The Application of Fuzzy Performance Modelling Procedures in Extended Enterprise Performance Measurement

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1. Introduction

The concept of performance, as it is measured and evaluated, is undergoing a transformation in modern business organisations. Globalisation, environmental issues, radical business and organisational structures have brought significant pressures to bear upon companies, who, in an attempt to address these pressures, are forming enterprise networks that work together across the value chain in order to meet more complex customer needs [Browne 1995]. The Extended Enterprise (EE) is a formation of closer co-ordination in the design, development, costing and the co-ordination of the respective manufacturing schedules of co-operating independent manufacturing enterprises and related suppliers [Jagdev & Browne 1998]; and is the consequent result of a move away from the traditional view of manufacturing companies with clear boundaries, limited relationships with other companies and a focus on internal efficiency and effectiveness only [Browne & Zhang 1999].

Performance Measurement (PM) has also begun to evolve to combat these new organisational realities, as the external environment is becoming identified as the next frontier of PM. In the current literature upon PM, the focus seems to be upon developing PM recommendations into PM frameworks, which, in turn, are to be developed into PM systems. This process is carried out upon an intra-organisational basis, with no analysis of the impact of this PM developmental process upon the external environment – in particular, upon the inter-organisational environment, where other EE nodes lie, such as suppliers and customers. While it may be argued that the PM system that any organisation puts into effect is solely their own business, the concept of PM is changing in the surrounding value chain: increasingly organisations are being asked (and in some cases forced) to accept performance measures from their supply chain partners that they have no immediate interest in. The concept of internal PM existing as a stand-alone concept at each EE node is becoming defunct; isolated internally-oriented PM systems existing at separate nodes in the EE make it difficult for PM information to flow unimpeded throughout the value chain to where it is required [Folan & Browne, 2005].

The situation is being exacerbated by the relative absence of research upon inter-organisational PM. Whilst, by the late nineties of the last century and the early years of this century, researchers had laid down numbers of ever-more complex PM recommendations, frameworks and systems that attempted to address the complicated nature of intra-organisational PM in a holistic manner; complimentary approaches towards inter-organisational PM are in danger of becoming out of touch with the modern propensity, on the part of organisations, to form enterprise networks such as the EE and the Virtual Enterprise. In the coming years, therefore, there is expected to be a significant increase in inter-organisational PM developments – such as supply chain PM and, more particularly, Extended Enterprise PM.

Most of the current inter-organisational PM literature concerns itself with supply chain PM, which focuses upon what are termed by Brewer & Speh [2000] as traditional logistics performance measures (e.g. inventory costs, delivery time etc.). Holmberg [2000] has suggested that a lack of systems thinking has plagued supply chain PM system design and development: he suggests that measurement activities in the supply chain should not be managed as one system, but as several independent, fragmented, firm-sized systems that are ultimately managed, upon the supply chain level, through the co-ordination of information exchange. A number of frameworks may be seen as extensions of well-established intra-organisational thinking [for example, Brewer & Speh 2000; Bullinger *et al.* 2002]; in particular of the Balanced Scorecard [Kaplan & Norton 1992] concept – probably owing to its advocating a "balanced" set of measures, which, in terms of inter-organisational PM, means a balance of internally-oriented measures against externally-oriented measures. For example, Kleijnen & Smits [2003], using the Balanced Scorecard approach, postulate that since each company is an economic – and legal – entity, each should have its own scorecard, while communication and co-ordination within the supply chain should be applied to overcome the obstacles created by this independent scorecard development process.

The EE PM system that is described below can theoretically present the model, measures and data from all aspects of the participating companies' functions in an EE; it was designed deductively based upon previous research, and from the empirical evidence of a test case EE in the automotive industry [see Folan & Browne, 2005]. The EE provided empirical evidence of the need for a PM system that is competent enough to work at two distinct levels: the holistic EE level, and the individual, EE node, level. Further, the requirements of the EE suggested the need for various levels of accuracy from the EE PM system, in terms of aggregation of measures; as well as a focus upon the need to overcome communication problems encountered by individual EE nodes in the EE.

Folan & Browne [2005] discuss the development of this system, specifically designed for the requirements of the EE, via two Performance Measurement frameworks: the structural EE Balanced Scorecard; and the procedural framework for the selection and implementation of measures. The EE Balanced Scorecard offers a four-perspective framework, implementable at each node, that provides a generic structure for the management of performance measures in the EE; while the procedural framework operates at both the local and holistic levels, to provide a step-by-step generic process towards performance measure selection and implementation. When combined, the two frameworks produce the basic EE PM system, which was subsequently tested at a first-tier supplier in the European automotive industry.

However, although a novel contribution to an inadequately-developed sector of the performance research, the EE PM system recounted by Folan & Browne [2005] has a number of inherent limitations, most serious of which we intend to rectify in this paper after a brief explanation of the main points of the system below. The greatest weakness of the methodology advocated by Folan & Browne [2005] is their reliance upon rather arbitrary means for the derivation of the correct set of performance measures to implement into their Balanced Scorecard – this, indeed, is a flaw that is found right across the performance measurement research, and is not confined just to Folan & Browne [2005] (see, for example, the subjective selection methodologies advocated by Medori & Steeple [2000] and Keung [2000] etc.). This requires us to briefly recall the present work performed upon inter-organisational performance measures, so that we can determine whether other methodologies have been proposed that can reduce the subjectivity inherent in performance measure selection and implementation; this is done in the next section (Section 2).

In the following section (Section 3), the development of the structural EE Balanced Scorecard of Folan & Browne [2005] is briefly recapitulated, followed by in Section 4 an innovative development of a fuzzy-based performance modelling method that acts as a supplement to the original procedural framework, enabling the development of a system of PM that is of greater relevance to both intra-organisational and inter-organisational levels, and which goes beyond Folan & Brownes' [2005] original efforts for greater reliability in the selection and implementation of performance measures. This modified procedural framework is subsequently presented in Section 5 and is exemplified through the use of a case study that focuses upon a first-tier supplier in the European automotive industry. Conclusions and lessons learnt subsequently complete the chapter.

2. Performance Measures in the Inter-Organisational Environment – the Extant Literature

Specifying inter-organisational performance measures has proved to be, unfortunately, a very inexact science. They should, according to Chan *et al.* [2003], who examined supply chain performance measures, be:

- of critical concern to supply chain common goals and strategies;
- of inter-influence and of common concern among the supply chain partners; and
- concern both internal partners and external customers.

However, at one level standardisation has been a challenge, with Hervani *et al.* [2005], for example, commenting on the difficulty of applying supply chain standards because of the existence of "various measurement taxonomies", including: the management level to measure (strategic, tactical, or operational); tangible or intangible measures; the existence of collection and reporting variations; supply chain partner's location along the supply chain; and the functional differentiation apparent in each individual supply chain partner. As may be seen from the case of Chan & colleagues [see Chan 2003, Chan & Qi 2003a, b, Chan *et al.* 2003 – also described further below], it seems to be relatively easy, but confusing for outsiders not acquainted with the particulars, to move from one taxonomy to another. As Hausman [2003] notes, local performance measure selection may often produce considerable inhibitions on the selection and performance of measures chosen for the inter-organisational level.

Performance measures are commonly derived from *either* a pre-defined list of measures held in reserve until the moment of selection has arrived, *or* they are developed as part of the PM methodology itself; Keung [2000] defines these two choices as *either* using a generic set of performance measures and picking up the right ones, *or* starting from scratch. The former provides for standardisation of the performance measures used, with the loss of flexibility in the development of new measures; and the latter method, while more difficult to implement and open to standardisation difficulties with the developed measures, has more flexibility in that each PM cycle can develop more precisely the measures required [Folan & Browne, 2005]. A key problem can be seen to attach itself to both of these methods of selection also: performance measurement specification has always been what can only be described as the "leap of faith" from the strategy of the company (or group of companies) to the actual selection of performance measures; no matter how precisely we try to make the intermediaries between the strategy and the selection method – call these intermediaries *critical success factors* or *customer requirements*, whatever – it is never enough to allow us to objectively define the "one true measure" that is required. Subjectivity, even if only in the selection of one measure over another, will have to be used. For example, if faced with the dilemma of choosing a performance measure to stand for a critical success factor such as "improve product quality", we could select any number of representational alternatives – such as the *cost* of improved product quality, or the amount of extra *time* taken to assess product quality etc. This issue is often more-or-less ignored in the research in favour of the derivation of multiple instances of implementable performance measures.

The research literature is not overly endowed with performance measures focusing explicitly on the inter-organisational environment, as most extant sources use, as Lambert & Pohlen [2001] point out, measures of internal logistics operations as substitutes for measures of the supply chain or other inter-organisational performance. In this instance it is important to examine the current literature on performance measures for the inter-organisational environment, which has seen steady development together with the introduction of the concepts of the supply chain, EE and VE. It will be recognised in the following literature that most authors have contented themselves with an examination of individual aspects – such as functional or competitive priority perspectives – of the performance measure problem, opting to seek a reasonable level of completeness in these narrow regions instead of attempting wider, more generic studies including multiple metrics (although there are a limited number of these also).

Caplice & Sheffi [1994] provided an early examination of the measurement of the logistics arena at the individual measure level; they outlined a taxonomy of logistics-related performance measures, and evaluated them using a methodology that tried to identify existing trade-offs where conflicting measures were liable to cancel each other out. Ramdas & Spekman [2000], in a survey of 22 extended supply chains across six broad industry groups, used six variables that, they felt, "reflect different approaches to measuring supply chain performance"; these are: inventory, time, order fulfilment, quality, customer focus, and customer satisfaction. They felt their performance measure selection "put forth a set of performance metrics that range from traditional measures that emphasise inventory management and cost reduction, to market-facing metrics that focus on end-customer considerations". Aiming to analyse the performance behaviour of conjoined supply chains, Beamon & Chen [2001] used five performance measures, from three performance measure classes, to discover that the most important for determining the effectiveness of the chain were: inventory system stock-out risk, the probability distribution of the demand, and transportation time.

Using empirical research performed on co-operative research centres in Australia, Zhao [2002] developed a performance index to measure inter-organisational performance. Although more related to public sector organisations, his study is interesting as it points out the disparity between actual reported performance measures and aspirational performance measures (for example in areas such as honesty and trust) that the co-operative research centres would like to use, but don't because they are deemed hard-to-measure. Lai *et al.* [2002], as part of their evaluation of supply chain performance in transport logistics, develop 26 generic logistics measures, partially drawn from SCOR, under three headings: service effectiveness for shippers, operations efficiency for transport logistics service providers, and service effectiveness for consignees. Harrison & New [2002], reporting on a major survey undertaken in 1999 on the current state of investment and competitive capability in supply chain management across major industrialised countries, suggested that only the crudest forms of supply chain performance measures were in active use, and that, for the most part, businesses and whole supply chains were "flying blind"; they present a table of the most consistently used performance measures in their survey, with the most popular being measures of increased customer service levels, reduced total supply chain costs, reduced order cycle time, and reduced inventory costs.

Hausman [2003] is especially concerned with the often unintended effects of using performance measures that operate in one dimension, which result in complications on other dimensions—that is, typically resulting in reduced overall performance. He specifically gives examples of where local firm's selection of optimising performance measures reduces overall supply chain performance. Consequently he suggests that supply chain performance should strive towards the *multi-dimensional* and *cross-enterprise* (as opposed to being *single-dimensional* and *single-enterprise*), and outlines for this purpose three supply chain performance measure categories:

1. Service – relating to "the ability to anticipate, capture and fulfil customer demand";
2. Assets – relating to "anything with commercial value, primarily inventory, and cash"; and
3. Speed – relating to "metrics that are time-related – they track responsiveness and velocity of execution".

Also in 2003, Chan and colleagues produced *four* different supply chain performance measure classifications [Chan 2003, Chan & Qi 2003a, b, Chan *et al.* 2003]; these are adapted and depicted in Figure 1 below, and may be described as follows:

A) is adapted from Chan [2003], and is structurally the most complex, with the main division being into quantitative and qualitative dimensions; note the relatively minor position of *time* which is unusual as it is usually a major dimension; also note that trust is measured only by attribute *consistency* (of delivery), ignoring other trust factors that are likely to impinge in the supply chain environment; and *visibility*, reliant on attributes of design-oriented time and accuracy, thus ignoring other parameters that allow an individual firm to come to prominence in the supply chain environment.

B) is adapted from Chan & Qi [2003b], and consists of three more process-oriented dimensions, with *composites* being a function of both *input* and *output* measures; note how *time* has re-emerged here as a major dimension; also note the vague division of dimensions in *output* including *tangible* and *intangible* divisions.

C) is adapted from Chan *et al.* [2003], and returns again to the original quantitative / qualitative divide we seen in A), now changed to suit the process-oriented needs of supply chain PM. The changes between the two are interesting: in C) the *quantitative* dimension retains the *cost* attribute, but has gained *customer responsiveness* and *productivity*, but has lost resource utilisation from A); in the *qualitative* dimension only the *flexibility* attribute remains, with all others being changed from A); note also *effective risk management* – presumably this incorporates the trust attribute of A)?

D) is adapted from Chan & Qi [2003a], and provides a performance measure breakdown based on tangibles and intangibles; again, note the re-emergence of *time* as a major tangible dimension, this time alongside *cost*, *capacity*, and *productivity utilisation*; further, note the position of *outcome* as "fairly intangible" [Chan & Qi 2003a]. It is extremely interesting to compare D) to B), where both tangibles and intangibles are listed under the *output* dimension, whereas *outcome* is listed as an intangible in D).

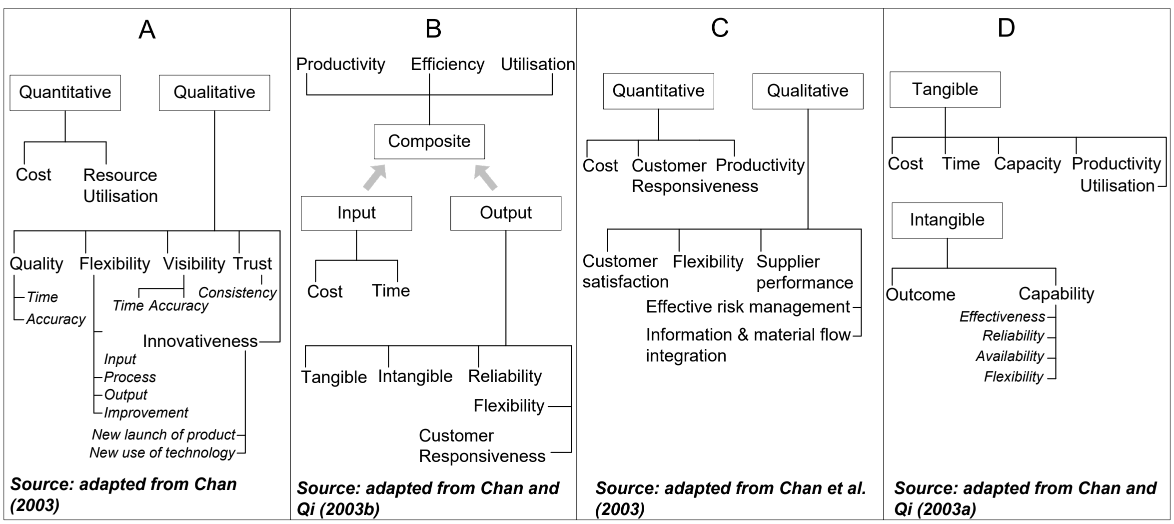


Figure 1: The four supply chain performance measure classifications offered by Chan & colleagues.

The fact that the same set of researchers have proposed four different performance measure classifications in the same year may be seen in two lights. First, it emphasises how fluid the barriers between measure dimensions are, and points out the fact that a particular performance measure may be as above, for example – tangible, quantitative, and an input – all at the same time, and it depends on a particular moment in time which particular attribute is emphasised. This example succeeds in capturing the complexity of a situation that has always been difficult for the PM researcher – determining which classification scheme is optimal. A second point that can be derived from this is the obvious fact that Chan and his colleagues have not yet settled on what they consider to be their optimum classification; indeed, even in two papers that are virtually the same – B) and C) above [Chan & Qi 2003b, Chan *et al.* 2003] – they use widely different classification schemes. This confuses their supply chain PM approach immeasurably, as it makes it difficult for any actual users to place confidence in any one classification scheme they propose. For long-term success, a robust performance measure classification scheme will have to be chosen as a standard in the inter-organisational environment; continual changing of the measure classification will only cause confusion and disorder in the multi-partner environment, making it difficult to determine whether everyone is measuring the right things in the right way at the right time.

Tian *et al.* [2003] propose supply chain performance measures at department, enterprise and supply chain levels using the competitive priorities time, quality, cost and flexibility as their framework of organisation; in their classification the enterprise's measures are organised into two groups – internal and external – where the referees of the internal measures are the internal stakeholders of the enterprise, the referees of the external measures are the enterprise's suppliers and customers, and, finally, the supply chain referees of both internal and external groups are the network of organisations that comprise the supply chain; for each of these levels they proceed to outline performance measures and proscribe evaluation techniques that are appropriate for use with them. Hull [2005] tackling the nature of elasticity in supply chains, develops a form of inter-organisational benchmarking and analysis of the individual supply chain, vis-à-vis other supply chains, and in so doing considers a range of supply chain performance measures that relate to elasticity, complete with formulas. Hervani *et al.* [2005] have outlined a list of environmental performance measures based upon toxins release inventory (TRI) data and the Global Reporting Initiative for their GSC/PM initiative; and an associated list of general measures. They suggest that measures should be selected from the list by agreement and negotiation, while "other design issues (e.g. collection of data) must be completed by major supply chain members" – not, it seems, by all participants in the supply chain however. Further they state:

> *…supply chain performance measures may be determined through supplier certification processes or surveys completed for current practices among organisations in the negotiation of future contracts.*

Thus they stipulate taking advantage of extra-PM procedures to try to ensure standardisation of the supply chain performance measures actually in use, and don't describe any particular PM tools to accomplish this instead.

The approach of Abu-Suleiman *et al.* [2005] towards developing a supply chain performance measure set, as part of their supply chain performance management system, is somewhat typical of a new breed of PM literature that is trying to use the best of existing practices to cover new eventualities; their model is somewhat typical of a natural attempt to include as much of the internal PM research as possible in their supply chain performance management methodology. As part of their model they outline the *metrics definition methodology* depicted in general in Figure 2; here we see a top-to-bottom disaggregation of the individual firm's vision and mission that uses the four perspectives of the Balanced Scorecard, meeting a bottom-to-top provision of measures from the SCOR model – these meet at the *translate to process specific KPIs* step, which produces the *process based, balanced metrics*.

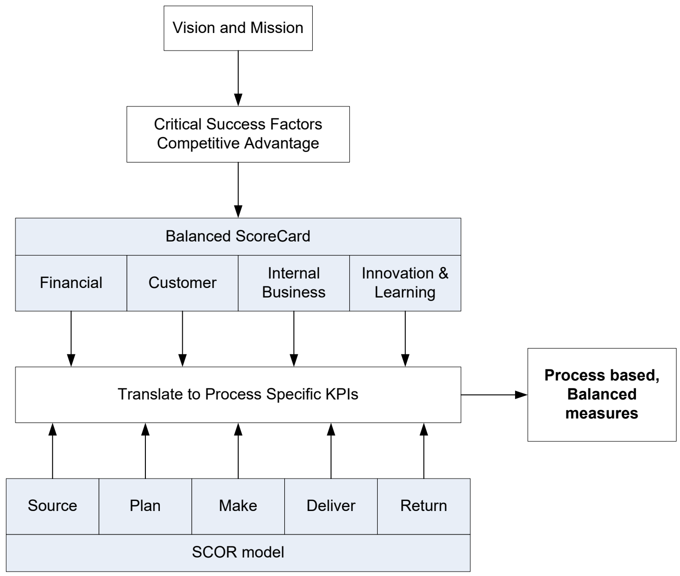


Figure 2: Metrics definition methodology (adapted from Abu-Suleiman *et al.* [2005])

What remains questionable in this approach is the confidence they place in being able to correctly align both the SCOR model process metrics, with the four perspectives of the Balanced Scorecard, and still produce a meaningful supply chain-oriented performance management system. We suggest that it is not so easy to implement, as there is bound to be an unnatural proliferation of metrics in particular perspectives (such as the internal business process), with a corresponding dearth of metrics in related perspectives (such as the innovation and learning or financial perspectives). It should be remembered that the Balanced Scorecard was designed explicitly for in-house operations, and not for the supply chain, so the perspectives it uses are not orientated towards supply chain parameters to enable a confident and balanced placement of metrics across all perspectives. Besides, the SCOR model itself contains some processes that are not easy to implement in the Balanced Scorecard: for example, the Source process metrics have no easy equivalent in the Balanced Scorecard; there is a dearth of natural financial metrics in SCOR to include in the financial perspective; and considerable subjectivity has to be applied to include some process metrics, such as return and delivery – should they go into the customer, innovation and learning, or internal business perspectives? – it is hard to tell.

Further, as the model uses SCOR exclusively, it is questionable just how far it can be deemed a "supply chain" methodology. There is no in-depth discussion of arrangements between supply chain partners concerning the selection and distribution of supply chain PM information, rather the methodology for decision support, developed on the above model, is clearly an in-house arrangement of internal databases and legacy systems. In effect, therefore, the so-called supply chain performance management system is an in-house management system that promotes the firm's own version of supply chain performance to enable managers to answer two questions (in their own words):

1. "how are we doing against our plan?" (that is, the internal plan—there is no mention of other supply chain partners' plans, so presumably they don't exist); and
2. "how are we doing against industry leaders?" (that is, the transformation of "supply chain"

performance management into benchmarking).

Having examined the general literature upon inter-organisational performance measures, we must turn our attention to Folan & Brownes' [2005] EE Balanced Scorecard, which will be used in this paper as the structural framework that allows us to select and implement performance measures for the EE. Its development briefly follows.

3. Balanced Scorecard for EE Performance Measurement

The development of a structural EE PM framework that captures the relevant measurement sectors and puts them into perspective, has been developed by examining an individual company (company X) at any tier in the EE. We can define four measurement perspectives for company X: internal-perspective – located inside the four walls of the company; supplier-perspective – located at the interface of the company and its respective suppliers; customer-perspective – located at the interface of the company and its respective customers; and the Extended Enterprise-perspective (EE-perspective) – the holistic system. These perspectives may be transposed into the EE Balanced Scorecard framework depicted in Figure 3; this framework is applicable for each node of the EE. The framework is 'balanced' by the presence of external perspectives and internal perspectives: the external interface perspectives (supplier, customer and EE) against the internal perspective.

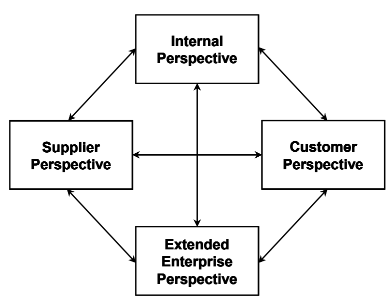


Figure 3: Extended Enterprise Balanced Scorecard framework

The interaction of the EE Balanced Scorecard at each EE node – from company x to its suppliers and customers - is depicted in Figure 4. Please note that the situation described by Bititci *et al.* [2003], i.e. the existence of more than one EE being serviced by any particular EE node is ignored for the sake of simplicity in Figure 4; this situation would give rise to a series of complex PM interactions outside of the focal EE, and is beyond the scope of this chapter. Each EE node is expected to apply the four perspectives of the scorecard – thus moving beyond measurement based upon 'traditional logistics measures' only – to enable an examination of both intra- and inter-organisational performance at each node. Each node is required to maintain their internal PM system as one perspective of the framework, while also up-keeping PM at the surrounding interfaces – supplier and customer; finally the holistic approach is completely covered by reminding each node to account for certain EE measures in the EE-perspective.

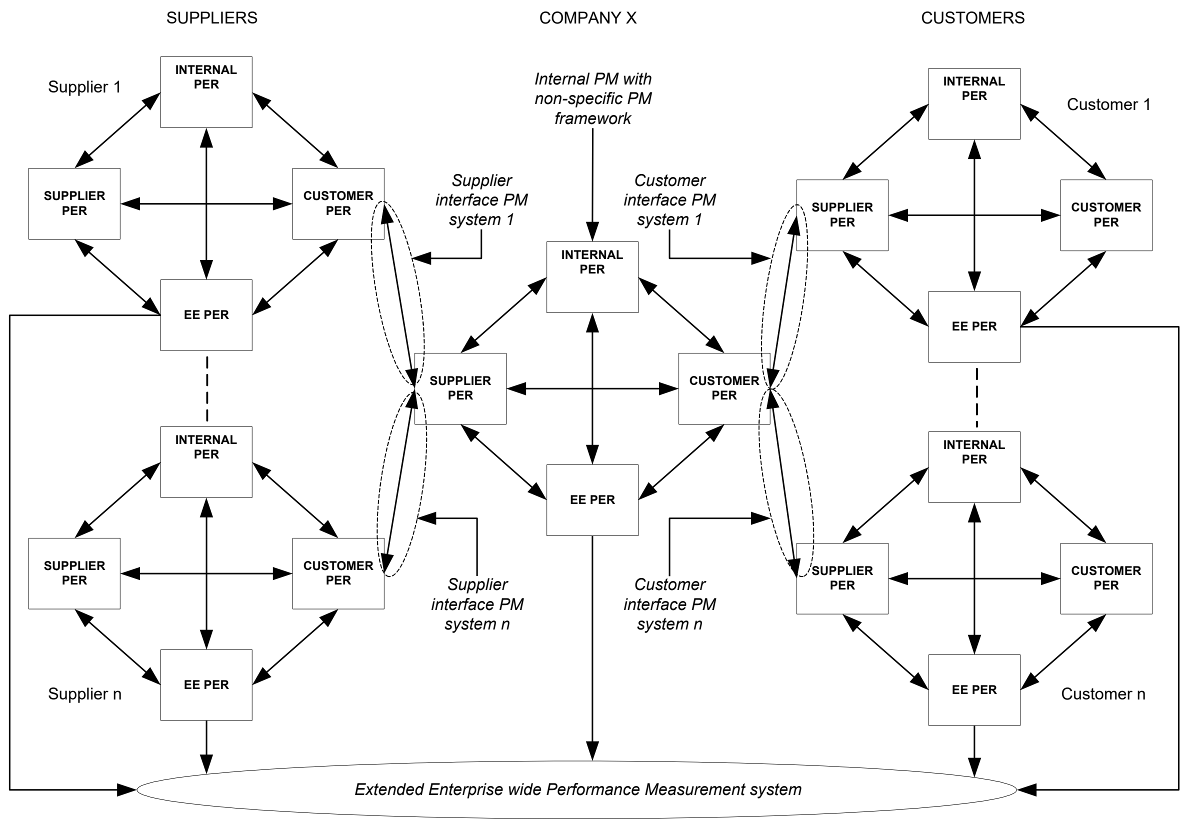


Figure 4: Interaction of the Extended Enterprise Balanced Scorecard

Note the labels 'supplier interface PM system' and 'customer interface PM system' in Figure 4; these represent the PM system that are held jointly between company x and each of its suppliers/customers, with each supplier/customer requiring a separate interface system. In these interface systems, measures such as 'delivery time' measure much the same thing whether it is inbound delivery time (for company x from its suppliers, or from company x to its customers), or outbound delivery time (for suppliers to company x, or company x to its customers) – the difference is often a matter of the viewpoint taken by the observer of the EE. Much of the raw data for these sorts of shared measures between succeeding EE nodes is found in their related information system or the documentation that passes back and forth between them in the supplier-customer relationship (for example, Requests for Quotations, orders etc.); the position of the observer's focal company in the EE determines whether the relevant performance measure belongs to the supplier or customer perspective of the EE Balanced Scorecard.

The internal perspective of Figure 4 is dominated by the requirement to allow EE nodes develop their intra-organisational PM systems with a freedom of choice concerning internally-oriented PM methods. Since the compositional nature of the EE – comprising large-scale OEMs on one hand, and small-scale SMEs on the other – is highly varied, advocating a one-size-fits-all PM specification is unlikely to work. However, each EE node is subject to the proviso that the standardised performance measure template list is used when it begins the process of selecting measures based upon its strategy. The performance measure template list is usually very bulky, mainly of a non-financial type, arranged according to seven macro measures of performance: cost, time, quality, flexibility, precision, innovation and environment; at three perspective levels: supplier, internal and customer; and replete with formulas for calculation purposes. Facilities have been put in place to ensure that this template list maintains its currency. This proviso allows individual nodes to express their independence at the intra-organisational level, while ensuring conformity to the standardised – EE wide – template list of measures; participation of the internal perspective of each EE node still remains despite the fact that different intra-organisational PM models may be in use at various nodes of the EE.

The EE-perspective should include local (that is node-level) measures that must be aggregated up into EE level measures. The EE-perspective of the EE Balanced Scorecard represents, at each node of the EE, the EE PM system used by that node. The measures used represent measures held by a particular node that will ultimately be aggregated upon an EE level; measures are drawn and aggregated from the performance measure template list. The EE PM system may be seen as a series of node systems that are combined to form the EE PM system; the more nodes an EE has, the larger the EE PM system may become, depending upon how many nodes wish to participate in the EE PM system. The methodology to perform this step requires co-ordination and information sharing, and is handled by communication mechanisms. The communication mechanisms that were developed to exploit this system of EE PM have been outlined in Folan et al. [2006], and the reader is referred to this publication for further information.

4. The Construction of Performance Model & its Related Measurement Method for EE

In this section we depart from the description of the EE PM system of Folan & Browne [2005] given above, to offer a new procedural framework that emphasizes the use of fuzzy methodologies in the EE context – this method is called the fuzzy performance modelling framework, and its details and effects are recounted below, where it is applied in conjunction with the EE Balanced Scorecard described above. For each PM system of internal-perspective, supplier-perspective or customer-perspective at EE node level, or for the holistic PM system of EE-perspective at EE level, the required performance model can be constructed respectively with the modelling method depicted in this section and the performance can be thus analyzed based upon the performance model proposed and its related measurement method.

In the original paper Folan & Browne [2005] developed relatively simple step-wise procedures to ensure the adaptability of the EE Balanced Scorecard at both the local and the holistic EE level; here this is supplemented with a more flexible fuzzy-oriented performance methodology that tackles the issue of performance measure selection and implementation by using fuzzy rules, thus replacing the rather rule-of-thumb based procedures previously advocated across the performance measurement literature.

Once explained, the new fuzzy performance modelling framework is incorporated with the existing step-wise procedural framework of Folan & Browne [2005], thus enabling the development of an innovative fuzzy-based procedural framework that further reduces the subjectivity of performance measure selection and implementation that has plagued the performance measurement research. Below, the fuzzy performance modelling framework is detailed first, and issues of performance measure selection and relationship-building are then recounted, followed by the re-integration of the method with the Folan & Browne [2005] procedural framework in Section 5.

4.1 Fuzzy Performance Modelling Framework

The performance model is always constructed as a structure that illustrates a multi-indicators hierarchy, which can be deduced from the view point of the depth/span of the performance indicator and the information delivery distortion [Wang 2006]. Among the multi-indicators, those with high depth form the bottom layer and are employed to gather professional and special information from the real system; while those with a wide span compose the top layer and provide the universal and integrated performance information of the model to the decision-maker. In certain circumstances, the information delivery through a medium layer can reduce information distortion, which results in a hierarchy structure for the performance model. To establish the performance model, the key problem remains the selection of indicators and how to bridge the relationships among these indicators. From industrial practice and literature, we know that the selection procedure has always depended upon experience, or rule-of-thumb methodologies that can hardly be described as scientific; while research on performance measure relationships remain immature or unscientific, even when configured by experts or related people [Folan & Browne 2005]. In this paper, the construction of the performance model will primarily be aligned with a ‘to-be’ process model.

A process model is a map or image of the logical and temporal order of business activities performed on a process object, and also contains both the behaviour and structure of all objects that may be used during the process execution. Also with the subdivided layers of the process model, those performance indicators related to process activities thus have clearer boundaries and there exists less conflicts and redundancies among them. Second, the hierarchy of the performance model can be constructed according to the process hierarchy; in other words, the hierarchy of the performance model will be similarly matched to the hierarchy of the relevant process model. Third, the process model is directly correlated with the business processes and a large sum of dynamic information is embedded into it, which can be useful for the establishment of performance models and performance analysis. Finally, in the period of adjustment (e.g. in process re-engineering), the project becomes more convenient and practicable with the correlation between the performance model and the process model. Peter [2000] also argues that performance measurement should be focused on processes, not only on organizations or organizational units; in addition to this, the research on process modelling has become more important and mature, so performance modelling aligned with it is expected to produce significant benefits and more promising results.

If we turn to the flourishing research realm of performance measurement, we can see that organizations and academics apply themselves to different measurement aspects, but underlining all their activities is a somewhat high level of confidence in the role and participation of experts in the most popular methods of today. This has concerned some; and to remove human subjectivity, some researchers are interested in formalized performance definitions and analysis, as well as performance modelling with rigorous logical reasoning, from the mathematical viewpoint [Wang 2006]. However, the inherent uncertainty of much performance information, such as qualitative elements and the calculation of intangible benefits, makes this completely-formalized research-orientation impracticable and currently inoperable. With the deep and wide application of information technology (IT) in enterprises, it is believed that performance measurement research, based on statistical learning and knowledge management, becomes an eclectic and more effective and efficient solution, which tries to make performance measurement more processible by computing systems, and can take advantage of abundant performance information available from extraneous systems (such as intranet and extranet systems), as well as from experts.

Accordingly, fuzzy logic is introduced here. Fuzzy logic provides a prominent paradigm in modelling and reasoning with uncertainty [Zadeh 2005, 2006] and has two major industrial applications in the literature: in the field of fuzzy controllers, and in information systems. In the integrated information system, there is an enormous amount of inherently uncertain information which can be exactly represented by fuzzy logic, while the relevant knowledge represented may still be process-able and mine-able by computers. Related performance knowledge management can thus be realized and supported effectively and efficiently. In view of these facts, performance modelling in this paper is chiefly based upon fuzzy rules and related fuzzy analysis methods that can be improved based upon statistical learning and knowledge management. In general fuzzy rules are obtained from experts and are formulated as a linguistic IF THEN paradigm; however many methods have also been developed for automatic extraction from numerical data [Lekova 1998, Gang 2005].

As discussed above, based upon statistical learning and knowledge management, the performance modelling in this paper will apply fuzzy rules and will be aligned with the process model; the performance model constructed will be a multi-indicators hierarchy.

The concept of fuzzy performance modelling is illustrated in Figure 5, and in the following description each element is numbered for ease of explanation. Initially, a large number of fuzzy rules (1), correlated to some process activities, are extracted and selected from the integrated system and related business processes, as well as the knowledge repository (2), to form a fuzzy rule set which will still be stored in the knowledge repository as the fuzzy rule set correlated to the ongoing performance modelling. Then, based on the knowledge repository (2), the process model context (3), and the fuzzy rule set (1) and related performance research (4), indicators are selected and the relationships among them are configured (5); accordingly the fuzzy performance model is established (6). Next, referring to the context knowledge and information of the process model (3), the performance of the integrated system is analyzed based upon the fuzzy performance model (6) and the fuzzy rule set (1). Finally, with the conclusions of the performance analysis, process re-engineering is implemented (7). To make the process re-engineering more feasible and effective, it will be very important and helpful to set mapping among the performance indicators concerning process re-engineering and the related process activities. Enterprise requirements and expert knowledge (8) are also used, respectively, as the guideline and reference in the whole process of performance modelling and analysis. To enrich performance resources for reuse, those indicators and fuzzy rules adopted – as well as fuzzy performance models – will be fed back respectively to the related knowledge repository (2) with certain knowledge learning mechanisms. The relevant modelling process and methods involved in this fuzzy performance modelling framework will be detailed in the following sections.

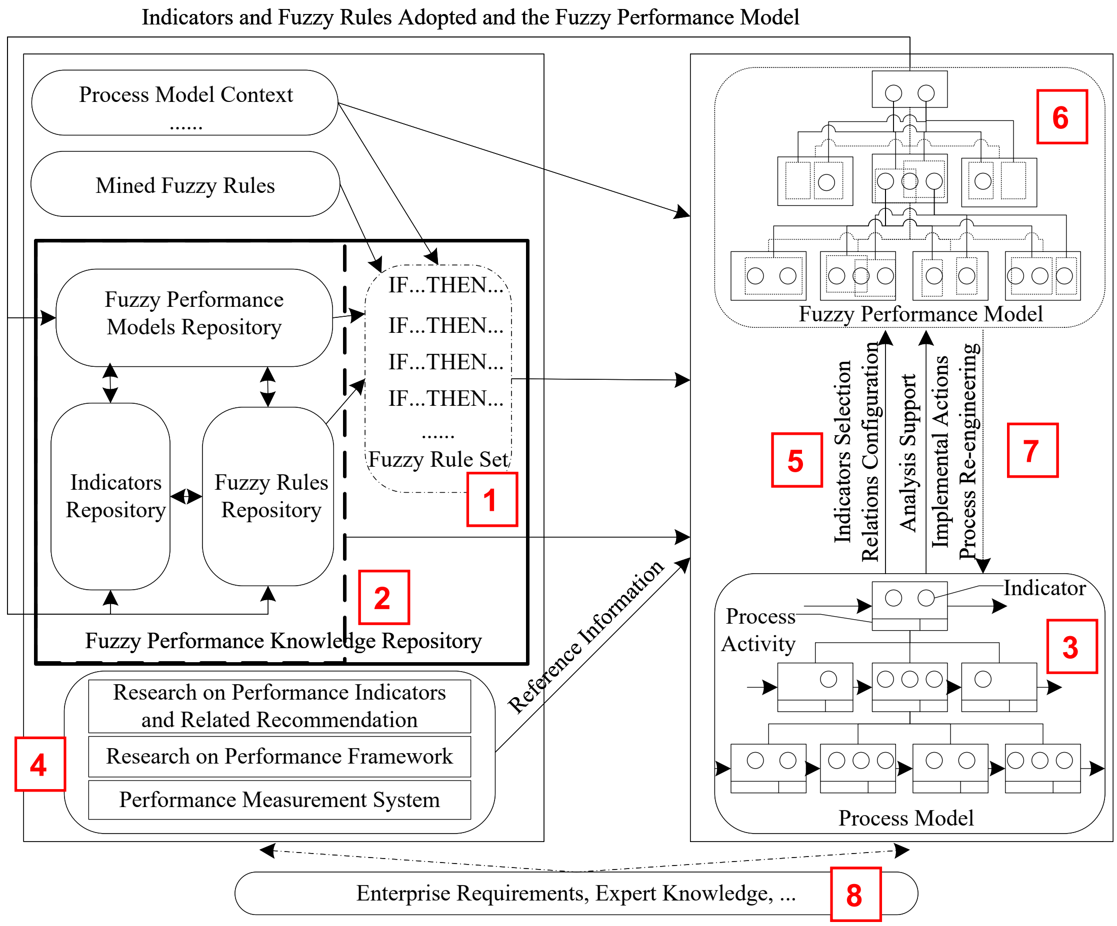


Figure 5: Fuzzy performance modelling framework

4.2 Performance Indicators Selection & the Configuration of their Relationships

For performance modelling, the first step is to construct a performance model which comprises two key points—to select the required indicators, and to bridge the relationships among these indicators. Then the related method to measure system performance can be discussed and applied, based upon this performance model construct.

The selection of performance indicators is principally based on the fuzzy rule set and aligned with the 'to-be' process model. As shown in the bottom right-hand corner of Figure 5, and in A of Figure 6, the core element in the selection of the indicators is the related process model; using this we must determine the right location for performance indicators in the process model; namely we must put those adopted indicators into their appropriate process activities. In this case performance indicators associated with every process activity in different layers of the hierarchy of the process model are selected and configured into the corresponding process activity. Because of the present weaknesses and deficiencies of establishing the hierarchy of the performance model independently, without the support of other related models, in this paper the hierarchy of the process model is retained throughout A, B and C in Figure 6.

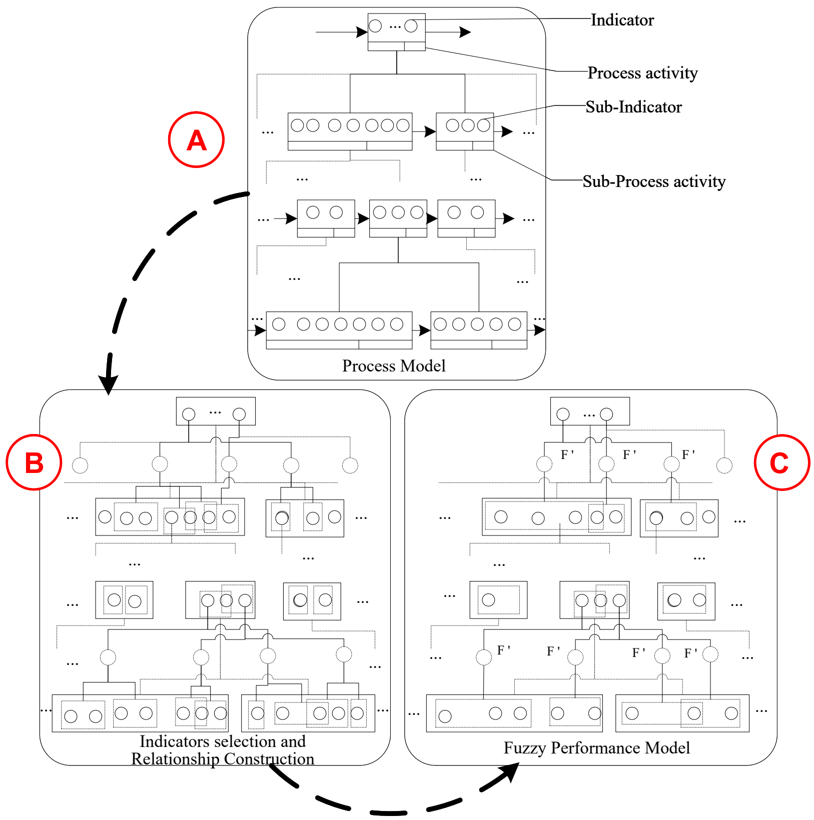


Figure 6: Indicators Selection and Inter-indicators Relationship Construction and fuzzy performance model

To make this selection process more reliable and dependable, the user is encouraged to source indicators from various possible aspects, because there is no generally accepted list of performance indicators and fuzzy rules, and even those selected in the fuzzy performance knowledge repository may not be sufficient. First it should be based upon the knowledge repository, especially those which similar fuzzy performance models may provide – not only the applied indicators and fuzzy rules, but also the relationships between them and the process activities, so as to make full use of the historical experience and knowledge that is available. Second, according to concrete enterprise characteristics and requirements, fuzzy-rules mining is the most important complement to obtain discriminative indicators for differently measured and applied objects. In addition to this, to make this selection process more sufficient and adequate, indicators will be sourced from various possible aspects, such as other research results on performance indicators, and be allocated into process activities. Finally, enterprise requirements and expert knowledge are used, respectively, as the guideline and reference in the whole process of the selection of the indicators. With these steps, the indicator to be selected, and the process activity they will be located with, is confirmed.

For the indicators adopted, it is important that only those favourable and reasonable indicators are selected and each indicator may be put into different process activities in the hierarchy, if necessary. Indicators in the top layer of the hierarchy mainly represent information with a wide span, which is always qualitative; those in the bottom layer depict information with a high depth, which is largely quantitative. In the fuzzy performance modelling process, both qualitative and quantitative indicators are concerned, and qualitative indicators are decomposed into measurable and quantifiable quantitative indicators, from the top to the bottom layer, until the total indicators in the bottom layer are guaranteed to be quantitative, with the associated decomposition of the process model.

One thing should be added concerning the use of the fuzzy rule set: with the fuzzy rules and the relationships between them and their process activities, it is easy to correlate the process activity with the performance indicators associated with the fuzzy rules, and then it becomes easy to locate these indicators in the appropriate process activity. Further, because the performance grounded on the fuzzy performance model in this paper will actually be measured through a set of fuzzy rules, and the relationships among the indicators will also be configured mainly based on the said fuzzy rules, the kinds of indicators related to certain fuzzy rules are thus even more important to the whole method. This is also a crucial reason for the employment of the relevant fuzzy rules for the selection of indicators. In addition, the fuzzy performance knowledge repository serves as the most important basis for the selection of performance indicators, which can provide favourable and abundant performance indicators, and fuzzy rules – as well as former fuzzy performance models as reference guides.

Based upon the indicators selected and their correlations with process activities, the relationships among the indicators can be constructed using the following steps.

With reference to the knowledge repository, process context, related research, enterprise experience and expert knowledge, performance indicators in every process activity are respectively categorized into different indicator subsets, according to the premises of the fuzzy rules and also taking their aggregate characteristics and functions into account. With the associated context of the process model, the performance indicator subsets are adjusted as appropriate, if necessary. Then the relationship between the indicator subsets and fuzzy rules is checked, and if some indicator subsets are not related to any fuzzy rule it may be a requirement to mine new corresponding fuzzy rules. The subsets can be formed into any significant and meaningful combination. There are no completely identical subsets in the same process activities, however different subsets can comprise several of the same indicators. Then, considering the relationship between the premises and the conclusion of the fuzzy rules, and also taking into account those relevant knowledge elements mentioned previously, the relationship between every subset in different child process activities and their parent indicators in the parent process activity is established respectively. With the above steps, the original performance model is formed, as shown in the bottom left-hand corner of Figure 6.

4.3 Fuzzy Performance Model & Measurement Method

Based on the original performance model, the final fuzzy performance model can be established with the following steps. First, the indicators involved in the original performance model are usually numerous, so some method should be proposed to prune relatively unnecessary indicators if it is necessary. Second, those indicators in a child process activity, and related to a certain indicator in the corresponding parent process activity, are put together as a single set. These indicators are supposed to be associated with premises of certain fuzzy rules, and the corresponding indicator in the parent process activity will be related to the conclusions of these fuzzy rules. Third, the relationship between the indicators and fuzzy rules is checked, and if some indicators or indicator sets are not related to any fuzzy rule it is normally required that new, corresponding, fuzzy rules are mined. Then the fuzzy performance model can be finally formed as shown in the bottom right-hand corner of Figure 6. Moreover, with reference to the process context, related research, enterprise experience, experts and knowledge repository, the result of any step may be adjusted appropriately if necessary; and the fuzzy rules involved may need consistency validation in the modelling process, such as in the final step to establish the fuzzy performance model.

Afterwards, based upon the related information and data, the fuzzy performance of every indicator in the bottom layer of the hierarchy is designated or calculated with a certain method, such as directly designated by experts or correlated to, or calculated referring to, key technology variables (KTVs) and key programme variables (KPVs) [Jagdev 2004]. The KTVs and KPVs represent key products or features of different information technologies or systems (or programmes), which can identify the various available application options and their consequential performance improvement more critically. In these circumstances, if they can be correlated with proper performance indicators in the bottom layer, the KTVs and KPVs are capable of bridging the gap between the application of technologies or systems and their related implementation consequences or benefits. To identify the KTVs and KPVs and to establish the relationship between them and the performance indicators, there are several steps to go through as shown in the left-hand of Figure 7.

First, the up-to-date, accurate documentation, experiences and knowledge concerning information technology and systems (or programmes) should be captured and analyzed in order to build realistic models. Second, a generic technology/programme model is created, which is concerned with the original and basic relationship between the technological or programme issues (KTVs and KPVs) and those more-likely indicators. Thirdly, the generic technology/programme model is edited based upon the specific object or domain, in order to modify or remove those KTVs and/or KPVs which are regarded as inappropriate; a specific model (KTVs and KPVs) then has been developed. Taking into account the fact that KTVs or KPVs may represent information technologies or systems with different granularities or different conceptual levels, those KTV or KPV at the general level of the information technology or system can be divided into more specific KTVs or KPVs. Therefore, the model of the KTVs and KPVs is always constructed as a multi-layers hierarchy, and there thus exist many potential overlapping and redundancies between different KTVs or KPVs – such as KPVs for ERP (Enterprise Resource Planning) systems, MRP (Materials Requirements Planning) systems, and WMS (Warehouse Management System) to give just some examples. However, the motivation here is principally based upon the specific application of a certain KTV or KPV to support acquisition of the consequential performance improvement or status for the related indicators. These KTVs and KPVs are supposed to be correlated with performance indicators and should have clear boundaries, and represent the technology or system independently with a certain granularity or conceptual level; they are not supposed to apply overlapped or redundant KTVs or KPVs together in the same case; thus KTVs and KPVs selected would normally come from the same layer of the specific model of KTVs and KPVs in each case, in accordance with the requirements and circumstances of the individual object analyzed. The KTVs and KPVs from a layer with a smaller granularity and lower conceptual level, makes the decision-making focus on more specific and particular information technologies and systems. To make the method more handy and easy to use, these

KTVs and KPVs can be linked to performance indicators directly, and those more specific ones related to them can be used as references to configure the relationships between them and the indicators. Accordingly, the selected KTVs and KPVs always form a one-layer structure, and each is directly linked with some indicators in the bottom layer, as shown in the right-hand part of Figure 7.

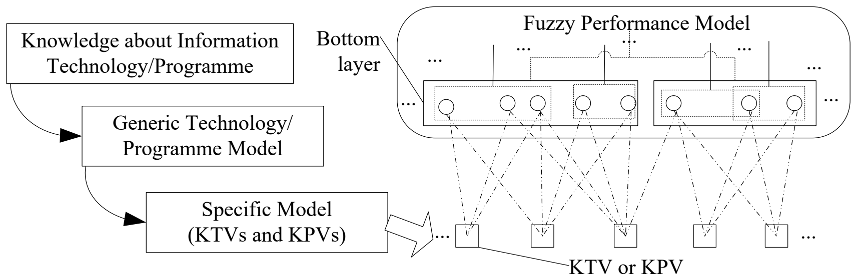


Figure 7: The KTV or KPV and indicators in the bottom layer

In addition, different methods to gather relevant data are apparently required. According to Sinclair [1995], the methods for gathering data can usually be divided into three categories that can be applied together in this paper: observational methods; database methods; and subjective methods, such as questionnaires and interviews. Other performance indicators, as well as the whole analyzed object, can be measured with certain fuzzy inference tools (e.g. the MATLAB fuzzy logic toolbox), based upon the following formulas. Management actions can thus be implemented correspondingly.

ψ'_{ij_ik} : If $PI_{(i+1)j_{(i+1)}} \in C'_{ij_ik}$ and ($PI_{(i+1)j_{(i+1)}}$ and $F_{(i+1)j_{(i+1)}}$ in correspondence with some fuzzy term) Then (F'_{ij_ik} in correspondence with the relevant fuzzy term), $\forall j_{(i+1)}$.

ψ_{ij_i} : If (C'_{ij_ik} and F'_{ij_ik} in correspondence with some fuzzy term) Then (F_{ij_i} in correspondence with the relevant fuzzy term), $\forall k$.

$$C'_{ij_ik} = \left\{ PI_{(i+1)j_{(i+1)}} \middle| PI_{(i+1)j_{(i+1)}} \in S_{ij_ikl}, \forall l, \forall j_{(i+1)} \right\}$$

$$F'_{ij_ik} = \left\{ F_{(i+1)j_{(i+1)}} \middle| PI_{(i+1)j_{(i+1)}} \in C'_{ij_ik} \right\} \otimes \psi'_{ij_ik}$$

$$F_{ij_i} = \left\{ F'_{ij_ik} \middle| C'_{ij_ik} \subseteq C_{ij_i} \right\} \otimes \psi_{ij_i}, \forall k$$

Where PI_{ij_i} is the j_i -th indicator in the i-th layer of the performance hierarchy, and S_{ij_ikl} is the l -th related indicator subset corresponding with the k-th child process activity of PI_{ij_i} . C'_{ij_ik} denotes the whole set of those related indicators associated with the k-th child process activity of PI_{ij_i} , and C_{ij_i} is the set of those related indicators in all of the associated child process activities of PI_{ij_i} . $F_{(i+1)j_{(i+1)}}$ is the fuzzy performance value of $PI_{(i+1)j_{(i+1)}}$ and F_{ij_i} is the corresponding value of PI_{ij_i} . F'_{ij_ik} is about the fuzzy performance value of C'_{ij_ik} , which reflects the synthetic performance of an indicator set. ψ'_{ij_ik} and ψ_{ij_i} are the fuzzy performance relationship functions that are mainly based on the fuzzy rule set.

5. Procedural framework for EE performance measurement

Having, in the last section, fully detailed the fuzzy performance modelling framework to be used here, we return to the procedural framework for EE performance measurement, as outlined by Folan & Browne [2005], and will illustrate how the above fuzzy-based model fits into the existing schema of that framework. As stated before, the greatest weakness of the methodology advocated by Folan & Browne [2005] is their reliance upon rather arbitrary means for the derivation of the correct set of performance measures to implement into the EE Balanced Scorecard – this, indeed, is a flaw that is found right across the performance measurement research, and is not confined just to Folan & Browne [2005]; here we tackle the issue by introducing the above research upon fuzzy-based performance modelling procedures into the initial procedural frameworks, which exist at both the local node (individual firm) level of the EE, and at the holistic EE level. Details of the original procedural frameworks are given below with the fuzzy performance model supplement included.

The procedural framework for EE PM provides the EE and its nodes with instructions for proceeding to distil their respective strategies into implementable measures and performance model for the internal-, supplier-, customer-, and EE-perspectives of the EE Balanced Scorecard outlined in section 3 above. Experiences from the automotive industry suggest that the procedural framework must have the ability to operate at two distinct levels; namely the holistic EE level, and the individual, EE node, level. It is for this reason that the procedural framework may be divided into two sections: the first section prescribes procedures suitable for the supplier-, internal-, and customer-perspectives; and the second section prescribes procedures for the EE-perspective. Essentially the first section concentrates upon developing a procedural PM framework for each EE node, without considering the EE in the holistic sense; the second section reinserts the EE-perspective into the discussion, to enable the development of the supplier-, internal-, and customer-based measures into aggregated EE-based measures.

To facilitate the second section, the concept of an EE host must be introduced. The EE host is the member of the EE responsible for formulating, detailing and distributing information concerning the EE direction and requirements to the other nodes of the EE; and for controlling the aggregated EE-perspective of the EE Balanced Scorecard. The recommended EE host is a first-tier supplier of the EE – a choice dictated by the need to avoid coercive practices in the EE from the introduction of a large-scale PM system that crosses a number of company boundaries. Lack of participation by EE nodes and failure of the initiative as a whole may result from the hijacking of the EE PM system by interested parties in the EE for their own direct needs; or by excessive PM politics that may complicate and weaken the implemented system. A first-tier supplier as EE host lies in an ideal position to counteract this: since they are suppliers to OEMs, and customers to second-tier suppliers, it is in their interest to see that the EE PM system can transcend the EE politics and technology differences found between OEMs and SMEs; plus the fact that they are also in a considerably weaker position – in terms of implementable political pressure – than an OEM, who, owing to their size and position, may inevitably try to manipulate the EE PM system for their own benefit only.

The following sub-sections outlines each of the procedural frameworks in greater detail; this will be performed using the details and position of a first-tier supplier company that produces aluminium chassis components for the European automotive industry, and holds the representative position of EE host in our schema below. Products are forged by the company to suit the requirements of three main customers, at seven separate locations in Europe; while the company has eleven suppliers, mainly based in Europe, that supply nineteen distinct components to the company. The company has its main manufacturing plant in Norway, and a duplicate plant in Canada to service their North American operations. This research is based upon collaboration with the Norwegian manufacturing plant, who were interested, as far as possible, in duplicating its European EE set-up in North America – hence its interest in EE PM. The following paragraphs examine the impacts of the updated procedural framework and EE Balanced Scorecard upon the company.

5.1 Case Study: Extended Enterprise Node Level Procedural Framework

The original procedural EE PM framework has relied upon the intra-organisational procedural PM frameworks proposed by Bradley [1996] and Medori & Steeple [2000]. Its updated instance, including the fuzzy module, is depicted in Figure 8 and detailed in a number of stages described below.

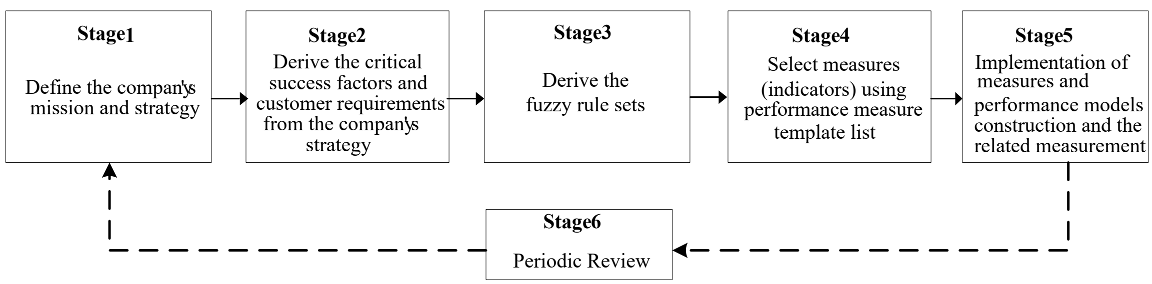


Figure 8: Procedural Extended Enterprise performance measurement framework – local node

5.1.1 Stage 1: Define the Company's Mission & Strategy

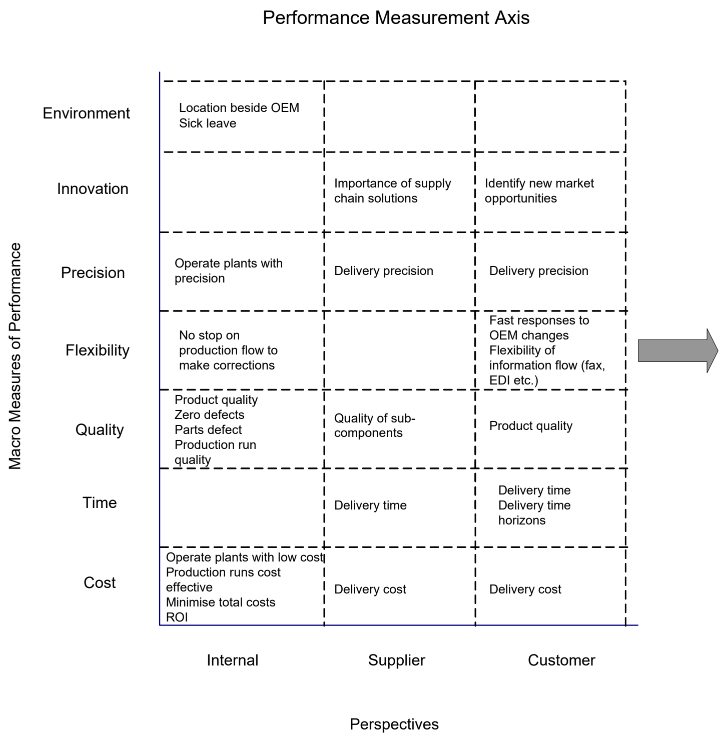
Depending upon the EE node's level of sophistication, this may be completed quickly. A series of interviews and workshops amongst top-level management is how Kaplan & Norton [1993] propose that this stage should be handled. Unhelpful, vague and misleading statements in the resulting strategy should be avoided, and additional documentation - such as documents that help illuminate strategy – should also be retained for future reference.

5.1.2 Stage 2: Derive the Critical Success Factors & Customer Requirements from the Company's Strategy

A PM axis may be used at this stage; Figure 9 is an example of one such application using a company who is a first-tier supplier of chassis component products to leading automotive companies in the European automotive industry as an example. The axis combines seven macro measures of performance from the performance measure template list on the vertical axes, with the internal-, supplier-, and customer-perspectives of the EE Balanced Scorecard on the horizontal axes, to accommodate 21 different types of success factor, each consisting of one macro measure of performance and one perspective. Critical success factors are identified from the derived strategy and added to the axis by:

- Determining the perspective - each statement in the mission and strategy statements is examined to discover whether the factor involved impacts upon our company alone, upon ourselves and our suppliers, or upon ourselves and our customers;

- Determining the macro measure of performance – how does each statement in the mission and strategy impact upon us? We determine if it affects us cost-wise, quality-wise etc.



Performance Measurement Grid

Macro measure of performance	Framework perspective	Critical success factors
Cost	Internal Supplier Customer	Plant operation costs Production cost runs Total costs Delivery cost Delivery cost
Time	Supplier Customer	Delivery time Delivery time Delivery frequency
Quality	Internal Supplier Customer	Product quality Zero defects Parts defect Process quality Product quality No. of defects Product quality
Flexibility	Internal Customer	Flow of materials Fast response Flexibility of information flow
Precision	Internal Supplier Customer	Plant operation Delivery precision Delivery precision
Innovation	Supplier Customer	Supply chain solutions Identify new market opportunities
Environment	Internal	Plant location

Figure 9: Company's performance measurement axis and performance measurement grid

This process is greatly facilitated by any additional documentation that may elucidate obscure statements in the strategy. Once the strategy and mission statements have been exhausted and the PM axis completed, the results may be converted into an adaptation of the Medori & Steeple [2000] PM grid.

5.1.3 Stage 3: Derive the Fuzzy Rule Sets

The fuzzy rule set is one of the most important bases for performance modelling mentioned above and is related not only to the model construction but also to its relevant measurement. As detailed in the above performance modelling method, the fuzzy rule set may now be composed of the fuzzy rules which are extracted and selected from the integrated system and related business processes, as well as the knowledge repository. Each fuzzy rule may have several premises, but only one conclusion; both premises and conclusions refer to performance indicators. The performance values of the fuzzy rule premise(s) and conclusion are normally qualitative, which can be represented in an appropriate way, for example by the application of linguistic terms. Various performance values of the premises and their combination in multiple ways will result in variable values for the conclusions. In addition, for each fuzzy rule, the premise is associated to a certain process activity, as is the conclusion. Each performance model of the PM system for the customer-, internal-, and supplier-perspectives is correlated to a fuzzy rule set which is exemplified respectively in the paragraphs below:

For the customer-perspective, the fuzzy rule set can be described as: {IF [(*Collection and packaging time*) and (*Shipping time*)] THEN (*Delivery tim*e); IF [(*Average time of distribution and outbound logistics*) and (*Percentage of orders distributed on-time*)] THEN (*Shipping time*); IF [(*Collection and packaging accuracy*) and (*Shipping accuracy*)] THEN (*Delivery accuracy*); ......}.

For the internal-perspective, the fuzzy rule set can be described as: {IF [(*Production planning and schedule quality*) and (*part manufacturing quality*) and (*Assembling and warehousing quality*)] THEN (*Manufacturing quality*); IF [(*Production planning and schedule flexibility*) and (*part manufacturing flexibility*) and (*Assembling and warehousing flexibility*)] THEN (*Manufacturing process flexibility*); ......}.

For the supplier-perspective, the fuzzy rule set can be described as: {IF [(*Time taken for suppliers to Collect and pack required materials*) and (*Shipping time from suppliers*)] THEN (*Delivery time*); IF [(*Average time of procurement and inbound logistics*) and (*Percentage of orders procurement on-time*)] THEN (*Shipping time from suppliers*); IF [(*Collection and packaging accuracy of the suppliers*) and (*Shipping accuracy from the suppliers*)] THEN (*Delivery accuracy*); ......}.

5.1.4 Stage 4: Select Measures using Performance Measure Template List

Using the derived PM grid from stage 2, the related fuzzy rule set and the performance measure template list, the selection of the most suitable measures that conform to the EE KPI template list can be made. Note how the additional use of the fuzzy rule set removes much of the subjectivity that traditionally plagues this step in most classic PM systems; the fuzzy rule set allows the user to reacquaint themselves with the underlying process model that typifies the PM axis and grid in Figure 9 above. Using the 'macro measure of performance' and 'framework perspective' columns as a guide, measures matching (or closely matching) the critical success factors identified may be quickly located within the performance measure template list. It is likely that some of the critical success factors that have been identified may not have suitable measures applicable to it in the template list; in this case the performance measure template list requires auditing to ensure its currency.

At the end of this section a list of measures for the internal-, supplier- and customer-perspective should have been specified under the various macro measures of performance. These measures must now be associated with certain fuzzy rules; if some indicators or indicator sets are not related to any fuzzy rule it is normally required that new, corresponding, fuzzy rules are mined. In addition, those measures, which are embedded in fuzzy rules and don't appear in the above collection, will also be considered and applied. As mentioned above, the premises and conclusion of each fuzzy rule actually refer to performance indicators. From the above discussion, it is understandable that the mined fuzzy rules can be an effective supplementary guide towards the selection of performance measures. Likewise, the performance measure template list can facilitate the development of required and appropriate fuzzy rules.

The supplier- and customer-perspective measures should be transmitted to the interested parties up- and down-stream of the company in order that they may be taken into account in their strategy-formulation exercises; minor alterations and/or additional measures may come from either parties.

5.1.5 Stage 5: Implementation of Measures & Performance Model Construction & the Related Measurement

The measures selected and collected together with the fuzzy rule sets are used to support the construction of the related performance models of the PM system for the supplier-, internal-, and customer-perspectives. As detailed in the above performance modelling method, the related performance measurement can also be implemented as well as the final management and adjustment actions.

5.1.6 Stage 6: Periodic Review

Each node of the EE will be expected to periodically review (the length of the periods between reviews is set by the EE host) the PM system put in place for the internal, supplier and customer perspectives.

5.2 Extended Enterprise Level Procedural Framework

The following procedural framework, being very much identical with the previously detailed framework upon many points, is only outlined briefly here. The stages in the process that the EE host should follow to develop an EE direction and requirements plan, reduce it to EE measures, performance model and implement it is shown in Figure 10.

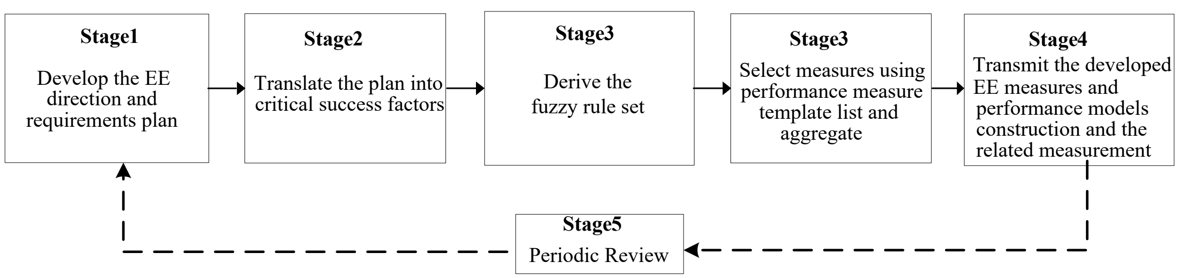
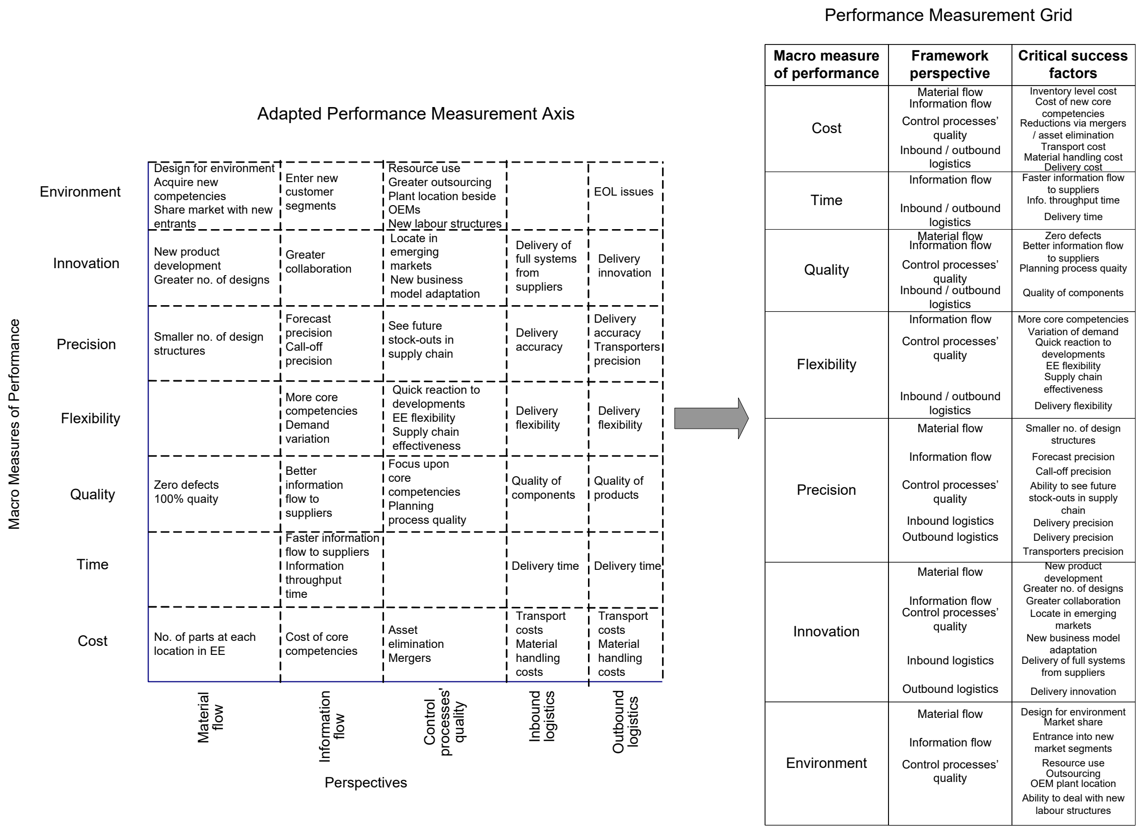


Figure 10: Procedural Extended Enterprise performance measurement framework – EE perspective

In developing the EE direction and requirements plan, the EE host should develop the plan through an examination of the four factors of Waggoner *et al.* [1999]: the internal, external, process and transformational issues of the EE should be understood in detail. The results of such a study should indicate the future impacts that may be perceivable upon the EE for all nodes of the EE. The O.E.M of the EE should also be able to provide a comprehensive overview of the requirements of the final customer of the EE; the expectations, needs and wants of the final customer are the driving force for the EE as a whole, and the EE plan should be formulated upon this. For stage 2 an adapted PM axis may be introduced: the adapted axis retains the macro measures of performance but changes the perspectives upon the horizontal axis to a number specifically developed for the EE arena; these are: material flow (e.g. no. of parts 'in' and 'out' of EE); information flow (e.g. orders, request for quotations up and down EE); control process's quality (quality of the planning processes involved in production planning and control in EE); inbound logistics; and outbound logistics. The process of identifying the critical success factors from the EE direction and requirements plan is performed in the same way as previously, whereupon the adapted PM axis is converted into a PM grid. Figure 11 illustrates the performance axis and performance grid for our case study company, the first-tier supplier of aluminium chassis component products.

At this stage the corresponding fuzzy rule set for the case study may be derived. Note that for the EE perspective we are naturally crossing organisational boundaries, such that fuzzy rules characteristically become boundary-spanning, and reliant upon those elements that are common in the set of EE firms. For example, the EE-perspective fuzzy rule set for the case in question here may be described as follows: {IF [(*Delivery time from nth tier supplier to (n-1)th tier supplier*) and ...... and (*Delivery time from 1st tier supplier to OEM*)] THEN (*Delivery time*); IF [(*Delivery flexibility from nth tier supplier to (n-1)th tier supplier*) and ...... and (*Delivery flexibility from 1st tier supplier to OEM*)] THEN (*Delivery flexibility*); ......}.

Subsequently, the selection of the most suitable unaggregated measures that conform to the performance measure template list may be made. In the derived PM grid, using the 'macro measure of performance' and 'framework perspective' columns as a guide, unaggregated measures matching (or closely matching) the critical success factors identified may be quickly located within the performance measure template list. Once unaggregated measures have been selected, the EE host must aggregate them in various combinations, and transmit them to those parties that require them in the EE. After this, the relationship between the collected measures and fuzzy rules is checked, and if some measures are not related to any fuzzy rule then there is a requirement for the derivation of new fuzzy rules. Those measures embedded in the fuzzy rules will be applied in the construction of the EE perspective performance model, and the relevant performance measurement and adjustment actions will be implemented. The EE host will be expected to periodically review the PM system put in place for the EE perspective, and communicate the results of this to the other companies participating in the EE PM system.



Macro measure of performance	Framework perspective	Critical success factors
Cost	Material flow Information flow Control processes' quality Inbound / outbound logistics	Inventory level cost Cost of new core competencies Reductions via mergers / asset elimination Transport cost Material handling cost Delivery cost
Time	Information flow Inbound / outbound logistics	Faster information flow to suppliers Info. throughput time Delivery time
Quality	Material flow Information flow Control processes' quality Inbound / outbound logistics	Zero defects Better information flow to suppliers Planning process quaity Quality of components
Flexibility	Information flow Control processes' quality Inbound / outbound logistics	More core competencies Variation of demand Quick reaction to developments EE flexibility Supply chain effectiveness Delivery flexibility
Precision	Material flow Information flow Control processes' quality Inbound logistics Outbound logistics	Smaller no. of design structures Forecast precision Call-off precision Ability to see future stock-outs in supply chain Delivery precision Delivery precision Transporters precision
Innovation	Material flow Information flow Control processes' quality Inbound logistics Outbound logistics	New product development Greater no. of designs Greater collaboration Locate in emerging markets New business model adaptation Delivery of full systems from suppliers Delivery innovation
Environment	Material flow Information flow Control processes' quality	Design for environment Market share Entrance into new market segments Resource use Outsourcing OEM plant location Ability to deal with new labour structures

Figure 11: Company's adapted performance measurement axis and performance measurement grid

5.3 Summary & Discussion

The above application of the procedural frameworks for EE PM, together with the innovative fuzzy performance modelling supplement, has ensured a greater precision in the selection and implementation of the EE Balanced Scorecard in our case study, the first-tier supplier of aluminium chassis components in the European automotive industry. From the case study we can see that the derivation of fuzzy rules has the following advantages for the PM practitioner.

1. It acts as a supplementary guide towards the selection and implementation of performance measures. Performance measures are commonly derived from *either* a pre-defined list of measures held in reserve until the moment of selection has arrived, *or* they are developed as part of the PM methodology itself; Keung [2000] defines these two choices as *either* using a generic set of performance measures and picking up the right ones, *or* starting from scratch. The former provides for standardisation of the performance measures used, with the loss of flexibility in the development of new measures; and the latter method, while more difficult to implement and open to standardisation difficulties with the developed measures, has more flexibility in that each PM cycle can develop more precisely the measures required [Folan & Browne, 2005]. Here the derivation of fuzzy rules has assumed the existence of a pre-defined list of performance measures that may or may not entirely cover the range of measurement areas of the EE; however, the availability of the fuzzy rule set constrains the user so that they are less reliant upon inexact rules-of-thumb techniques in selecting and implementing measures; while the fuzzy rules, in combination with the performance axis and grid quickly

illustrates areas where "gaps" exist in the measure list which need to be filled; indeed, the fuzzy rules are a material help in the filling of these gaps.

2. The fuzzy rule set constrains the user by making them concentrate explicitly upon the process model. All too often in performance measure selection and implementation exercises, non-process related subjectivity can arise, especially in contexts where the user is given free reign to conceive of the initial strategy as they wish. A chief characteristic of modern non-financial PM is its supposed link to strategy, in that all measures chosen should be, somehow, derived from an initial strategy [see, for example, Azzone *et al.*, 1991; Bititici *et al.*, 2000; Eccles, 1991; Medori & Steeple, 2000; Kennerely & Neely, 2003; Kaplan & Norton, 1992]. This is fine; however anecdotal evidence illustrates that strategy, especially if stated vaguely and unclearly, becomes open to all forms of subjectivity, such that users must decide for themselves exactly how to capture the performance that the strategy under consideration seems to imply. PM specification has always been what can only be described as the "leap of faith" from the strategy of the company (or group of companies) to the actual selection of performance measures; no matter how precisely we try to make the intermediaries between the strategy and the selection method – call these intermediaries *critical success factors* or *customer requirements*, whatever – it is never enough to allow us to objectively define the "one true measure" that is required; subjectivity, even if only in the selection of one measure over another, will have to be used. For example, if faced with the dilemma of choosing a performance measure to stand for a critical success factor such as "improve product quality", we could select any number of representational alternatives – such as the *cost* of improved product quality, or the amount of extra *time* taken to assess product quality etc.

The fuzzy rule set in the case study has helped to constrain this problem. By requiring the user to take into account a set of fuzzy rules that have a hierarchy and structure that is provided by the initial process model, the selection and implementation of performance measures is explicitly tied into the initial processes that underlie the strategy; thus, process model considerations become preliminary necessities in the selection and implementation exercise.

Such being the case, the EE Balanced Scorecard for the case study, the first-tier supplier of aluminium component products to the European automotive industry may be presented as in Figure 12. For the sake of completeness, the fuzzy rule set that has been derived throughout the case study is also appended here in Table 1a and 1b. In Table 1a we have exemplified the related four fuzzy rule sets for the EE: in the customer-, internal-, and supplier-perspectives, which only clarifies indicators referred to by the premises and conclusion of the specified fuzzy rules; whereas, in Table 1b, we take one of the fuzzy rules for customer-perspective as an example, and give details of the relevant performance values of its premises and conclusion, as well as their logical embedded relationship.

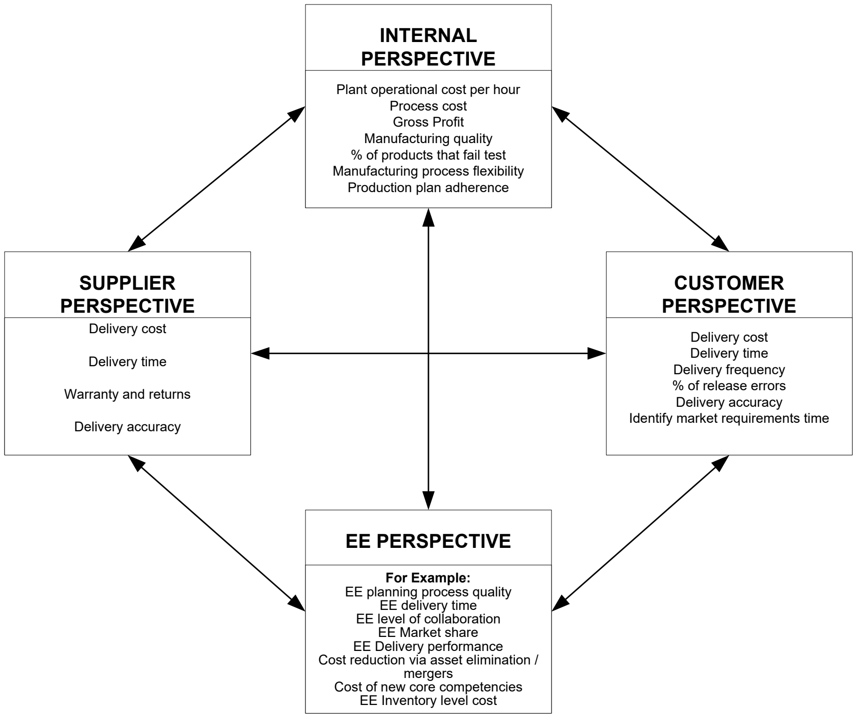


Figure 12: Case study EE Balanced Scorecard

Table 1a: Fuzzy rule set for the case study

PERSPECTIVES	**THE PREMISES IF [( ) and … and ( )]**			**THE CONCLUSION THEN ( )**
EE-	Delivery time from nth tier supplier to (n-1)th tier supplier	…	Delivery time from 1st tier supplier to OEM	Delivery time
	Delivery flexibility from nth tier supplier to (n-1)th tier supplier	…	Delivery flexibility from 1st tier supplier to OEM	Delivery flexibility
	……			……
Customer-	Collection and packaging time	Shipping time		Delivery time
	Average time of distribution and outbound logistics	Percentage of orders distributed on-time		Shipping time
	Collection and packaging accuracy	Shipping accuracy		Delivery accuracy
	……			……
Internal-	Production planning and schedule quality	part manufacturing quality	Assembling and warehousing quality	Manufacturing quality
	Production planning and schedule flexibility	part manufacturing flexibility	Assembling and warehousing flexibility	Manufacturing process flexibility
	……			……
Supplier-	Time taken for suppliers to Collect and pack required materials	Shipping time from suppliers		Delivery time
	Average time of procurement and inbound logistics	Percentage of orders procurement on-time		Shipping time from suppliers
	Collection and packaging accuracy of the suppliers	Shipping accuracy from the suppliers		Delivery accuracy
	……			……

Table 1b: Fuzzy rule set for the case study

THE PREMISES IF [( ) and … and ( )]		THE CONCLUSION THEN ( )	THE PREMISES IF [( ) and … and ( )]		THE CONCLUSION THEN ( )
Average time of distribution and outbound logistics	Percentage of orders distributed on-time	Shipping time	Collection and packaging time	Shipping time	Delivery time
Long	Superlative	Relatively short	Long	Long	Long
Relatively long	Superlative	Relatively short	Relatively long	Long	Long
Relatively short	Superlative	Relatively short	Relatively short	Long	Relatively Long
short	Superlative	short	short	Long	Relatively Long
Long	High	Relatively long	Long	Relatively long	Long
Relatively long	High	Relatively short	Relatively long	Relatively long	Relatively long
Relatively short	High	Relatively short	Relatively short	Relatively long	Relatively long
short	High	short	short	Relatively long	Relatively short
Long	Average	Long	Long	Relatively short	Relatively Long
Relatively long	Average	Relatively long	Relatively long	Relatively short	Relatively short
Relatively short	Average	Relatively short	Relatively short	Relatively short	Relatively short
short	Average	short	short	Relatively short	Short
Long	Low	Long	Long	Short	Relatively long
Relatively long	Low	Long	Relatively long	Short	Relatively short
Relatively short	Low	Relatively long	Relatively short	Short	Short
short	Low	Relatively short	short	Short	Short
…	…	…	…	…	…

6. Discussion and Conclusion

The PM arena has embraced many changes in the last 35 years or so: there has been a consistent evolution from a focus upon internalised procedures and a consequent retreat from the hegemony of financially-oriented, bottom-line measurement; to a focus upon the creation of holistic PM systems, prompted by an integrated performance management approach, enabling both internal and external measurement. The widespread currency of inter-organisational PM concepts has developed, in part, from the desire to have closer monitory control upon our immediate collaborative partner's activities, so as to benefit our own internal processes; and, also in part, as a natural result of the continuing evolution of the collaborative typologies that espouse greater co-operation and openness with our near neighbours in the value chain – alliances, supply chain management (SCM), the Extended Enterprise (EE), and the Virtual Enterprise (VE).

Within this sphere of operation, however, many initial issues have continued to be regarded as troublesome, not least the selection and implementation of performance measures—a problem carried over from the internal PM perspective into the inter-organisational arena. Solutions or at least methodologies that can reduce the high levels of inexact, unscientific subjectivity that surrounds measure selection and implementation are a necessary requirement if the future of PM in the inter-organisational arena is to be successfully applied.

Here, Folan & Brownes' [2005] EE PM system is described in some detail. The EE Balanced Scorecard offers a four-perspective framework – to be implemented at each EE node – that provides a generic structure for the management of performance measures in the EE. The procedural framework operates at both the EE node and holistic EE levels to provide a step-by-step generic process towards the selection and implementation of measures as well as the construction of a performance model with its relevant measurement and management requirements. The complete system makes a number of assumptions, all of which result from the fusing of two diverse subjects; by attempting to combine the EE with PM they are, in effect, combining the practicalities and problems associated with the EE under the PM umbrella. They therefore emphasise that the PM system described here is designed to work within the EE paradigm; issues of co-operation and trust, for example, in the EE are taken as essential starting-point assumptions.

Although a novel contribution to an inadequately-developed sector of the performance research, the EE PM system recounted by Folan & Browne [2005] has a number of inherent limitations, the most serious of which we examine in this paper. The greatest weakness of the methodology advocated by Folan & Browne [2005] is their reliance upon rather arbitrary means for the derivation of the correct set of performance measures to implement into their Balanced Scorecard – this, indeed, is a flaw that is found right across the performance measurement research, and is not confined just to Folan & Browne [2005].

In the original paper Folan & Browne [2005] developed relatively simple step-wise procedures to ensure the adaptability of the EE Balanced Scorecard at both the local and the holistic EE level; here we supplemented this with a more flexible fuzzy-oriented performance methodology that tackles the issue of performance measure selection and implementation by using fuzzy rules, thus replacing the rather rule-of-thumb based procedures previously advocated across the performance measurement literature.

Once explained, the new fuzzy performance modelling framework was incorporated with the existing step-wise procedural framework of Folan & Browne [2005], thus enabling the development of an innovative fuzzy-based procedural framework that further reduces the subjectivity of performance measure selection and implementation. This was illustrated via a case study that used the details of an EE first-tier supplier of aluminium components to the European automotive industry.

The case study illustrated two specific advantages of deploying a fuzzy rule set in the procedural framework: it acted as a supplementary guide towards the selection and implementation of performance measures; and the fuzzy rule set constrained the user by making them concentrate explicitly upon the process model even after they had deployed strategy. By taking full advantage of the process model and the related fuzzy rules, the performance modelling method depicted here becomes operable and practicable. Further, the proposed performance model is closely correlated to the process model; and it can also be potentially associated with other models, such as those of function and organization.

The use of fuzzy logic enables the user to reason in uncertain informational environments; and based upon knowledge learning and management, it can be deemed as a significant contribution to shifting much of performance measurement from being qualitative in nature, to being quantitative in nature.

Of course, some issues remain. It may not be apparent each time that the EE PM system is deployed how exactly the fuzzy rules main be determined. As noted in the detailed section on fuzzy methodologies above, the fuzzy-rules base oftentimes utilises previous models of fuzzy-based performance; but this facility is not available to EEs that are only beginning. Further, it is expected that the deployment of the process model, which the fuzzy model is based upon, and the strategy may not be compatible every time: it is likely, for example, that considerations other than those that dominate the process model will be utilised to develop the strategy document, therefore it is likely that a partial fit between the process model and the strategy will be the actual result. This has implications for the deployment of the fuzzy rule set, the derivative of the process model, when it comes into contact withy the performance axis and grid, the derivative of the strategy deployed; a partial fit should be expected. These areas remain in the area of future work for the fuzzy-based performance methodology outlined here, especially in the assessment of how it may be aligned with entities other than the process model.

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