HOW KNOWLEDGE ENGINEERING SOLUTIONS IMPACT THE PERFORMANCE IN MANUFACTURING

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Abstract. Recent studies found that many firms fail to include knowledge workers in developing knowledge engineering (KE) solutions and formulating performance objectives. Many KE approaches are application-based. Additionally, present metrics also fail to address both the current and future user-domains. Evidence shows that collective performance can be included parallel with KE solutions, and more critically, the solutions could yield impacts on the level of performance of users. This paper discusses the applicability of KE solutions and their impact on performance measures. An ontological KE approach is proposed with its attributes be identified and the linkages with performance measurement established in the manufacturing contexts. The approach considers both individual and group performance and sets forth the implementation strategies of KE solutions in manufacturing organisations. This paradigm also serves to strengthen present and future KE solutions in different environments giving consideration to the past, current and possible future performance of the users. The paper further points to the development of a compensating model that can incorporate performance measurement in the development and application of KE solutions in manufacturing enterprises.

Keywords: Knowledge engineering, performance measurement, manufacturing, ontology

1. Introduction

The advent of the information technology age has presented more novel means for affording the development of the ways that knowledge can be used. Traditional shop floor boards, memos, flyers and posters have made way for email, blogs, chat applets, XML schema and the like. Meanwhile, traditional manufacturing is developing beyond single plant operations to multi-site operations connected via the virtual web. Further, manufactures have begun to adopt more flexible supply chains to include smaller vendor firms, collaborative partners and even competing firms (Pun and Graham, 2005).

Rise in competition among global manufacturers has motivated changes in management strategy in order to maintain viability (Conger and Chiavetta, 2006). The recent dominance in the automobile industry by Asian competitors for example has compelled their Western counterparts to adopt more lean manufacturing and agile practices. Nonetheless, cost margins erode and innovation has seemed to freeze. Though lean and agile manufacturing points directly to improving the sales and engineering and development in manufacturing; the

two most important keys to success are knowledge re-use and automation (Shelly, 2005).

According to Conger and Chiavetta (2006), the new manufacturing model requires adapting and flexible qualities. The authors continue to point out that most importantly is the human capital within these organisations. Since the manufacturing environment has become flattened by advances in technology such as: 1) Information technology, 2) Broadband, 3) Biology, 4) New materials and 5) Micro and nano-scale technology. Knowledge engineers have become outspoken and influential advocates for changes in manufacturing practices relating to product development and the supporting scanning and evaluating knowledge-based systems (KBS).

One the same theme, Grosse et al. (2005) argue that in the global marketplace of evolving technology and highly competitive markets, manufacturing companies depend heavily on knowledge engineering (KE) in regard to providing information for design and analysis quickly and cost effectively. Further, many KBS can provide in-process utility to the knowledge worker, by allowing goal assessment, solution approach optimisations, interoperability of multiple distinct analyses and customised user environment interaction.

How does the knowledge worker know that he has chosen the correct analysis, or collected the right data, or shared the correct information with experts? Current metrics fails to address the adequacy of solutions for present and future knowledge problems. KBS rely on some form of language and indexing method in order to details rules for search access, file sharing and updates (Ahmed, 2005). Consequently in assessing the quality of KBS solutions one must uses these two points as foci for assessing the quality and performance of the system. The focus of this paper is the discussion on how KE solutions impact manufacturing. In addressing this, different approaches to formulating KE solutions are looked at. In particular, the ontological approach will be examined. Taxonomies required for a compensating paradigm are explored.

2. From 'Knowledge' to KE and KBS

Increasingly, the subject of knowledge is forming an integral part of the way organisations do business. Moreover, managers, academia, experts and frontline operators alike, recognise that in order to maintain growth and viability, an organisation must share this knowledge, record and importantly find new ways of adapting past experiences for future projects. Knowledge is therefore, present at all work domains (i.e. gemba) and in every action event (i.e. motta). Knowledge re-utilisation has been recognised by experts as;

- The ability to re-use “know-how” for the same application with minor adaptation to the original/expert model (Grosse et al. 2004)
- A process through which the knowledge engineer can effectively manage knowledge derived from information and data along with prompt user feedback to the validity of the same…. (Huang et al 2005)
- Provides for the indexing of knowledge through the use of taxonomies of 1) design process, 2) product, 3) functions, and 4) issues as a part of ontological approach to engineering design (Ahmed, 2005)
- The rehearsed practice of saving time and money through knowledge that is both shared and embedded in software (Shelly, 2005)

The mechanism of gathering, storage, combination and re-use of knowledge is referred to as Knowledge Engineering (KE). KE forms and integral part of the modern manufacturing

organisation through determining how knowledge innovation and network manufacturing is realised (Wang et al, 2000). While many approaches can be presented for the design of a KBS, the use of the system is restricted to; 1) the approach taken to develop the solution, 2) the retrieval technique and data storage, 3) the human will of the knowledge worker in actually using the solution, and 4) the appropriateness of the data retrieved to the situation under current observation. It seems therefore, that knowledge-based solutions can be rendered useless unless they are convenient deriving performance and solutions.

3. The Role of KE in Manufacturing

In the manufacturing environment, there is a mixture of engineering design, production, support services, quality, procurement and other support services that comprise the supply chain. In light of today's challenges, a combination of over-arching methods are critical for the operational execution this emerging viability strategy. This has lead manufacturers and practitioners alike to address the human factors aspect of manufacturing more carefully, in particular in respect of knowledge engineering. Consequently, the current KE efforts focus on approaches for record of data relating to designs, problems, analyses, interoperability of models, customising interfaces for novice users, engineers and the learning challenged alike.

Present practices in manufacturing depend heavily on the use of information technology to the execution of day-to-day tasks. At the operational level, they take the form of sending and retrieving vital pieces of data and information. Now data acquisition systems (DAS) are used to automate many of these functions. There has been now more than ever a push toward having the storage and retrieval of the information and knowledge that is gathered through the use of management systems such as KBS (Ahmed, 2005; Huang et al, 2005; Shelly, 2005; Wang et al, 2000).

Production systems are at the heart of manufacturing systems. While traditionally production was carried out in one sole facility using pick lists and job orders in the past, current manufacturing systems employ sophisticated information based production systems (Metaxiotis et al., 2001; Wang et al 2000). Features of such systems include a structure; work centres, routings, batch quantities, capacities, etc. Newer techniques in development and use of such systems have grown beyond optimisation of cost and means, to agile production, reduced cycle time, quality and customisation (Mextaxiotis et al. 2001; Shelly, 2005). Therefore as a requirement, a KBS should include production as one of the taxonomies used in designing the ontology.

Likewise, distribution, inventory storage, quality, procurement, human resources have been identified as crucial functions (taxonomies) of present day manufacturing (Shelly, 2005; Wang et al., 2000). These functions represent what has now become known as the core of any manufacturing system. In each organisation however, each function may take on distinct features. For example, in a printery quality, production and inventory aspects will form a more central part of the firms operations. Accordingly, the KBS that is designed for such a firm must representatively translate this priority along with attributes and behaviours are each level of activity (sub-system biases).

In its present form, there are two distinct approaches that academics and practitioners take to addressing the set of KBS. This is shown in more details in **Figure 1a** and **1b**. The former (1a) shows stand-alone or single factory automated systems using the information from DAS and information from documents, and data gathered from human interaction.

Figure 1 Showing the 2 Pre-dominant approaches to development of Knowledge Based Systems (KBS) Network

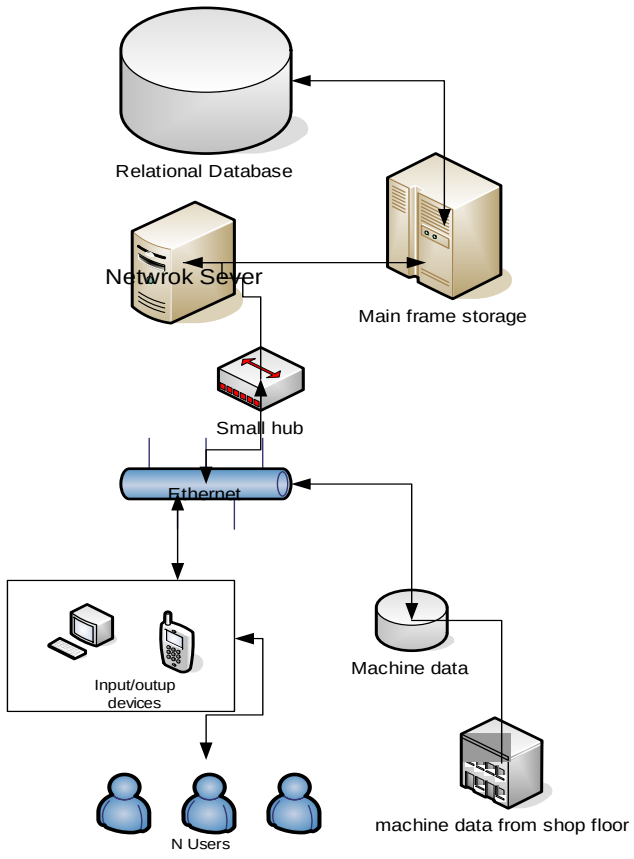


Figure 1a: Single Factory KBS

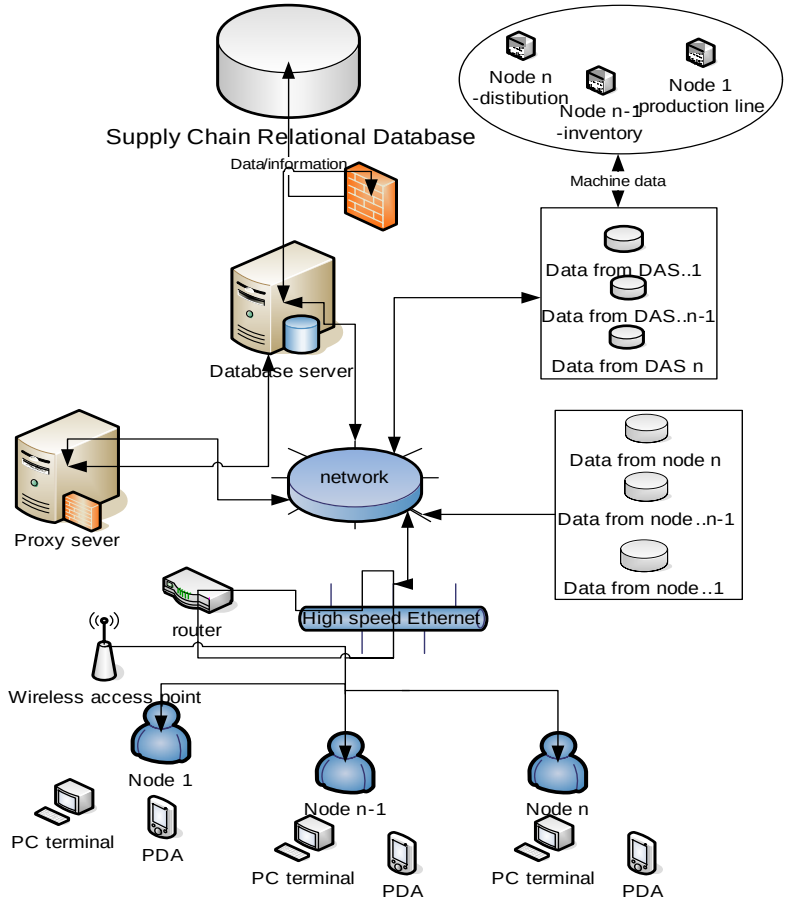


Figure 1b: Supply Chain Factory KBS

This approach concentrates on viewing the manufacturing organisation as one single entity. In creation of sub entities, it restricts the interaction with other "non-structured" data from external sources. One main data storage is kept with acquires data from machine and human interfaces such as terminal and hand held devices such as personal data assistants (PDA). Internal severs transmit data to and from a mainframe which stores mater data and information on the KBS database. It is here where rules based on how the KBS functions and its features (taxonomies) are determined. Written standard query language (SQL), extensible mark-up language XML or some indexing methods are often used (Metaxiotis et al., 2001, Ahmed, 2005, Wang et al., 2000).

The second approach (1b) shows a distributed knowledge co-ordination network in a supply chain. This involves the design of the KBS in a B2B approach using a multi-tier on a hub. Each part of the supply chain is modelled uniquely from s rules-based approach. At each interface, as data in inputted, it goes to a predetermined database which performs rule translation and relates it attributes and behaviours into a common data set. Database and proxy-firewall severs then send this data to the global supply chain relational database. KBS actions such as indexing, queries and storage are carried out ion the parent sever which sits behind a firewall.

Depending on the approach adopted, the effectiveness of the system will be varied. A determination has to be made from the start of the KE/KBS processes on the taxonomies, cardinalities, sub-system biases. This will affect how the firm will be viewed, whether as a single entity or a supply chain network (Wang et al. 2000). The overall performance of the manufacturing systems is achieved from the unified production, distribution, quality, inventory, human resources, procurement subsystems (Metaxiotis et al., 2001). Consequently, KE/KBS from conceptualisation to implementation and maintenance directly impacts the overall performance of a manufacturing firm.

The knowledge engineer works in collaboration with domain experts, and other knowledge workers (software analysts, novices, practioners, and knowledge managers) to conceptualise and design the KBS. While the expertise of what goes into the system rests with the domain expert and the knowledge manager, the how and long-term structure of the system will be determined by the knowledge engineer who is therefore responsible for how the manufacturing system will perform.

The performance objectives of the KBS are often determined at the design stage by the knowledge engineer with the domain expert and knowledge manager. Performance objective are important in the evaluation of how effectively the system is performing it intended function (Ahmed, 2005). Consequently, it is crucial to adequately determine how the system will be evaluated from the design phase. To further illustrate the point, let us examine the following example.

> *"A knowledge based system designed for the same printery illustrated previously requires that data and information relating to the core taxonomies of production, quality and inventory be design with procurement and distribution as secondary taxonomies. Given the nature of the operations the KBS will be evaluated using; record accuracy, relational hierarchy, information analysis, report grouping etc."*

Audit and maintenance assessments along with evaluation stages rely on performance criteria derived from the above conditions. Solution adequacy is often only determined post implementation by the knowledge worker’s critiques point to incompleteness.

3.1 KE Solutions and Reusability Difficulties

Many recent studies found that many firms fail to include knowledge workers in developing KE solutions and formulating performance objectives (Cogner and Chivetta, 2006; Gao et al, 2003; Grosse et al., 2005; Metaxiotis et al, 2001). Many KBS being used are inadequate leading to wrong production routings, back orders pile up and manufacturing operations crash. The genesis of such catastrophic effects on the manufacturing operations comes from the design and conceptualisation phase of the KE process. It is at this point where the knowledge worker should be fully consulted on designing performance criteria.

Nonetheless, some information systems work quite efficiently to link various facets of the integrated manufacturing system. The performance criteria set for these systems tend to be "for the while" designs and maintain little flexibility for future adjustments (Veres, 2005; Yuan and Sun, 2005). Hence, present metrics also fail to address both the current and future user-domains in respect of the manufacturing firm's life cycle.

Some firms end up frustrated at efforts to tweak the present KBS solution build from scratch and opt for an off the shelf modular system such as SAP, BAAN or People Soft (Metaxiotis et al, 2005). Resulting from this, good information system solutions are overlooked. However, firms find themselves having to curb their already learnt manufacturing subsystems behaviour to fit external rules. A deeper look into the KE process is needed to refine the solutions obtained. Specifying the abstraction and structure of such an approach can prove useful in overcoming these user problems. Some KE approaches are application-based.

Taxonomy differences influence the inter-exchangeability of databases (Gichrist, 2003; Ahmed, 2005). The resulting effect on most KBS for manufacturing is that there are hoards of data relating to inadequate data, products and schedules that do not match, design and analyses that are incompatible and users who are confused as to how to get the right information from such a system. The knowledge analyst would run several "language" commands to diagnose the root problem of these bugs. Meanwhile, millions are lost in revenue, production downtime, repairing damages inflicted and training or re-learning among knowledge workers.

3.2 Ontologies and Model Building

There is no jack-in the box solution that can be derived for bugs of KBS implementation or final ontology. A large number of domain-specific ontologies have been developed to various manufacturing applications, including information retrieval, knowledge re-use, enterprise modelling and machine translation (Gilchrist, 2003). Knowledge engineering of such systems is being pursued actively in semantic web concept. Gilchrist (2003) points out that experts have related the exploration of ontologies into four transformation processes for information and knowledge transfer and retrieval;

1) Personalisation (knowledge sharing)
2) Creation Innovation
3) Codification/discovery
4) Capture/monitor (knowledge elicitation)

The role of ontologies in KE approach to model building is clear. It is used to describe the structure and format that the information system must take. This is useful in that attributes relating to functions (taxonomies) of the system can be moulded on top of this basic platform.

The content of the information source can be described using an ontological approach. Importantly, individual and grouped behaviours are essential in designing any information system (Gao et al, 2003; Huang et al, 2005). If only the individual behaviour of the knowledge worker is modelled into the KBS, then during implementation vital analysis in regard to group approaches to problems, design and information sharing become impossible.

Whereas grouped behaviours is welcomed in the general sense of modelling an information system, distinction must be made of particular instances when such association is not required to be inferred by the relational database. Grosse et al (2005) argue that in the case of few domain experts (e.g. senior design engineers) and many trainees (novices), grouped behaviour in respect of design adequacy, component inclusion etc. are undesirable. In this instance the novices final design must be overseen by the senior design engineer before in become accepted as useful. The learning steps to achieve this result (i.e. the knowledge sharing with other novices and iterations to the design) are useful to model as grouped as well and individual behaviour.

In building a KE model solution for a manufacturing firm, the knowledge engineer must therefore take into account different aspects of the "blank" abstraction taken of the intended system. Grosse et al. (2005) suggest that consensus be obtained from the knowledge workers based on the implication of the ontology present. Consequently, the positive impact of the KBS on the manufacturing firm would be improved during the KE process.

3.2.1 Attributes/taxonomies

According to Huang et al (2005), the building of corporate memory (equivalent to KBS) can be achieved through the following six steps, namely:

1) Detection of the needs from KBS;
2) Construction of the KBS;
3) Diffusion or distribution of KBS;
4) Use of the contents of the KBS;
5) Evaluation of the KBS; and
6) Maintenance and evolution of the KBS.

The content of the KBS can be defined as the "nuts and bolts" data that comprise the system and analytical interpretation of knowledge extracted from the data-storage systems. The first two steps rely on knowledge discovery that features the domain expert aggregating information along with the knowledge worker(s) such as data analyst, knowledge analyst, knowledge engineer, manager and/or user.

On the same theme, the creation, distribution and evaluation of the KBS rely on the taxonomies used to develop the blueprint or abstraction of the system (Gilchrist, 2003; Metaxiotis et al., 2001). The main feature of this aspect of the KBS development process is the constant rationalisation of how data relate, input, control and mechanism and output at each level of activity within the system. Structured approaches such as integrated computer-aided manufacturing definition (IDEF) derived from Structures analysis design technique (SADT) is a suitable approach for KBS development based on its process oriented and hierarchical features (Huang et al. 2005). The SADT framework is useful in specifying details for each activity level within the abstraction process.

Literature suggests that the taxonomies useful in the ontological approach to KE can be defined as:

1) Functions, stages and issues (Ahmed, 2005)
2) Functions and sub systems (Metaxtiotis et al., 2001)
3) Subject memory, Input, Output, Control and Mechanisms (Huang et al., 2005)
4) Graphical structure of the organisation, personnel and content (Gilchrist, 2003)

While functions of the manufacturing firm can be interpreted as generally as its overall behaviour, the sub-system attributes is most critical is determination of the KBS. According the Ahmed, 2005 the function taxonomy is best developed using a shared understanding of the organisations knowledge content. The author further points out in his empirical survey on the subject that knowledge workers agree is using this taxonomy as a basis in KBS development.

Additionally, taxonomies relating to performance, people skills and business operation are included. By including such taxonomies, the re-usability of the manufacturing systems would be improved along with the performance of the manufacturing firm. This includes 1) performance criteria, 2) human resources (domain expert, novices, knowledge manager, and knowledge analyst), 3) supply chain (relations and cardinality). Moreover, future implications of the KBS must be examined. To this end, the collaborating partners, and internal supply chain make up are to be considered. This will impact the single design approach or knowledge supply chain approach (Wang et al, 2000).

3.2.2 Performance Metrics

Prescribing the performance metrics of a KBS is difficult without detail specifics on the system. Additionally, present metrics also fail to address both the current and future user-domains. This study identifies the reasons behind the difficulties to apply KE solutions and points to possible strategies to overcome them. Generally, experts agree that factors such as; data accuracy, query search time, data record rate, security and preservation of database, closeness of query results to required solution and accuracy of system solution (Ahmed, 2005; Huang et al, 2005; Metaxiotis et al, 2001).

4. Discussion

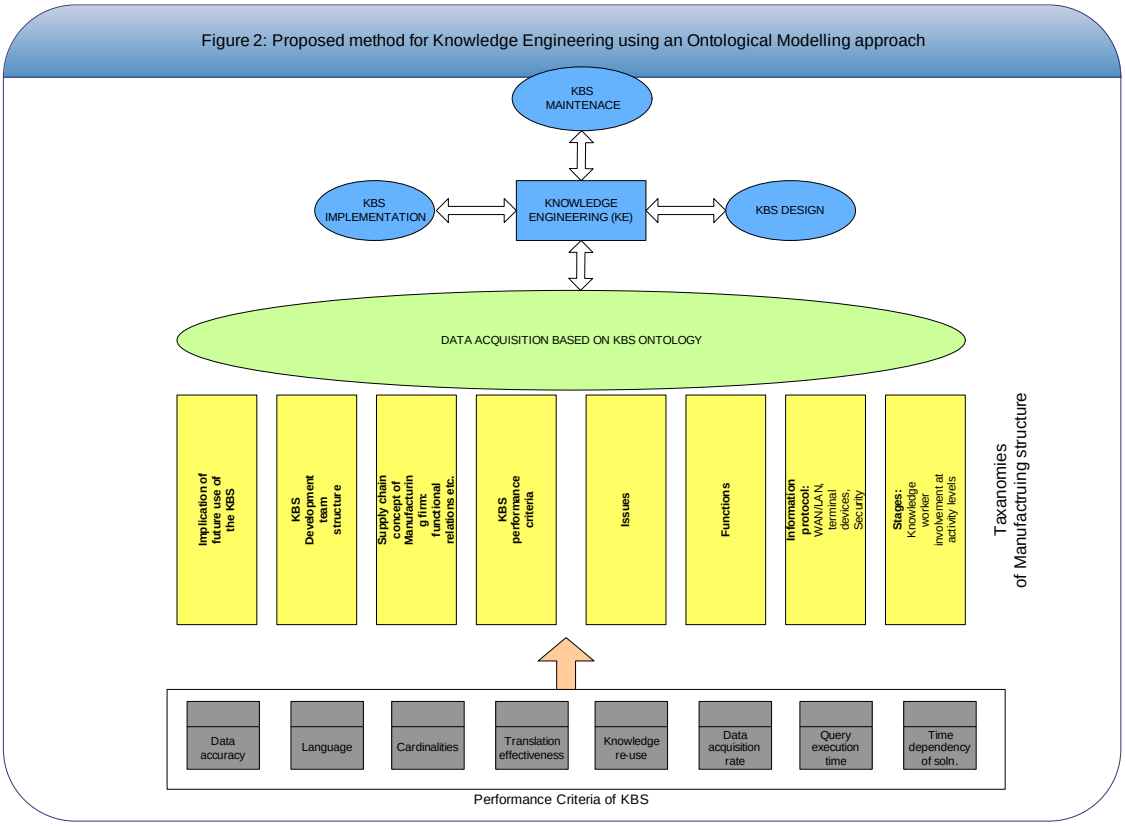
Today's managers concentrate on the productive time of the workforce. This motivates the knowledge practitioner to choose the record data relating to designs, production orders, work orders, best practices? Lean thinking has influenced emaciation of once amorphous productive centres. The ontological approach allows the academic and practitioner to constantly re-invent KBS as problem dimensions change. Gilchrist (2002) point out that the field of knowledge engineering and information sciences regards ontology as:

> "A formal and explicit specification of a shared concept....
> ....a scientific approach to the study of things or basic abstraction...
> .....information contained in shared conceptual models at the organisational, domain and enterprise level."

Many world's widely known KE ontologies (such as Word-Net and CYC) are manipulated by own (programming) "languages" and domain-specific applications (Gilchrist, 2002). Such domain-specific ontology has been developed for machine translation, enterprise modelling and knowledge re-use and retrieval. What causes the practitioner to seek out more appropriate KBS? and what role does an ontological approach play in the KE of such

solutions?

This paper points out that collective performance can be included parallel with KE solutions. Critically, the solutions yielded impact the level of performance of the user. Moreover, a compensating paradigm is proposed in **Figure 2** to address the re-usability and performance issues relating to the ad hoc development of KBS. The model allows KE solutions to incorporate performance measurement (PM) in its development and application.



PM support the proposed paradigm via 1) Data accuracy, 2) System language, 3) Cardinalities of the data base (DB), 4) Translation of analyses between taxonomies and related information sets, 5) Knowledge re-usability, 6) Data acquisition rate, 7) Query execution time, and 8) Time dependency (longevity) of solutions. In the generic sense, the KE modelling can be carried out using two basic sub-classes: continuum-based finite element models and lumped parameter or discrete analysis method (Grosse et al., 2005). Critically, the performance assessment derived from either approach; serve to improve the accuracy, adaptability, re-use of KBS solutions derived using an ontological KE approach. Therefore, modelling knowledge bases developed using our approach, provide for improved manufacturing performance in firms where adequate deployed.

Similarly, taxonomies supporting the proposed paradigm include; 1) Future use implications of the KBS, 2) KBS team structure including knowledge engineer, knowledge manager, knowledge e analyst, domain experts, novices and practitioners, 3) Supply chain concept of manufacturing firm including functional relations, 4) KBS performance criteria, 5)

Issues relating to information and data structure that are determined by knowledge workers, 6) Functions of data and information sets, 7) Information/communication protocol including wireless area networks versus local area networks, database security, input/output devices, and 8) Stages of activity involving knowledge worker at different levels.

Conceptually, the KE process itself is conjoined within the ontological abstraction of the proposed knowledge base. Based on an ontological approach, 1) Meta data is gathered at the level of the organisation e.g. The structure and format of information sources (lowest organisational level), 2) Domain ontology used to describe the content of the information, 3) Enterprise ontology for modelling business processes indicating context and enabling active knowledge sharing.

The compensating paradigm proposed serves to robustly improve the approach taken by knowledge engineers and knowledge practioners in the development of KBS's. There are four (4) main feature of the paradigm;

- The inclusion of performance criteria in parallel to the KE process.
- Adaptation of KBS taxonomies listed.
- Data acquisition using the ontological approach (meta-level, domain and enterprise).
- Robust inclusion of the ontological method to from an ontological KE approach to knowledge systems development. The KE development process becomes complete when knowledge based performance measurements that support improving manufacturing performance is met.

This is a novel structured approach to knowledge engineering process. The approach preserves the integrity of human systems integration through the redesign of critical subsystems of the KE process (Gerth, 2005; Gilchrist, 2002). Further, the approach allows for the examination of new ways of overcoming performance related issues prevalent in KBS development. In the context of manufacturing, the ontological KE approach can provide the development of better KBS. Improved systems are essential to the accurate transaction of manufacturing information and the smooth flow of manufacturing operations (Metaxiotis et al., 2001). More efficient data transactions, better knowledge re-use, inclusion of the knowledge worker at different levels of activity are expected in the KE process.

5. Conclusion

The ontological KE approach considers individual and group performance in manufacturing enterprises. There are several reasons behind the difficulties to apply KE solutions and points to possible strategies to overcome them. The adoption of KE solutions involves incorporating performance criteria with KBS taxonomies to form KE ontology for knowledge acquisition, information indexing and retrieval various levels of expertise and knowledge in user domains. This work can further be extended by creating new solutions which will adequately incorporate performance metrics in the ontological KE approach. The proposed compensating paradigm can strengthen present and future knowledge solutions in different environments giving consideration to the past, current and possible future performance of the users. Collective performance can be included parallel with the KE solutions that would yield impacts on the performance levels of manufacturing organisations. It is anticipated that the sharing of such knowledge and experience is critical to increasing the capacity for developing products and to increasing the quality. Empirical results from past and future KBS can be pursued.

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