wise comparison judgements and force their reciprocals
- Calculate prioritise by adding the elements of each column and dividing each entry by the total of the column. Average over the rows of the resulting matrix and get the priority vector.

Referring again to the structure of KBPMS Model as illustrated in the **Figure 2** and considering the step of implementation AHP stated above, the AHP hierarchy embedded within the KBPMS Model is shown in **Figure 3** which basically has a structure and logic as explained in Section 2. From **Figure 3**, it can be seen that the AHP is a five level hierarchical structured model, which is able to analyse the given manufacturing competitiveness based upon the focus on *Business Perspective* performance. *Business Perspective* performance is influenced by the company performance on *Customer Perspective* which consists of three main factors namely *Customer Satisfaction*, *Customer Loyalty* and *Customer Acquisition*. The performance of *Customer Perspective* is influenced by the company performance on *Manufacturing Competitive Priorities Perspective that* consists of performance on *Quality, Flexibility* and *Delivery*. The performance in the *Manufacturing Competitive Priorities Perspective* is influenced by the performance on *Internal Process Perspective* which consists of *Innovation, Manufacturing Process, Marketing* and *Post Sales Service*. The root alternatives should be improved to increase performance on *Internal Process Perspective* are *Human Resource, Technology, Method* and *Supplier*.

The pair-wise comparisons start from the level II of the AHP; *Customer Satisfaction (CS), Customer Loyalty (CL) and Customer Acquisition (CA).* The data for these comparisons is transferred directly from the process of GAP analysis embedded in the KBPMS Model. This means that the AHP Model decides which one of these three factors (CS, CL, CA) should be in priority of improvement to increase company competitiveness for *Business 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.

The combination between the GAP Analysis and the AHP approach needs a consolidated 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 [28] provides nine *Intensity of Importance* to be implemented for each sub-module level. Thus the five scale GAP methodology was scaled to the nine scale AHP methodology.

It needs to be reiterated that the KB-GAP analysis provides the priority actions needed *internal* to each and every sub-module (in terms of *Problem Categories)* contained within the KBPMS model, whereas the AHP output provides the prioritised actions *across* (*external to*) the sub-modules. Thus the user can obtain information about which main modules/sub-modules need to be prioritised for improvements through the AHP methodology, and then what precisely needs to be done *within* each of these identified modules/sub-modules in terms of eliminating the Problem Categories through the earlier exercise carried out by the KB-GAP aspect of the KBPMS model, thereby providing detailed and practical information for assisting in the decision making process.

VI. Typical KB Rule Base in KBPMS

Although the complete KBPMS system is shown in **Figure 2**, for the sake of brevity, only the Level 3 module *Manufacturing Competitive Priorities Module will be discussed in detail. This module* consists of three sub-modules that need to be assessed: *Quality, Flexibility* and *Delivery*. Again, for the sake of brevity, only the sub-module *Quality* is illustrated in detail.

Quality is positively and significantly related to a higher Return On Investment for almost all kinds of products and market situations. Companies whose products are perceived as having superior quality have more than three times the return on sales versus companies whose products are perceived as having interior quality. Measuring quality from a customer's point of view is very complex since customers are unique and vary in needs and demand. The practical method is by measuring the 'un-met' demand that can be represented through customer claims and product returns. By managing customer claims and product returns, a company will have crucial information and therefore it can make an improvement of its product quality based upon customer needs and inputs.

There are sequential questions implemented in the *Quality Sub-module* following the general patterns. The assessments conducted in the *Quality Sub-module* related to the *company's commitment on quality, company's quality programmes, employees participation on the quality programmes development, programmes manager existence and reliability, reliability of quality programmes* and *company's quality programmes achievement in the last three years*. The term 'quality' in this sub-module refers to the quality from the customer's point of views. The procedures of KB assessment for the four aspects: *company commitment, employee participation on the programmes development, the programmes manager existence and reliability, and the reliability of the programmes* are typical and same as these procedures conducted for the *Customer Perspective Module.*

An example of KB rules to assess programmes content in the *Quality Sub-module* is listed below:

IF *the company has systems & procedures for product recall (Good Point)*
AND *does not have systems & procedures for warranty claims (Problem Category 1)*
AND *does not have systems & procedures to control all documents & data related to the products & services offered (Problem Category 1)*
AND *the company measures customer claims (Good Point)*
AND *company measures customer claims in terms of product performance (Good Point)*
AND *the customer claims of product performance in 3 years ago < 0.1% (Good Point)*
AND *the customer claims of product performance in 2 years ago > 2.5% (Problem Category 1)*
AND *the customer claims of product performance last year > 2.5% (Problem Category 1)*
THEN *the company achieves 4 Good Points and 4 Problem Category 1 for long term programmes content and customer claims in terms of product performance.*

TABLE 1 QUESTIONS AND PROBLEM CATEGORY FOR QUALITY SUB-MODULE

Aspect	Quality Submodule	Number of questions	Problem Category				
			1	2	3	4	5
Commitment	Top management on quality	20	1	3	2	0	0
	Budget allocation	20	3	3	3	3	0
Programmes	Content of quality programmes	35	10	6	0	0	0
	Employee participation on quality programmes	30	1	4	4	0	2
	Project manager existence & reliability	30	10	0	0	0	2
	Quality programmes reliability	30	5	5	1	1	0
Programmes achievement	Customer claims	35	5	8	8	8	0
	Product returns	30	5	6	3	5	0
TOTAL		230	40	35	21	17	4

In summary, the number of questions asked and the *Problem Category* for the *Quality Sub-module* is shown in **TABLE I**. Again this table shows a summary of where the management needs to focus their efforts to improve their performance.

In this way, the KB rule base is developed for the whole of the *Quality* sub-model, which has three main sections: *Commitment, Programmes and Programme Achievements*. **TABLE I** summarises the results for this sub-module. As can be seen, there are a total of 230 KB rules for this sub-module, out of which a total of 113 Good points were recorded (i.e. the pre-requisites existed). However, the KBPMS system has identified a total of 117 Problem Categories, of which there were 40 Problem Category 1, 35 Problem Category 2, and 2140 Problem Category 3 issues, across the *Quality* sub-module, thus determining the priority improvements that need to be made to achieve a benchmark position.

VII. APPLICATION OF THE KBPMS

Verification and validation is an important step in the development and implementation of the KB systems. Verification of the KB system is the determination of whether or not the system is functioning 'as intended'. This involves the determination of input information accuracy, output information accuracy and checking the explanation and justification. This section briefly describes the testing, verification and validation of the KBPMS Model within Company A, an electrical machinery manufacturer with a turnover of over £10.0 Million and having over 1200 employees.

In the *Manufacturing Competitive Priorities Module*, shown in **TABLE II**, the KBPMS Model acquires input information regarding commitment of top management on improving manufacturing competitiveness in terms of *Quality, Flexibility* and *Delivery*, existence of improvement programmes for these three aspects, participation of employees on the development and implementation of the programmes, existence and reliability of the programmes manager, reliability of the programmes and company achievement of these three aspects in the last three years.. For this Company A,, the *Manufacturing Competitive Priorities Module* is tested and verified in detail for the accuracy of the input information and knowledge contained within the module. The information of Company A is used as a detailed example to illustrates the Module and the KBPMS Model ability. Thus **TABLE II** shows an example of company response on *Manufacturing Competitive Priorities Module.* There are a total of 230 questions asked for *Quality* aspect, 84 for *Flexibility* aspect and 80 for *Delivery* aspect.

From **TABLE II**, as discussed in Section 6, for the *Quality Programmes*, the company has very poor employee participation, poor project manager reliability and average achievement for programme content and programmes reliability. The poor condition of *Quality Programmes* has impact on the subsequent programme achievement. The company performance for *Customer Claims* and *Product Returns* are both very bad. This evidence gives a clue that only a company commitment is not enough to improve company competitiveness in quality aspect. Without employee participation, reliable project manager, good and reliable

TABLE II SHOWING THE SUMMARY FOR LEVEL III MODULE: MANUFACTURING COMPETITIVE PRIORITIES

Sub-Module	Aspect	*Manufacturing Competitive Priorities*	Number of questions	Good Point	Bad Point Problem Category				
					1	2	3	4	5
Quality	Commitment	Top management on quality	**20**	6	1	3	2	0	0
		Budget allocation	**20**	2	3	3	3	3	0
	Programmes	Content of quality programmes	**35**	12	10	6	0	0	0
		Employee participation	**30**	3	1	4	4	0	2
		Project manager existence & reliability	**30**	8	10	0	0	0	2
		Qualityprogrammes reliability	**30**	12	5	5	1	1	0
	Programmes achievement	Customer claims	**35**	0	5	8	8	8	0
		Product returns	**30**	0	5	6	3	5	0
	TOTAL		**230**	**43**	**40**	**35**	**21**	**17**	**4**
Flexibility	Commitment	Top management on Flexibility	6	0	1	3	2	0	0
		Budget allocation	3	0	3	0	0	0	0
	Programmes	Content of flexibility programmes	7	0	1	6	0	0	0
		Employee participation on flexibility	19	0	2	3	5	0	9
		Project manager existence & reliability	23	0	11	0	0	0	12
		Reliability of the programmes	18	0	10	7	1	0	0
	Programmes achievement	Lost sales	4	0	4	0	0	0	0
		Back order	4	0	4	0	0	0	0
	TOTAL		**84**	**0**	**36**	**19**	**8**	**0**	**21**
Delivery	Commitment	Top management on delivery	6	3	1	2	0	0	0
		Budget allocation	3	0	3	0	0	0	0
	Programmes	Content of delivery programmes	7	0	1	6	0	0	0
		Employee participation on delivery	19	0	2	3	5	0	9
		Project manager existence & reliability	23	0	11	0	0	0	12
		Reliability of the programmes	18	5	6	6	1	0	0
	Programmes achievement	On time delivery	4	0	4	0	0	0	0
	TOTAL		**80**	**8**	**28**	**17**	**6**	**0**	**21**
GRAND TOTAL			**394**	**163**	**60**	**61**	**24**	**24**	**46**

programmes contain, these commitments have no impact on the company achievement significantly. Again, this related to the earlier module, whereby the middle management aspects scored very poorly.

In the *Flexibility* aspect, Company a again scores poor and does not have any commitment, programmes and monitoring of the flexibility achievement at all. From **TABLE II**, it can be seen that it achieves maximum potential *Problem Category* for all questions with no a single *Good Point*.

Referring again to **TABLE II**, performance in the *Delivery* aspect is slightly better compared to the *Flexibility* aspect but worse compared to the *Quality*. Top management seems to have little commitment to improve delivery, which is very surprising. It is well known that delivery due dates are the most important aspects of any orders, as far as the customers are concerned. Consequently the *Delivery Programmes* achievement is also poor, achieving only 5 *Good Points* out of total a total 71 points. The overall performance for this

Manufacturing Competitive Priorities module is also poor. Out of a possible of 394 questions, it scored only 163 *Good Points* and the remaining 231 were *Problem Categories.* Even more worryingly, the majority of its *Problem Categories* (121) were of type 1 and 2.

Based on the GAP analysis shown in **TABLE II** above, the KBPMS then processes the results using the AHP approach to determine which one from the *Quality*, *Flexibility* and *Delivery* should be in priority of improvement. **TABLE III** shows an example of the AHP result of *Manufacturing Competitive Priorities.*

TABLE III AHP RESULT FOR MANUFACTURING COMPETITIVE PRIORITIES

Aspect	Quality	Flexibility	Delivery	Priority Vector
Quality	1	1/2	1	**0.50**
Flexibility	2	1	2	0.25
Delivery	1	1/2	1	0.25

TABLE III shows the figure of improvement priority between *Quality*, *Flexibility* and *Delivery* aspects in the *Manufacturing Competitive Priorities Module*. It can be seen from the AHP output that the improvement priority for *Quality* aspect is twice that for the *Flexibility* and *Delivery* aspects. The *Flexibility* aspect has same priority to the *Delivery* aspect. This is not stating that *Quality* is more important than *Flexibility* (or *Delivery*). However, what the AHP output is stating is that, under the present circumstances within Company A, their *Flexibility* and *Delivery* are performing much better than their manufacturing *Quality*, and hence to gain maximum benefits, their focus for performance improvement should initially be on the *Quality* of their operations.

TABLE IV 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)* whereas the AHP output provides the prioritised actions across the sub-modules. **TABLE IV** shows the content findings by the KBPMS for Company A, both for the GAP and the AHP analysis. The AHP is shown in the last column whereas the previous data columns are for the GAP analysis. **TABLE IV** indicates that the present performance of Company A is distant from the benchmark standards contained in the KBPMS model. The results indicate where it needs to focus for each of the module and their sub-modules. For the GAP Analysis, it can be seen that out of a total of 1603 questions asked through the KBPMS, only 710 were Good Points (i.e. the benchmark GAP aspects existed). This implies that 893 were Bad Points (around two thirds), with various problem categories. More worryingly, the majority of these Bad Points were Category 1 (319) and Category 2 (270).

One can further look at the data to see that the most critical module is the *Customer Perspective:* a total of 350 questions were asked for this module, of which only 94 were Good Points. The remaining were Bad Points having 125 Problem Category 1 and 63 Problems Category 2. Similar analysis can be done for the remaining modules and sub-modules. The important thing to note is that the KBPMS model keeps track of each of the Bad Points and informs the user what needs to be done to overcome the identified GAP. Thus when referring to the detailed results, it clear that there are consistent (negative) findings in all the four perspectives, stemming from the root cause of leadership and culture. It seems that the senior management vision and commitment is perceived to be strong, however at the lower levels it is not being translated into actions, leading to the said question of leadership.

This failure of implementation of senior management leadership and commitment permeates throughout the whole organisation, resulting in the poor performance in all four aspects.

TABLE IV also provides a summary of the AHP analysis and shows, relatively, which issues need to be tackled initially. The bold figures show the priorities for each major perspective. Hence for this Company A:

- For the *Customer Perspective*, The priority is deemed to be CS (over *CL* and *CA*),
- For the *Manufacturing Competitive Priorities Perspective* the priority is *Quality* (over *Flexibility* and *Delivery*),
- For the *Internal Process Perspective*, the priority is *Manufacturing Process* (over *Innovation*, *Marketing* and *PSS*)
- For the *Resource & Method Availability Perspective*, the priority is *Suppliers* (over *HR*, *Technology*, and *Method*)

Thus the KBPMS 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. The decision-making path can be traced for these requiring further details as to how the KBPMS Model arrived at a particular decision.

VIII. CONCLUSION

This paper has described the details of the KBPMS Model, which is novel and improved methodology compared to the previous PMS frameworks. The proposed model has introduced new aspects that have not been covered by previous researchers, especially in terms of the implementation of a KB expert system approach, and the combination of GAP and AHP analysis in an integrated model, as a supporting decision making tool.

In the design of the KBPMS, a conceptual model was developed which consists of three stages: *Basic Information*, *Core of Performance Measurement* and *Mechanism of Performance Measurement.* Every stage has several aspects that play an important role and thus have been described in detail.

The proposed KBPMS model can be visualised from a strategic and operational structure. In the strategic part, there

TABLE IV SHOWING THE SUMMARY KBPMS MODEL AND AHP RESULTS

Module	Sub-Module	Number of questions	GAP analysis						AHP Vector Priority
			GP	Bad Point Problem Category					
				1	2	3	4	5	
Customer Perspective (*CP*)	**CS**	184	50	78	33	2	0	21	**0.500**
	CL	87	22	21	20	3	0	21	0.250
	CA	79	22	26	10	0	0	21	0.250
	TOTAL	**350**	**94**	**125**	**63**	**5**	**0**	**63**	**1.00**
Manufacturing Competitive Priorities Perspective (*MCPP*)	**Quality**	230	113	40	35	21	17	4	**0.500**
	Flexibility	84	23	18	14	5	3	21	0.250
	Delivery	80	27	13	12	3	4	21	0.250
	TOTAL	**394**	**113**	**60**	**61**	**29**	**24**	**46**	**1.00**
Internal Process Perspective (*IPP*)	**Innovation**	114	64	16	10	0	3	21	0.173
	Man. Process	130	37	32	23	17	0	21	**0.399**
	Marketing	104	32	19	25	7	0	21	0.069
	PSS	88	47	9	10	1	0	21	0.359
	TOTAL	**436**	**180**	**76**	**68**	**25**	**3**	**84**	**1.00**
Resource & Method Availability Perspective (*RMAP*)	**HR**	109	57	16	13	13	1	9	0.244
	Technology	94	42	10	14	7	0	21	0.099
	Method	145	55	21	33	15	0	21	0.219
	Supplier	75	19	11	18	6	0	21	**0.437**
	TOTAL	**423**	**173**	**58**	**78**	**41**	**1**	**72**	**1.00**
GRAND TOTAL		**1603**	**710**	**319**	**270**	**100**	**28**	**265**	

are three modules namely: *Company Environment*, *Business Perspective* and *Customer Perspective*. The *Company Environment Module* determines the particular environment the company operates in. *Business Perspective Module* analyses financial and market share performance. *Customer Perspective Module* analyse customer satisfaction, customer loyalty and customer acquisition as a key measure of external performance measurement in which the performance on these aspects will influence company performance financially. In the operational part, three modules: *Manufacturing Competitive Priorities Perspective*, *Internal Process Perspective* and *Resource & Method Availability Perspective* are developed, where in each module there are sub-modules and performance variables are discussed in detail. The proposed KBPMS model implements GAP analysis, benchmarking process and the AHP approach in an integrated performance measurement system. The process of translating *Problem Category* in the GAP analysis for each assessed performance into the *Intensity of Importance* in the AHP approach is conducted through mechanism and weighting process that are consistent. As can be seen from the presented results, the hybrid KBPMS model provides a detailed and accurate decision making tool for the improvement of the PMS and hence the performance measurement in a manufacturing environment.

REFERENCES

[1] Laihonen, H., Jaaskelainen, A., and Pekkola, S. (2014), "Measuring Performance of a Service System – from Organisations to Customer-Perceived Performance", *Measuring Business Excellence, Vol. 18, Iss. 3, pp. 73-86.* CrossRef

[2] Choong, K. K. (2013), "Understanding The Features of Performance Measurement System: a Literature Review", *Measuring Business Excellence, Vol. 17, Iss. 4, pp. 102-121.* CrossRef

[3] Badinelli, R., Barile, B., Ng, I., Polese, F., Saviano, M. and Nauta, P. (2012), "Viable Service Systems and Decision Making in Service Management", *Journal of Service Management, Vol. 23, No. 4, pp. 498-526.* CrossRef

[4] Bititci, U., Garengo, P., Dorfler, V. and Nudurupati, S. (2012), "Performance Measurement Challenges for Tomorrow", *International Journal of Management Reviews, Vol. 14, No. 3, pp. 305-327.* CrossRef

[5] Sousa, G. W. L., Carpinetti, L.C. R, Groesbeck, R. L. and Van Aken, E (2005), "Conceptual design of performance measurement and management systems using a structured approach", *International Journal of Productivity and Performance Management, Vol. 54, No. 5/6, pp385-39.* CrossRef

[6] Gosselin, M. (2005), "An empirical study of performance measurement in manufacturing firms", *International Journal of Productivity and Performance Management,* Vol. 54, No. 5/6, pp 419-437. CrossRef

[7] Medori, D. and Steeple, D. (2000), "A framework for auditing and enhancing performance measurement systems," International *Journal of Operations & Production Management* , pp. 520-533. CrossRef

[8] Cross, K. F. and Lynch, R. L. (1989) "The 'SMART' way to define and sustain Success", *National Productivity Review*, winter, pp.23-33.

[9] Maskell, B.H. (1991), *Performance Measurement for World Class Manufacturing*, Productivity Press, Cambridge MA.

[10] Hronec, S. M. (1993) *Vital Signs : using quality, time, and cost performance measurements to chart your company's future*, Amacom, New York.

[11] Kaplan, R. S. and Norton, D. P. (1996) *The Balanced Scorecard: Translating Strategy into Action*, Harvard Business School Press, Boston, MA.

[12] Neely, A., Adams, C., and Kennerly, M., (2002), *The Performance Prism The Scorecard for Measuring and Managing Business Success*, Prentice Hall, London.

[13] Zairi, M. and Letza, S. (1994),"Performance measurement: a challenge for total quality and the accounting professions", *Asia Pacific Journal of Quality Management,* Vol. 3 No. 2, MCB University Press, pp. 26-41.

[14] Neely, A. and Bourne, M. (2000),"Why measurement initiatives fail", *Measuring Business Excellent, Vol*. 4, No. 4, pp. 3-6. CrossRef

[15] Lonnqvist, A. and Laihonen, H., (2012), "Welfare Service System Productivity: The Concept and its Application", *International Journal of Productivity and Performance Management, Vol. 17, No. 3, pp. 315-339.* CrossRef

[16] Laats, K., Haldma, T. and Moeller, K. (2011), "Performance Measurement Patterns in Service Companies – an empirical study on Estonian service companies", *Baltic Journal of Management, Vol. 6, No.3, pp. 357 – 377.* CrossRef

[17] Kaplan, R. S., Norton, D. P. and Rugelsjoen, B. (2010), "Managing Alliances with the Balanced Scorecard", *Harvard Business Review, Vol. 88, No. 1, pp. 68 – 75.*

[18] Taticchi, P., Tonelli, F. and Cagnazzo, L. (2010), "Performance Measurement and Management: a literature review and a research agenda", *Measuring Business Excellence, Vol. 14, Iss. 1, pp. 4-18.* CrossRef

[19] Tucker, M. and Pitt, M. (2009), "Customer Performance Measurement in Facilities Management: a strategic approach", *International Journal of Productivity and Performance Management, Vol. 58, No. 5, pp. 407-422.* CrossRef

[20] Schmenner, R. W. and Vollman, T. E. (1994),"Performance measures: gaps, false alarms and the 'usual suspects," *International Journal of Operations and Production Management,* pp. 58-67. CrossRef

[21] Centre of Business Performance (1999). VIEW

[22] Hayes, R. H. and Pisano, G. P. (1996),"Manufacturing strategy: at the intersection of two paradigm shifts", *Production and Operation Management,* Vol. 5, No. 1, spring, pp. 25-41. CrossRef

[23] Willmott, P., and McCarthy, D. (2001) *TPM A Route to World-Class Performance*, Butterworth-Heinemann.

[24] Wibisono, D. and Khan, M. (2002a),"A framework of performance measurement system design for manufacturing", *Advances in Business Paradigms and Supporting Technologies,* Proceedings of the 18th International Conference on CAD/CAM, Robotics and Factories of the Future, 3-5 July, Porto, Portugal.

[25] Wibisono, D. and Khan, M. (2002b),"A hybrid knowledge-based/Analytic Hierarchy Process (AHP) performance measurement system for manufacturing", *Advances in Business Paradigms and Supporting Technologies,* Proceedings of the 18th International Conference on CAD/CAM, Robotics and Factories of the Future, 3-5 July, Porto, Portugal

[26] Stoop P.P.M. (1996) *Performance Management in Manufacturing: A method for short-term performance evaluation and diagnosis,* PhD theses, Technische Universiteit Eindhoven, Holland.

[27] Skinner, W. (1969) "Manufacturing: missing link in corporate strategy", *Harvard Business Review,* May-June, pp. 136-45.

[28] Milana, M., Khan, M. K., and Munive, J. E. (2014), "Development of the Conceptual Design of KB System for Intergrated Maintenance Strategy and Operation", *MaterialsScience and Engineering, V. 65, 012035, pp. 1-6.*

[29] Razmi, J., Rahnejat, H. and Khan, M. K. (1998),"Use of analytic hierarchy process approach in classification of push, pull and hybrid push-pull system for production planning", *International Journal of Operations and Production Management,* Vol. 18, No. 11, pp. 1134-1151. CrossRef