15th Triennial World Congress, Barcelona, Spain

INTEGRATED ENVIRONMENT TO MODEL AND SIMULATE THE EXTENDED ENTERPRISE

Arturo Molina, Veruzcka Medina

Centro de Sistemas Integrados de Manufactura (CSIM),
Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM),
Avenida E. Garza Sada 2501 Sur, C.P. 64849, Monterrey, NL, México

Abstract: The emerging of the new global economy has forced companies to adopt innovative manufacturing practices. In this context the concept of Extended Enterprise has emerged as a model which companies are pursuing in order to remain competitive in global markets. A research project named Extended Enterprise Demonstration Factory program is being carried out in order to create reference models, methodologies and tools for the implementation of the concept of Extended Enterprise in Mexican SMEs (Small and Medium Enterprises). From this project an integrated methodology for planning and implementation of best manufacturing practice has been developed. This methodology consists of five phases: 1) Evaluation of the enterprise in terms of performance indicators; 2) Modelling and Simulation of AS-IS core process; 3) Selection of best manufacturing practices for core process enhancement; 4) Modelling and simulation of TO-BE core process; 5) Evaluation of manufacturing practices implementation in terms of their impacts and benefits. *Copyright © 2002 IFAC*

Keywords: Extended Enterprise, Core Process, Modelling, Simulation, Performance Indicators, Manufacturing Practices.

1. INTRODUCTION

Manufacturing Enterprises, in order to remain competitive, must be able to adapt their business processes, and the associated resources and information systems, to ongoing change. The implementation of best manufacturing practices is a must for any company that wants to remain competitive in a global economy. However, decisions related to these manufacturing practices have to be made, for example: which best practice will have a major impact on the company productivity, how a process can be re-engineered to be more profitable, or how a practice will change the value added for employee. These issues are difficult to analyse and their impact in the business is difficult to assess.

The article proposes a methodology for the selection and evaluation of manufacturing practices for enterprise improvement based on modelling and simulation tools. The objective of this methodology is to guide decisions makers in the enterprise to have a more structured way of building an Integrated Extended Enterprise, by planning and integrating an adequate use of manufacturing practices.

2. LITERATURE REVIEW

Major research has been done related to model and simulate business processes in order to optimise and integrate enterprises, however, these has been isolated approaches, and it is still difficult to measure the total impact of decisions. Simulation modelling is applied to real world problems in order to get a clearer view of problems, this benefit is only achieved if the analyst succeeds in capturing real world relationships, however, no methodologies are used to capture these relationships. Simulation tools need for well-defined simulation model specifications, otherwise it results in many hours lost developing simulation models that the customers does not want, or cannot use (van Rensburg, et. al., 1995). Some efforts have been done regarding integrating methodologies for decision support systems. For instance those developed by Kengpol and O´Brien (2001) in the University of Nottingham in UK, which proposes the structure of a decision support tool for the selection of advanced technology to achieve rapid product development. Other effort is the GI-SIM (GRAI/IDEF-Simulation) modelling method (Al-Ahmari, et. al. 1999). This project emerged as a response of the necessity for model, analyse and design complex manufacturing systems, not only for representing the basic manufacturing operations, but also relevant management decisions and information systems. This modelling method is based upon the GRAI method to illustrate the main functions, decisions and activity centers. Relationships between activity centers are of three types: decisions, information and materials. The second step is construction of IDEF0 models for every activity in order to analyse different sub-activities, their inputs, outputs, controls and mechanisms. The third step involves translating IDEF0 models into simulation models using SIMAN to represent the dynamic behaviour of the system.

3. THE EXTENDED ENTERPRISE DEMONSTRATION FACTORY PROGRAM

The Extended Enterprise Demonstration Factory (EE-Factory) Program rises from the necessity of developing a framework for research, education and training on the concept of Extended Enterprise. In the every-day changing manufacturing environment, for an effective decision-making, real-time information from the enterprise, customers and suppliers is essential, additionally, shop floor control and integration is required for an adequate response to customers changing demand. The concept of Extended Enterprises aims to address all of these issues, however it is difficult for companies nowadays to understand this concept and realise how it could be implemented in their business. The EE - Factory program has been designed to demonstrate and transfer this concept to the companies and to educate and train engineers.

3.1 Scope of Research and Education.

The Extended Enterprise Demonstration Factory Program (EE-Factory) has the following objectives:

- Academic: achieve world-class education at undergraduate, master and PhD level in the field of Enterprise Integration Engineering.
- Industry: Improve the competitive position of the national industry. Reinforce industry/education links to improve capability of manufacturing workforce/education and to facilitate the application of R & D to national industry for manufacturing decision and planning tools, enterprise modelling and simulation, application of manufacturing information technology to support e-Business in Manufacturing.
- Applied Research: explore state of the art concepts related to Extended Enterprise, best manufacturing practices, information technologies, advanced manufacturing technologies and facilitate their transfer to the national industry.

EE - Factory program comprises the following working packages:

1. Create an Enterprise Modelling and Simulation Environment for decision-making regarding the implementation of manufacturing strategies, best practices, and performance indicators.
2. Design and develop an Extended Enterprise ERP (Enterprise Resource Planning) based demonstration facility. The demonstration facility will be a Surface Mounting Technology Assembly Site.
3. Integrate Manufacturing Execution Systems (MES) and Demonstration Factory for shop floor control.
4. Design educational/training activities based on the Extended Enterprise Demonstration Factory for the different academic programs to support Enterprise Integration Engineering Curricula.

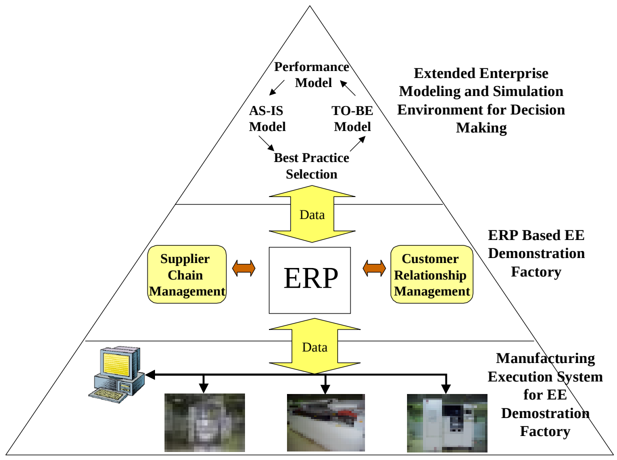

Fig. 1. Extended Enterprise Demonstration Factory

3.2 Infrastructure.

The Electronic Manufacturing Laboratory of CSIM-ITESM is used for developing the Extended Enterprise Demonstration Factory. The Electronic Manufacturing Laboratory was created in 1999 to promote and support research, training, technological development and innovation activities for the electronic board assembly industry in Mexico. Board Assembly consists on soldering, process by which pre-assembled electronic components are properly joined and fixed onto a designed board that integrated can appropriately carry out its intended functions. The original purpose of this laboratory is to use it as a learning environment for the many Electronic Manufacturing Enterprises that are starting in Mexico. The ERP system will be the central database from which information and data will be retrieved and feed for each stage development and implementation. At this stage of the project the ERP system being considered is SAP. Figure 1 illustrates what is intended in this program. The results reported in this paper are related to the working package 1 with the objective of design and develop an Integrated

Modelling and Simulation Environment for decision-making regarding the implementation of manufacturing strategies, best practices and performance indicators.

4. EXTENDED ENTERPRISE MODELLING AND SIMULATION ENVIRONMENT FOR DECISION MAKING

A major component of the EE - Factory is a decision support environment. This environment allows managers in the educational programs to experiment ideas to improve operational performance of the companies through the implementation of best manufacturing practices. The Extended Enterprise Modelling and Simulation Environment for Decision-Making is base in integrated methodology for planning and implementation of best manufacturing practice described in figure 2. In this environment the enterprise manager will have to:

1. Define a business performance model using the system dynamic software to analysis the situation of a company.
2. Model the core process models of the organisation under analysis to identify potential areas of improvement.
3. Select from the database of best manufacturing practices, those practice that could have impacts and benefits in the company. In order to implement best practices changes have to be made in the core process. However, these changes will have to be modelled and simulated in the ARIS and simulation models in order to foresee impacts before its real implementation.
4. Built scenarios TO-BE in order to measure feasibility and convenience of the Best Practices implementation, as well as behaviour and possible eventualities of the affected process.
5. Represent the expected results in the business performance model to evaluate the effectiveness of implementing the manufacturing practice.

4.1 Evaluation of enterprise

Nowadays, a higher emphasis is given on performance measures that are easy to use, directly related to the manufacturing strategy, that provide fast feedback to operators and managers and that foster improvement rather than just monitoring (Molina et al. 1999a). Different enterprise performance models have been developed to create different scenarios of the EE - Factory. These scenarios mainly consists on performance measures evaluation involving enterprise business, processes, and functions in terms of costs, productivity, quality, volume and time (ENAPS 1999):

- Business: All the indicators related with the business strategy and financial aspects. For instance, gross profit rate, value added for employee.
- Process: All the indicators related with practices of an enterprise, in most cases these are indicators that are intangible, because most of them are not associated with physical objects. For instance, inspection labour hours as % of total shop labour hours.
- Function: All the indicators that are related with tangible factors of the enterprise. For instance, scrap rate due to errors.

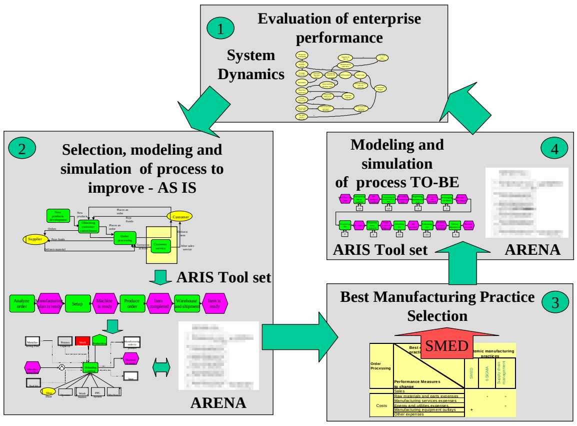

Fig. 2. Extended Enterprise Modelling and Simulation Environment for Decision Making

This analysis is supported using the concept of dynamic systems. System dynamics is the process of understanding and modelling the basic structure of a system, e.g., a manufacturing facility, through repeated computer simulation. A commercial software named SIMetrics AdvisorTM (Nexus, 1997) is used to create different scenarios for the EE - Factory. The software is capable of estimating the impacts of changes in manufacturing performance on company financials using a system dynamics model of manufacturing operations. This software use customised user input to generate estimated parameters, ensuring by this way, that results of changes in manufacturing performance will reflect what is actually occurring in the plant. From the results of this stage, critical performance measures and opportunity areas are identified. Therefore different strategies for process improvement can be defined.

4.2 Modelling and Simulation of AS-IS core process.

The development of core processes models in an enterprise requires the analysis of several strategic and operational criteria, for instance: strategy (Product Innovation, Operational Excellence, Mass Customization), enterprise typology (ETO, MTO, ATO, MTS), performance measures related to range of products, processes, sales, costs and/or production volumes. In order to ensure the adequate integration and complete business process visualization of an Extended Enterprise, reference models will be used. The reference model used in this activity, it is based on the Extended Enterprise concept (Vernadat, 1996; Gott 1996; Browne, et. al. 1998, Molina et al. 1999b) and ENAPS Reference Models (ENAPS, 1999). It comprises 8 business processes to describe a generic structure of an ideal intra and inter integrated-extended enterprise. Following there is a brief description of the business processes comprised in the Integrated Extended Enterprise Reference Model:

- Co-Engineering. Encompass all activities related to suppliers capabilities management regarding product design and engineering
- Customer Driven Design. Includes all activities concerned to product design and engineering based on customer specifications.
- Supplier Relationship Management. Is the process related to supplier capability management, evaluation and monitoring.
- Customer Relationship Management. It is focused to compile, analyse and share among enterprise stakeholders all information regarding customer needs and expectations
- New Product Development. Includes all activities for creating new products and/or services and related manufacturing and logistic processes.
- Obtaining Customer Commitment. It is the process, which brings the products or services to the customers. The process starts with market analysis and identifying the needs of the clients. It ends with the confirmation of an order.
- Order Fulfilment. Encompass all activities concerned to process orders coming from customer. It starts with the order release from sales departments and ends with the product or services delivery.
- Customer Service. It is focused to maintaining customer satisfaction after the point of purchase. It deals with all activities from the delivery of a product or service to when it is no longer in use (end of life).

This general reference model is particularised to the enterprise and its core process is chosen for modelling and simulation. In this case, the Electronic Manufacturing Demonstration Factory is considered as Assembly-To-Order (ATO), typically with low costs and product prices, high quality, high volume, and process flexibility. Therefore, the core processes to focus on could be Order Processing, Obtaining Customer Commitment, Customer Service and its related extended enterprise processes: Customer Relationship Management and Supplier Chain Management.

ARIS modelling Toolset is used to model at different levels of detail the core processes. The detail level is defined according to the specification level of the activities included. First level considers only general process functions; second level, considers specific activities of each function from the first level; and in the third level, a deeper specification of activities is achieved for the specific functions from the second level, furthermore materials and information flows can be included. In order to guarantee an effective global analysis, it is required the development of models covering the function and control views. These views are explained next (Scheer, 1998):

(a) Function Tree (Function View): Model the functions or activities in a hierarchic manner, pointing the main function in the upper area and associating it with specific activities to come to the basic and not sub-activities. (From first to third level of detail)

(b) Event-Driven Process Chain - eEPC/PCD (Control View): Models the interrelations among functions, events, organisation and data. Includes logic operators for decision making during the process, which gives it the name of control view. A detailed level of indicating material and information flows through process, can be reached, which would represent a third detailed level.
process

For the electronic manufacturing demonstration factory, models from first to third level of detail has been developed, in order to analyse all the core processes activities that affect critical performance measures behaviour. In this manner, the actual status of a business process can be known. Parallel to the third level modelling development, a simulation model of the core process “AS-IS” is built in order to have a more realistic picture of the process selected, as well as to understand its dynamic behaviour. Moreover, the model is necessary in order to assure that natural variability and dynamism of production floor is described, for example: potential characteristics of material, equipment inefficiencies, goods perishable time, or environmental conditions, conditions not reflected in business process models developed before. This simulation at least must represent the dynamic behaviour of the activities modelled in the third level of detail, the model has been developed using the software ARENA. Figure 3 represents the core process Order Fulfilment of the electronic manufacturing demonstration factory.

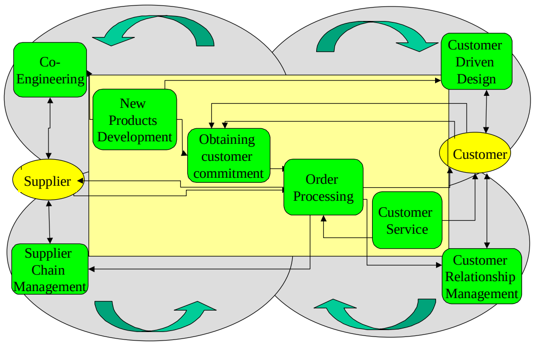

Fig. 3. Integrated Extended Enterprise Reference Model

4.3 Selection of best manufacturing practices for core process enhancement.

From several research and consulting projects developed at our research group, a Database of Best

Manufacturing Practices has been collected (Table 1). Results of this investigation are organised using a logic models structure. A Logic Model can be seen as a conceptual map that supports planning and that can be use it as a framework for evaluation. A logic model states short and long term impacts and what resources and methods are to be used (Coffman, 99; Alter, et al., 97). In the manufacturing practices database, the logic models should be organised into results, effects, impacts and benefits allowing evaluation and planning of changes (figure 4). In this stage, a best manufacturing practice database will be developed and organised accordingly to a logic model structure, which describes benefits expected, and performance measures of interest in order to evaluate its effectiveness and feasibility of implementation for optimising the critical performance measures. For the Electronic Manufacturing Pilot Plant, best practices that can be applied are: SMED, JIT or SPC.

Table 1 Example of manufacturing practices according to related process (Order Processing) and complexity

Function	Practices	Techniques	Basic Methods
Production	6 sigma	SPC	Control Chart
and		DOE	Experiments
Planning	JIT	TOC	Critical Operat
Control		Kanban	Inventory Level
	Kaizen	QC	Teams
		SMED	Poka-Yoke

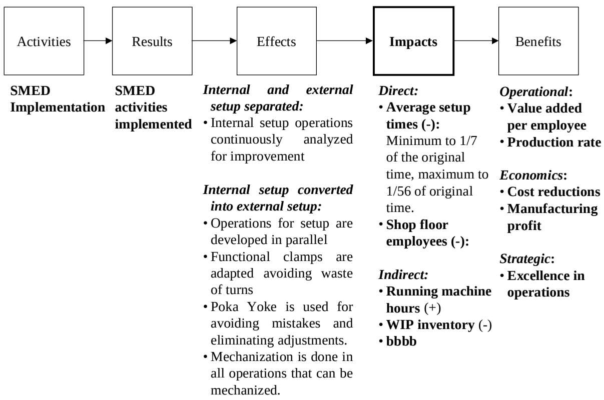

Fig. 4. Logic model of manufacturing practice: SMED (Single Minute Exchange of Dies)

4.4 Modelling and simulation of TO-BE core process.

From previous stages a real representation of the enterprise in terms of modelling and simulation can be developed. On the other hand a Manufacturing Practice could be selected, and its effects in organisation, technology, functions and resources were identified. However, feasibility of manufacturing practice implementation and implications of changes has not yet been demonstrated. Therefore, the AS-IS process model of the enterprise is used as a base for evaluating feasibility and implications, thus a TO-BE model has to be created and the best practice incorporated in order to evaluate its impact in the process.

Modelling of process TO-BE. Third level modelling of the process is used in this methodology as a support for identification of the functions and activities where the Manufacturing Practice could have a major impact. Effects of the manufacturing practice selected are linked to activities related on the third level modelling, in this manner, people, data and functions involved can be monitored on ARIS. Moreover, specific costs of implementing changes can be identified when analysing at a more level of detail changes on activities. On the other hand, reengineering of the process at an activity level, can be developed as a result of applying manufacturing practice, as is shown in Figure 5.

Simulation of process TO-BE. On the original simulation model, direct input performance measures are modified according to the values of the manufacturing practice (% scrap, % Rework rate), this modification allows measuring indirect impacts (material costs, value added for employee). Furthermore, it is possible to foresee eventualities and consequences of these changes as a result of the dynamic relations among components of the shop floor. Direct performance measures modified by the manufacturing practice are introduced as inputs on the simulation model, therefore, changes in indirect performance measures can be measured from the simulation.

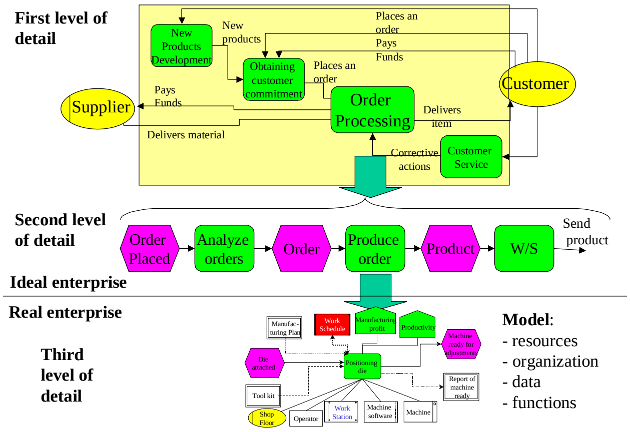

Fig. 5. Different levels for modelling a core process, example of the Order Fulfilment process

4.5 Evaluation of manufacturing practices implementation in terms of their impacts and benefits

Finally when all the performance measures (direct and indirect) are known, as well as costs involved at implementing the manufacturing practice, a final evaluation on SIMetrics is performed. This evaluation is developed, in order to measure "real" impact of changes in output performance measures monitored, as way to verify effectiveness of implementing manufacturing practice. Based on the results of the simulation the implementation can be carried out in a more confident environment that the desired results can be obtained. Modelling and simulation models can be updated regularly, in order to use them as decision tools for future manufacturing practices evaluation. Furthermore, this methodology can be constantly used for continuous improvement of the company.

5. Conclusions

A program with the objective of defining models, methodologies and tools to demonstrate the implications and benefits of the concept of Extended Enterprise in Mexican Industries has been presented. One of the major components in this program is a Modelling and Simulation Environment for Decision-Making. This environment is based in a methodology that consists of five phases: 1) Evaluation of the enterprise in terms of performance indicators in order to assess possible strategies for improvement, 2) Modelling and Simulation of AS-IS core process to identify areas of improvement; 3) Selection of best manufacturing practices for core process enhancement; 4) Modelling and simulation of TO-BE core process to demonstrate the use and application of best practices, 5) Evaluation of manufacturing practices implementation in terms of their impacts and benefits described in terms of performance indicators. The tools used to support this methodology are: SIMETRICS, Aris Tool Set and ARENA. These tools were selected because they were available and the researchers had previous experience of working with them. This environment has been used to train managers of Mexican companies in the concept of Extended Enterprise.

REFERENCES

Al-Ahmari, A.M.A.; Ridgway, K. (1999). *An integrated modelling method to support manufacturing systems analysis and design*, Computers in Industry, **Vol. 38**, 1999.

Alter, Catherine and Egan, Marcia (1997). *Logic Modelling: A Tool for Teaching Critical Thinking in Social Work Practice*, Journal of Social Work Education, **Vol. 33**, No. 1, Winter 1997.

Browne, Jim; Hunt, Ingrid; Zhang, Jiangang (1999). The Extended Enterprise; In *Handbook of Life Cycle Engineering: Concept, Methods and Toosl*, Molina A.; Kusiak, A.; Sanchez (Eds), Kluwer Academic Publishers; p. 3-29, 1999.

Caballero D., Molina A., Bauernhansl T., A (2000). Methodology to Evaluate Enterprises to become members of Virtual Industry Clusters, In *E-Business and Virtual Enterprises: Managing Business-to-Business Cooperation*, L.M. Camarinha-Matos, H. Afsarmanesh, Rabelo (Eds.), Kluwer Academic Publishers, 2000, pp. 443-454 .

Coffman L. (1999). Learning From Logic Models: An Example of a Family/School Partnership Program, *Harvard Family Research Project*, http://gseweb.harvard.edu/~hfrp/pubs/onlinepubs/logic.pdf; 1999.

ENAPS, ENAPS Model, http://www.enaps.com/public/public.htm, 1999

Gott, B. (1996). *Empowered Engineering for the Extended Enterprise – A management guide*, Cambashi Ltd., Cambridge, England, 1996.

Kengpol, A. and O´Brien C. (2001). The development of a decisión support tool for te selection of advanced technology to achieve rapid product development, *International Journal of Production Economics*, January, 2001.

Michael F., Jordan J. (2000). *Next Generation Manufacturing Methods and Practices*; National Association of Manufacturers, NGM Knowledge Systems, 2000.

Caballero D., Molina A., Bauernhansl T. (1999[a]). A Methodology to Evaluate Enterprises to become members of Virtual Industry Clusters, In *E-Business and Virtual Enterprises: Managing Business-to-Business Cooperation*, L.M. Camarinha-Matos, H. Afsarmanesh, Rabelo (Eds.), Kluwer Academic Publishers, 2000, pp. 443-454 .

Molina, A. , Kusiak, A. and Sanchez J.M. (1999). *Handbook of Life Cycle Engineering: Concept, Methods and Tools.* Kluwer Academic Publishers, 1999.

Nexus Associates, SIMetrics Advisor Guide, 1997. http://www.simetrics.com

Scheer, A-W. (1998). *ARIS – Business Process Frameworks*, New York: Springer-Verlag; 1998.

Scheer, A-W. (1999*). ARIS – Business Process Modelling*. New York: Springer-Verlag; 1999

Van Rensburg, A.; Zwemstra, N. (1995). *Implementing IDEF Techniques as Simulation Modelling Specifications*. Computers In Industry, **Vol. 29**, 1995.

Vernadat, F.B. (1996). *Enterprise Modelling and Integration*, Chapman & Hall, 1996