(T&F) TCIM100497

INT. J. COMPUTER INTEGRATED MANUFACTURING, ?MONTH? – ?MONTH? 2004, VOL. 17, NO. 0, 00–00

Performance measurement systems for virtual enterprise integration

RICARDO CHALMETA and REYES GRANGEL

Abstract. A performance measurement system (PMS) is a decision support system that through a set of indicators allows an analysis the current state of an enterprise and to compare it with the strategic objectives. It is therefore a fundamental tool for management control in business.

1. Introduction

Although different methodologies have been proposed to build a performance measurement system (PMS) at individual enterprises, they are not completely satisfactory for their application to virtual enterprises. A virtual enterprise (VE) is a temporary alliance of globally distributed independent enterprises that come together to offer a product or a service. Therefore, a VE is also an aware enterprise that should use a PMS in the kernel of its strategic management system (SMS) to achieve a high level of integration and efficiency among the different enterprises that form it.

This paper presents a proposal for a methodology to define and develop a PMS suitable to the necessities of VEs. In addition, it shows a practical case of its application to a virtual transport enterprise, indicating the activities that were carried out and the obtained results, as well as the computer infrastructure developed to support the PMS.

2. Performance measurement systems

In any enterprise there are a number of targets to be achieved, which are often termed strategic objectives and which are considered fundamental for its success and the maintenance of its competitive advantage. To monitor the degree of fulfilment of these objectives and to assist in suitable decision-making to achieve them, a PMS needs to be developed. The purpose of this system is: (1) to provide quantitative information about important aspects of the enterprise through a set of indicators; and (2) to establish the necessary action plans to reach the strategic objectives (Corbett and Claridge 2002).

The indicators measure the efficiency and effectiveness of an enterprise taking into consideration different perspectives (such as financial, productivity, customer satisfaction, quality or ability to adapt to changes), decisional level (strategic, tactical and operative) and organizational areas (store, production, purchases, administration, etc.). The choice of the set of indicators depends on each enterprise and for the correct identification it needs to define several parameters such as its name, purpose, related aims, value to be achieved in a period of time, method of calculation, unit to be used, how frequently it must be calculated, data source, compression criteria or form of presentation. On the other hand, the indicators must be distinguished between cause indicators, which show what has to be done to achieve the objectives, and effect indicators, which define how to measure the effect of the cause indicators.

In the design of a PMS, one of the most difficult aspects to achieve is to get correct alignment with the enterprise strategy in order to show information about the degree of attainment of the strategic objectives. On the other hand, in subsequent phases of its deployment, this kind of tool allows users to value the importance of the information as support for the decision-making and the advisability of developing an information system within the framework of a strategic plan process.

Authors: Ricardo Chalmeta and Reyes Grangel, Grupo IRIS - Departamento de Lenguajes y Sistemas Informáticos, Universitat Jaume I, Campus Riu Sec s/n 12071 Castellón, Spain. Email: e-rchalmet@uji.es/grangel@uji.es

International Journal of Computer Integrated Manufacturing
ISSN 0951-192X print/ISSN 1362-3052 online © 2004 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/0951192042000213164

3. PMS for virtual enterprises

A VE is a temporary alliance of globally distributed independent enterprises that come together to share resources, skills and costs, supported by information and communication technologies (I&CT), in order to better attend market opportunities and successfully fulfil a responsible corporate strategy (Gunasekaran 1998).

As a consequence of this high level of characterization, an integrated VE is also an aware enterprise; meaning that changes in the internal or external environment should as soon as possible be reflected in the objectives and in its actions; making sure that the activities of all the components contribute to the overall objective in a coordinated way. Within this framework, a PMS is a fundamental tool for achieving a high degree of integration since it can be employed as the foundation of an integrated and iterative strategic management system, that will allow the VE to measure and assess its performance against its strategic objectives. At the same time, it will assist in the decision-making and the design of action plans. Figure 1 shows the position of a PMS within a virtual enterprise integration project (Chalmeta and Grangel 2003).

A PMS will enable a virtual enterprise to:

- Clarify and update strategy.
- Reconsider the situation of each enterprise that forms it and of the VE as a whole.
- Communicate strategy throughout the VE.
- Align enterprises, unit and individual goals with the VE strategy.
- Link objectives to long-term targets and annual budgets.
- Conduct periodic performance reviews to learn about and improve strategy.

4. Methodology for virtual enterprise PMS development

Previous research has been carried out to provide methodologies that allow managers to develop PMS in individual enterprises and to assist in the decision-making at different levels (Kaplan and Norton 2000). However, they are not completely satisfactory when it comes to meeting the peculiarities of VEs. Table 1

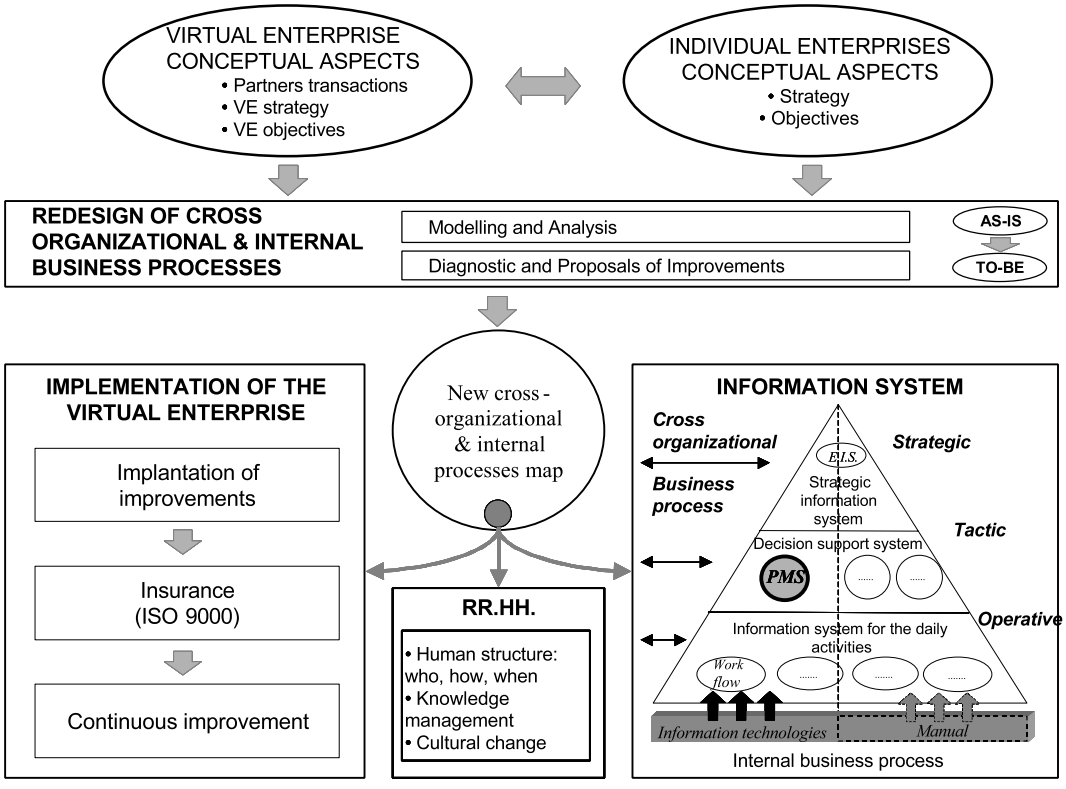


Figure 1. ????.

Table 1. Some differences between a single and a virtual enterprise (adapted from Burn 2000).

	Traditional enterprise	Virtual enterprise
Concept	Profitability today Static Collection of functions (personnel, manufacturing, etc.) or resources (people, machines, etc.)	Profitability tomorrow Dynamic (agile) Add value processes and capacities
Resources	Co-location	Competency
Time	Sequential	Parallel
Information	Completeness and paper distribution	Incomplete electronic sharing
Technology	Data Flow	Information access and interpersonal communications
Knowledge		
Behaviour	Learning	Sharing and codifying
Beliefs	I am responsible for learning	My knowledge grows when it flows and my company benefits from my knowledge
Values	Self-esteem	Respect and trust
Infrastructure		
Physical (physical and workflow area)	JIT (just-in-time)	Lack of dependency on processes that cannot be scaled for physical or time reasons ...
Legal/explicit (business practices area)	Flat organization	Distributed responsibility for handling complaints and researching improvements ...
Cultural/social (cultural area)	Empowered, motivated workforce	Leadership is attentive to and leverages basic patterns of human behaviour, group dynamics, and individual/team motivation Synergism of business processes leveraging the diversity of business culture ...

shows some of the differences between a single and a virtual enterprise.

To solve the problem of developing a PMS for VEs we need to adopt a wider view that considers their special features, such as the assessment of co-ordination mechanisms or the relations between staff from different enterprises.

The methodology proposed in this paper for VE PMS development considers the above VE aspects. It is the result of the work carried out by the IRIS group from Universitat Jaume I in Castellón, Spain. The methodology is organized as a sequence of hierarchical deployment. The first step begins at the strategic level, when the managers of the different partners design the VE as a whole. Then, they go through an iterative cycle that contains the following activities (see figure 2):

- To define virtual enterprise strategic objectives.
- To translate virtual enterprise strategic objectives to action plans.
- To select strategic cause-effect indicators and to establish the relations among them.

The next step consists in turning the organization's high level strategic objectives and measures into low level objectives and measures that identify the performance and the degree of integration achieved in the VE, take different perspectives, decision levels and organizational areas into consideration. The identification and organization of the objectives and measures depends on each type of virtual enterprise, but the following aspects must be analysed and assessed:

- Mechanisms for organization and coordination of all the enterprises involved in the virtual enterprise, in order to: (1) develop a specific action plans and joint activities; and (2) identify the organizational changes that facilitate the enterprises joint operation and the transference of knowledge among them.
- Working practices in the critical inter-organizational business processes.
- Technological infrastructure that allows the automation of the information flow of the inter-organizational business processes.

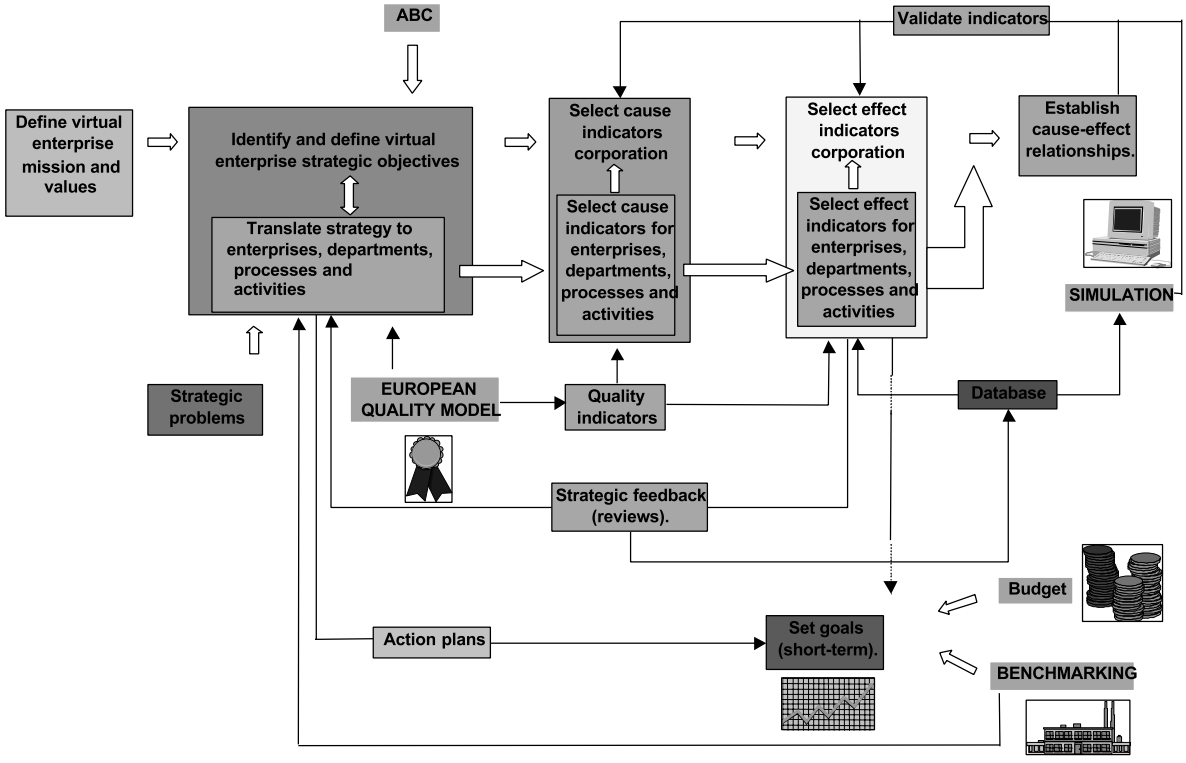


Figure 2. ????.

- Communication techniques to reduce the differences that exist among the different enterprises.
- Relationships between people from different enterprises, to share information, exchange technology and take part in group work together.

Once the objectives and indicators to manage the virtual enterprise are defined, the previous steps have to be applied to each enterprise that make it up. The objectives and indicators to be defined depend on each type of enterprise, but they must be consistent with the ones previously established for the VE management. Therefore, the PMS will give managers a way of ensuring that all levels of the VE understand the long-term strategy and that everything (individual enterprises, departments and local objectives) are aligned with it.

The last point as regards the methodology is to update through reviews the strategy or business processes of the virtual enterprise and the individual enterprises. Therefore, the PMS must not just be considered as a way of obtaining a set of indicators but instead as a mechanism to improve the efficiency and competitiveness of the virtual enterprise.

Five techniques are used in the methodology to develop a PMS: ABC (activity based costing); Hoshin Kanri; benchmarking; European Quality Model; and simulation.

- ABC: analysis of the factors that are the causes of costs in the different activities and processes.
- Hoshin Kanri: deployment of a quality strategy for the VE and for each individual enterprise. This tool tries to align the quality strategy with operative plans and tactics.
- Benchmarking: through the analysis of competitors' behaviour and performance, specific areas for improvement can be identified.
- European Quality Model: this establishes practical guidelines to obtain a Total Quality System, through the compliment from ISO 9000 standard.
- Simulation: this is a tool used to identify the relationships between objectives and indicators that are based only on subjective. The feedback about indicators information and its relations to the strategic objectives must be stored in a database that constitutes the historical data source to establish simulation and validation about previous relations.

Once the PMS has been designed, there is a need to build a computer infrastructure that supports the

processes that are carried out for the establishment and running of the system. This infrastructure must allow the system, first, to collect and integrate the scattered information in the various databases and others sources from each individual enterprise in a data warehouse. The data warehouse structure must be optimized for the subsequent consultation and analysis of the data. The data warehouse can be analysed from three perspectives (Jarke and Vassiliou 1997):

- Conceptual perspective: represents the usefulness of the data warehouse to impose an overall business perspective, a conceptual enterprise model, on the information resources and analysis of the tasks of an organization.
- Logical perspective: conceives a data warehouse from the viewpoint of the actual data models involved, while considering the wrapping of heterogeneously represented data sources, and the integration of data from multiple sources into particular views.
- Physical perspective: interprets the data warehouse architecture as a network of data stores, data transformers, and communication channels, aiming at the quality factors of reliability and performance in the presence of very large amounts of slowly changing data.

The steps, which should be carried out to create a data warehouse following a top-down design are (Inmon 1996):

(1) Data extraction (once the potential structured and unstructured data sources have been identified and selected).
(2) Data transformation (once the quality has been checked and the data cleaned).
(3) Data migration.
(4) Data and metadata loading in the enterprise warehouse and centralized metadata repository (once the links between origin and destination have been set). These first four steps must be carried out by using the extraction transformation migration and loading tools (ETML).
(5) Creation of data marts, (a set of data warehouses that represents different views of the enterprise), from data warehouse and metadata.

In addition, other previous technical activities have to be carried out, such as: integrating the servers, storage, and customer tools; designing the warehouse schema and views; defining the physical warehouse organization, data placement, partitioning, and access methods; connecting the sources using gateways, ODBC drivers, or other wrappers, etc. (Chaudhuri and Dayal 1997).

Second, to calculate and present indicators using on-line analytical processing (OLAP) tools. Once the data has been integrated in the data warehouse, it is then possible to calculate and analyse the VE indicators. OLAP tools are used for that. They are a kind of software technology that allows quick access into the strategic information, due to using multidimensional views of added data to carry out many important analysis that are difficult or impossible to express in SQL using tabular structures. OLAP and data warehouses are complementary. A data warehouse stores and manages data. OLAP transforms data from the data warehouse into strategic information that ranges from basic navigation and browsing, to calculations and more serious analyses such a time series and complex modelling (OLAP Council 1997).

Three categories of OLAP architectures can be identified, depending on the paradigm that they use for the physical storage of the data (Dinter *et al.* 1999):

(1) MOLAP (Multidimensional OLAP): these systems have a multidimensional database management system (MDBMS) designed for multidimensional query processing. They are not commercially implemented by means of a uniform and commonly accepted technology. However, due to the great amount of data that must be handled in the PMS (many cells from the multidimensional cube will be empty), these systems are very useful. In one way, they use techniques for optimum data storage, the majority based on two levels of data structures, while in another, they efficiently manage the multi-user access to writing and reading.
(2) ROLAP (Relational OLAP): this provides multidimensional user views of data, which still resides in a relational database management system (RDBMS). The ROLAP engine usually translates relational schema into a multidimensional schema, and the majority of systems require star or snowflake schemas. From a technical point of view, putting the ROLAP engine into operation is the critical point of this kind of systems. The multidimensional schema (the equivalent to the entity/relation model in the relational database) is made up of fact tables and several dimension tables linked with each of the fact tables.
(3) HOLAP (Hybrid OLAP): this is the integration of MOLAP and ROLAP, in order to take

advantages of both of them and avoid their inconveniences.

Third, to obtain the necessary data at the right time. A vast amount of information is handled inside the virtual enterprise and it will increase due to the quick advance of new computer technologies. However, the problem with the exchange of information needed to build a PMS it is not the handling of large amounts of information, but rather the control of certain characteristics of that information, such as the variability in data format, the data validity, their exchange and ways of sharing them, etc. All these factors are especially important in the integration of the VE information system and they are solved by the two technologies mentioned above.

5. Case study: PMS for virtual transport enterprises

5.1. *Virtual transport enterprises*

In the global market environment, most transport enterprises do not have the financial and structural capability to afford the cost of operating direct routes with different points of origin and destination. Therefore, in order to satisfy the customer requirements, local transport enterprises must work together through the establishment of co-operative agreements to set up what we call virtual transport enterprises (VTE).

A VTE should be capable of taking full responsibility for a door-to-door transport service on behalf of its customers, and should be capable of defining an optimal solution, taking advantage of the availability of different types of transport and finding true added value for transport services.

5.2. *Application of the methodology*

Below, we show the results of a contract research study, which was conducted by the IRIS group from Universitat Jaume I in Castellón. The purpose of this study was to apply the methodology described above in the development of a PMS for CAVE Logística. CAVE Logística is a VTE made up of group of more than 50 Spanish individual transport enterprises, of small and medium size, that exchange information and goods among themselves and with enterprises from other countries.

The services it offers can be summed up as follows: (1) pickup at sender's location, conventional or express transport, and delivery to any part of Spain, of fractioned or complete loads; and (2) goods depot and storage. The company also offers its customers the possibility of international transport and delivery, thanks to agreements reached with logistics enterprises in other countries. As regards the resources at its disposal, the CAVE Group has 1105 employees, its premises cover a total surface area of 105 000 m^2, it covers over 350 delivery routes per day and has a fleet of 875 vehicles.

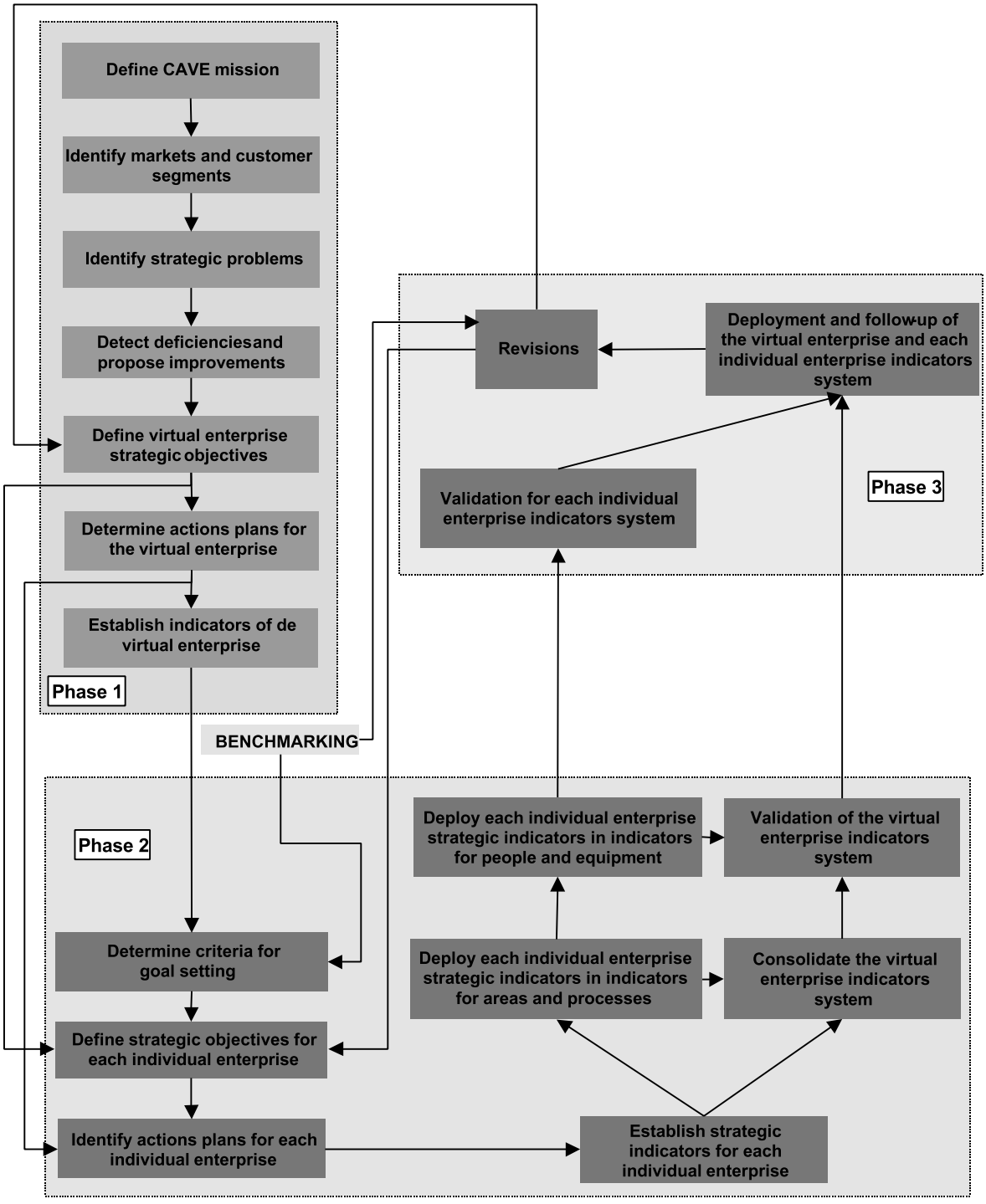
In addition, an enterprise called Central was set up to manage and organize this virtual enterprise, as well as to develop the computer infrastructure. Some of the tasks it is responsible for include logistics management, quality control, national and international sales, accounting and technical consultation.

The project for obtaining a PMS for CAVE Logística was structured in three phases, which are divided into different activities, as shown in figure 3. The starting point was to establish the VE master lines, beginning with the definition of mission, vision and values. Next, they identified the markets and customers segments in which the organization competes taking different criteria into consideration such as the geographical zone to which the goods are destined, the type of clients, the type of goods to be transported (bulky, difficult to handle, stored on pallets), etc.

The following task was to define the VE strategy, considering this phase as an opportunity to improve. To do it, it was necessary to: (1) analyse the strategic problems; (2) define the main deficiencies regarding the formulation of the virtual enterprise's strategy, and propose improvements that determine the right mechanism for a correct and co-ordinated strategic planning of the virtual enterprise and the different individual enterprises; and (3) establish the strategic objectives of the VE. Table 2 shows examples of the results obtained from these activities at phase 1.

Once the strategic objectives had been defined, following the Hoshin Kanri model, it was necessary to determine: (1) the different action plans to solve the strategic problems that were detected and how to achieve the objectives set; and (2) the cause and effect indicators that allowed it to measure the attainment of the objectives set for the VTE. Those indicators were linked by relationship of cause and effect, which, in some cases, made it necessary to use simulation techniques.

The objectives, the action plans and the indicators that would allow evaluation of the degree of fulfilment were organized in eight different perspectives (virtual enterprise integration, customer, commercial, financial, internal process, learning and growth, quality and environmental impact), which at the same time were broken down into views (table 3). Each view could be analysed considering different decisional levels and



① ②

Figure 3. ????.

organizational areas. Table 4, shows an example of the relationship among objectives, action plans, cause indicators, and effect indicators for the customer's satisfaction view of the quality perspective, at the operative and tactical level, and at the traffic and sales organizational areas.

The PMS employed to evaluate the VTE performance as a whole was applied to each individual transport enterprise (phase 2). The procedure was similar to the one that was carried out to obtain the PMS for the VE. The VE objectives were taken as principal reference points together with the peculia-

Table 2. Examples of results of the application of the methodology phase 1 to the CAVE Logística organization.

Strategic problems	• Deficiencies in the quality of service. • Criteria diversities and ways of work at the individual enterprises in both the treatment of the goods and the treatment of information. • Lack of cost control, both fix an variable. • Lack of a true corporate image at the organization. • Insufficient technological infrastructure.	
Main deficiencies and proposal of improvement	Deficiency	Proposed improvement
	The virtual enterprise strategic objectives just set an example to follow by all the individual enterprises, without having a clear commitment to comply them.	Creation of a committee that determines the strategic objectives to follow by the different independent enterprises.
	Establishment of goals by the zone manager of the different individual enterprises, using very subjective criteria.	Deployment of a unique goal setting system from the information given by the following tools: • Competitor enterprises evolution (benchmarking). • Future PMS indicators.
	The strategic revision by the virtual enterprise is currently limited to obtain information from the different individual enterprises. As a result, the flow of information only has one direction.	Periodic meetings between central executives with the individual enterprises managers to revise the strategic objectives by means of the information given by the future PMS and its co-ordination with the virtual transport enterprise objectives. So the flow of information will be in both directions.
	Every enterprise measures customer's satisfaction in a different way.	Deployment of a system to measure the customer's satisfaction using the indicators to define in the PMS.
Virtual Transport Enterprise strategic objectives	Two aspects are specially important: (1) Customer's satisfaction, for which it must take as reference the added value that the transport service offer them. That value includes three points: The relationship with the customer, the image that is offered by the enterprise, and the service attributes (functionality, quality, price and time). (2) The processes that the organization needs to promote to improve the customer's satisfaction. These processes are classified in three groups. Innovation Processes, to identify the needs of current and future customers; Operative Processes, such as collection, collection handling, transport, intermediate handling, delivery handling, goods delivery and documentation; and after-sales service processes, such as incident treatment, customer services, etc.	

Table 3. Perspectives and views of the objectives, actions plans and indicators.

Perspective	Focus	Views
Virtual enterprise integration	This perspective analyses the level of integration that is achieved by the different enterprises that make up the virtual enterprise.	Enterprise, technology and culture.
Customer	It focuses on analysis of the customers' profitability.	Customer's individual analysis and customers' group analysis (acquisition, retention, profitability).
Commercial	It analyses the customer relationship management.	Sales, sales department, market, charge/payment management.
Financial	This perspective focuses on translating the mission and strategies into key financial objectives.	Analytic running account, profit and loss account, fixed expenses, global follow-up, analysis by product and strip, costs, income and balance analysis.
Internal process	It considers the performance measures that are used in the business processes.	Goods transport and handling, goods flow analysis, vehicles fleet management, collection and delivery operating management, international relations and administration.
Learning and growth	It is focused on the bases of any possible future success.	Employees (satisfaction, productivity, retention), knowledge management and inter-personal relationship.
Quality	It represents the total quality view.	Customer's satisfaction, new products, processes and incidents.
Environmental impact	These indicators are focused on the transport business environmental impact.	Environment.

rities of each enterprise such as its culture, sizes, customer segment they work with, etc. Therefore each enterprise had to revise its mission, vision, strategy and strategic objectives; to identify its action plans; and to establish the cause and effect indicators, but always in line with those defined for the VE.

The indicators of each individual transport enterprise are the data that allow us to calculate the VE indicators. Thus, the system of indicators from each enterprise had to be similar and consistent with the ones designed for the VE. Therefore, the same structure, units, calculation procedures, etc. were used in order to make comparisons. Some of the criteria considered to group the indicators of the individual enterprises, were the geographical zone, the enterprise size, the type of transported goods, the type of customer they target at, the amount of business done, the strategic objectives to be achieved, the similar working ways, and the market share.

The final phase of the PMS development was its validation and deployment (phase 3). The validation considered the way of obtaining the information (methodology used to acquire it and information sources), its introduction in the system, the periodicity, and the users to whom it is directed. On the other hand, deployment was carried out progressively, first at some pilot enterprises, so as to be able to detect possible initial deficiencies and then, once it was validated and revised, at the rest of the enterprises.

Within the deployment phase, and in order to get the maximum benefit from the PMS, it was necessary to introduce benchmarking techniques in the individual enterprises and in the management of the VE. Thus, the enterprises would have some reference values to set forecasts or objectives for the indicators in order to compare whether the real enterprise data correspond to those initially planned. The viewpoints considered within benchmarking were:

- Internal: establishing comparisons among the individual transport enterprises at the department and process level.
- Competitive: analysing the ways principal competitors work.
- Out of the sector: identifying better work practice, taking as a reference all sorts of enterprises.

Reference enterprises, competitors' most outstanding activities, indicators to chose for comparison, benchmarking users and application areas were defined for each one of the benchmarking points of view.

Table 4. Relationship among objectives, action plans and indicators for the customer's satisfaction view of the quality perspective.

Objective	Action plans	Cause indicators	Effect indicators
To improve the quality of the service offered to the customer.	• To analyse and improve the process of transporting goods. • Development of a computer tool for the truck fleet organization.	• Compliance with service period, origin/destination. • Correct documentation of goods. • Correct transport of goods.	• Delivery dates not complied with. • Service average time. • Goods delivered with incidents. • Goods delivered without incidents. • Total goods awaiting delivery. • Delivery average time of the goods with incidents. • Economic sanctions.
To improve customer's satisfaction	• To expand the Computer System functionality to control the state of the orders. • Employees training in marketing techniques.	• Punctual and reliable information about the physical/geographical position of the goods. • Improvement of personnel's treatment of the customer (telephonist salesman, distributor, executives). • Good use of the information given by the customer, especially as regards to priority goods.	• Customer complaints. • Incidents by customer and expedition. • Number of incidents by expedition. • Number of customer queries about the state of the orders.

5.3. *Computer infrastructure*

As it has been said above a PMS for VE becomes operative, it needs a computer infrastructure that allows it to automatically integrate the information from the different enterprises that form it.

From a physical point of view, the developed computer infrastructure for CAVE Logística is supported by an extranet that links Central with each of the individual transport enterprises that make up the VE and with one another. This extranet is just the result of the connection of the intranet of each of the individual enterprises with Central, which then allows external access after self-identification. Its purpose is the creation of a high quality information exchange network by means of a fast, efficient and secure system. This solution was evaluated as being less costly and simpler than contracting the services of an added value network.

From a logical point of view, the computer infrastructure adopts a pyramidal structure (see figure 4). The bases of the pyramid are: (1) the structured data that are in the RDBMS that supports the enterprise ERP, in the RDBMS of the application of customer relationship management (CRM), and in the databases and spreadsheet that the executives have developed to cover their specific needs; (2) the non-structured data from e-mails and letters; and (3) the information of each individual enterprise concerning PMS (strategic objectives, action plans, etc.). This data is computerized in order to obtain a data warehouse, in which only the information that is important and significant for the PMS is stored.

The process that was followed to obtain the data warehouse, using OLE DB techniques, included: the identification of the data sources (structured and non-structured data and PMS data), the extraction and assessment of their quality (through validation techniques, cleaning, and tidying), the creation of the data warehouse structures, and the achievement of the connection process and data feedback between the databases.

With regard to the data warehouse, the PMS software allows the calculation of the indicators, carries out a multidimensional comparative analysis using the OLAP tools and assesses the level of fulfilment of the objectives. Thus, complex queries can be carried out in a fast and simple way even non-technical personnel. For example, the sales by customer can be analysed simultaneously, taking its geographical location area and type of goods to be transported into consideration.

The PMS software offers detailed graphic reports with all the cause and effect indicators that are

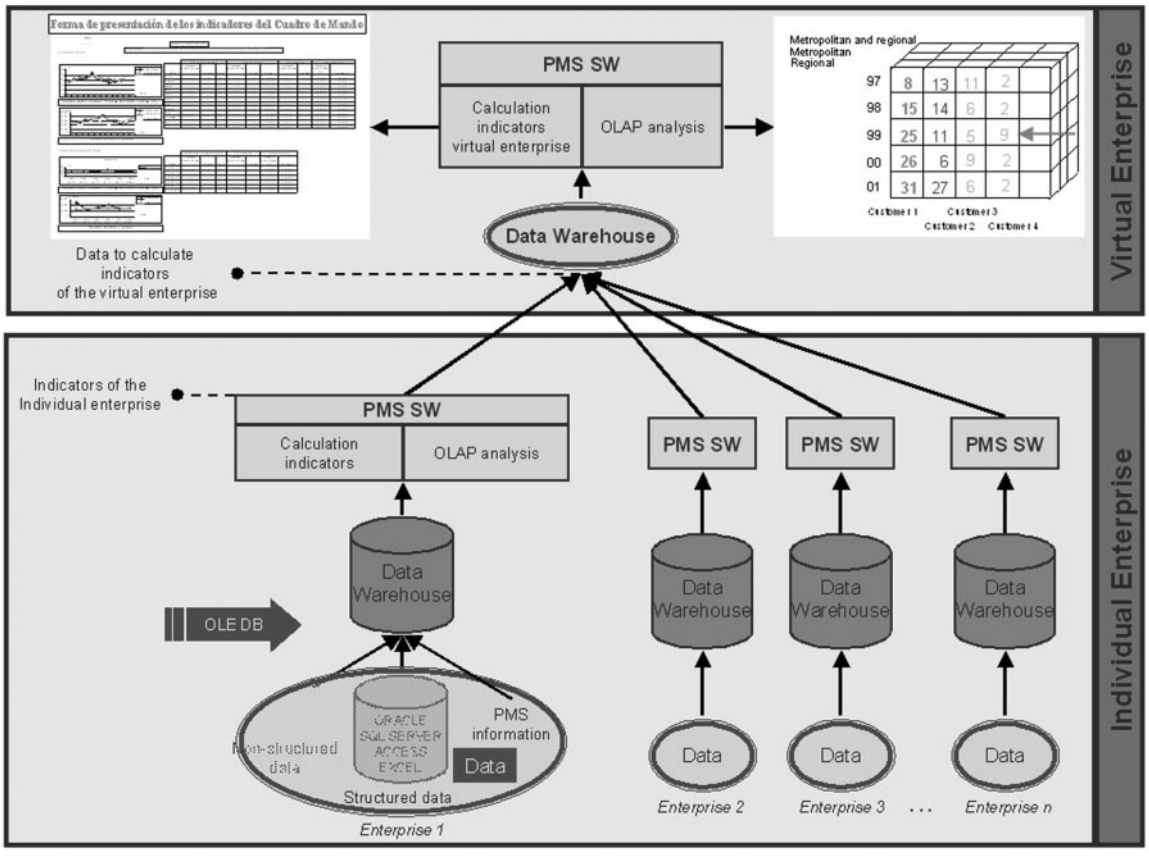


Figure 4. ????.

contained within the PMS and allows them to be grouped according to the perspectives, decisional levels and organizational areas that were previously defined. The application has been tested to:

- Supply information for each of the users.
- Show the level of improvement for each of the indicators as regards the goals set for the users.
- Calculate the trends followed by the indicators.
- Generate simplified but significant reports.
- Test the temporal accuracy of the information.

When the enterprises have calculated their indicators, the information is sent to Central through the extranet that links them. These indicators, together with the structured and non-structured data and the PMS information that Central has, are turned into the data that serve to calculate the virtual enterprise indicators with the Central PMS software, once they have been incorporated into the data warehouse of Central.

5.4. *Lessons learned*

The main difficulties in applying the methodology developed by the IRIS Group in the virtual enterprise, CAVE, arose during the implementation of the first and second phase. It is important to bear in mind that the virtual transport enterprise CAVE is made up of a set of transport enterprises each of which has its own size, structure and organization. Although their alliance is based on common goals, the way each enterprise is organized and how it aims to reach those goals is different. Consequently, in the first phase, it was difficult to reach an agreement about the posture to be adopted by all the members of CAVE because, although CAVE was set up with the clear objective of offering its customers the best service, it was quite difficult to turn the strategic objectives of the VE into what would become the action plans and indicators that would allow a control over whether or not those aims had been accomplished.

Once the indicators of the VE had been agreed on, the second difficulty come about when each of the enterprises involved had to carry out the second phase. In the enterprises that had already implemented a PMS there was some resistance to change, as it was necessary to swap the indicators that had been used up till then for others that allowed a certain degree of consistence with the new indicators that had been defined for the VE. In enterprises that did not use any kind of indicator, however, the company culture had to be changed so that its employees could recognize the value of using them and could work in the desired manner. After all the work that was carried out, the enterprises had a very positive appraisal of the effort that had been made, above all when the first results began to come in and they were able to evaluate the indicators obtained both on an individual level and for the VE. Implementing a computer infrastructure which, among other things, allowed the indicators to be submitted to an OLAP analysis was one of the points that contributed to the enterprises' satisfaction and to the fact that the results obtained were really of value to the VE. Moreover, this common infrastructure and the set of indicators that were defined for the virtual enterprise played an important role in its success, since in this way it became an entity in its own right and was able to control its working and the level of results. Thus, one of the main changes carried out in each of the individual enterprises that went to make up CAVE was a change in their company culture.

Another benefit that was obtained by implementing the PMS is that it improved the level of integration in the VTE, better decisions were made and their competitivity was increased. Thus, the following quantitative results were obtained: lead time reduction, 30%; cost reduction, 25%; productivity increase, 30%; human satisfaction, 20%; new customers, 80%; no quality cost reduction, 20%.

6. Conclusion

A PMS is a type of decision support system that provides a set of important indicators to assess the enterprise state. There are in the literature different methodologies to develop a PMS, but they are all focused on the problems of individual enterprises; so they do not take into consideration the peculiarities of the virtual enterprises, such as the assessment of the co-ordination mechanism among the enterprises, the efficiency of the inter-organizational processes or the relationships among the personnel from different enterprises.

This paper has introduced a proposal to develop a PMS for a virtual enterprise, together with a case study. The PMS resulting from the proposed analysis is not only considered as a way of obtaining a set of indicators, but also as a mechanism to improve the efficiency and competitiveness of the VE by adapting it to the market evolution. Thus, the application of the proposed methodology allows managers to establish a continuous improvement procedure that links the strategic objectives with the operating procedures of each of the individual enterprises.

To make it operational, a PMS for the virtual enterprise needs a suitable computer infrastructure that allows it to integrate and process, in an automatic way, the information from the different enterprises that make it up. Within this infrastructure, different technologies must be combined in order to: (1) extract the data from different sources and assess their quality; (2) create data warehouse structures; (3) carry out comparative multidimensional analysis; and (4) establish a process for the connection and feedback of data between the data warehouse of the different enterprises.

Acknowledgements

The VITI project was founded by CICYT DPI2003-02515 and Bancaja.

References

Burn, J. M. and Ash, C., 2000, *Managing Knowledge for Strategic Advantage in the Virtual Organization* (Edith Cowan University). (3)

Chalmeta, R. and Grangel, R., 2003, ARDIN extension for virtual enterprise integration. *Journal of Systems and Software*, **67,** 141–152.

Chaudhuri, S. and Dayal, U., 1997, An overview of data warehousing and OLAP technology. *SIGMOD Record*, **26**(1), 65–74.

Corbett, L. M. and Claridge, G. S., 2002, Key manufacturing capability elements and business performance. *International Journal of Production Research*, **40**(1), 109–131.

Dinter, B., Sapia, C., Blaschka, M. and Höfling, D. G., 1999, OLAP market and research: initiating the cooperation. *Journal of Computer Science and Information Management*, **2**(3). (4)

Gunasekaran, A., 1998, Agile manufacturing: enablers and an implementation framework. *International Journal of Production Research*, **36**(5), 1223–1247.

Inmon, W. H., 1996, *Building the Data Warehouse* (New York: John Wiley & Sons).

Jarke, M. and Vassiliou, Y., 1997, Data warehouse quality: a review of the DWQ project. *Proceedings 2nd Conference on Information Quality*, Cambridge, MA. (5)

Kaplan, R. S. and Norton, D. P., 2000, *Cuadro de mando integral (The Balanced Scorecard)* (Barcelona: Gestión).

OLAP Council, 1997, *OLAP and OLAP Server Definitions* (OLAP Council). (3)

TCIM	
Manuscript No.	100497
Author	
Editor	
Master	
Publisher	

International Journal of
Computer Integrated
Manufacturing
Typeset by Elite Typesetting for

Taylor & Francis
Taylor & Francis Group

ELITE TYPESETTING TECHNIQUES LTD
www.elitetypesetting.com

QUERIES: to be answered by AUTHOR

AUTHOR: The following queries have arisen during the editing of your manuscript. Please answer the queries by marking the requisite corrections at the appropriate positions in the text.

QUERY NO.	QUERY DETAILS	QUERY ANSWERED
1	Please supply captions for the four figures	
2	No electronic copy supplied for tables and figures	
3	Place of publication?	
4	Page range please?	
5	Dates for conference, any publication details?	