A proposal for a standard framework for simulating and modeling manufacturing systems

Claudia Battista[1] (A), Francesco Giordano (A),
Raffaele Iannone (B), Massimiliano M. Schiraldi (B)

(A) *Department of Enterprise Engineering, "Tor Vergata" University of Rome, Via del Politecnico, 00133 Rome, Italy*

(B) *Department of Mechanical Engineering, University of Salerno, Ponte Don Melillo, 84084 Salerno, Italy*

Abstract: Process efficiency is definitively a critical factor for manufacturing enterprises and the literature review clearly shows how researchers and operations managers consider simulation as a useful tool to study and optimize production processes. Nevertheless, even the studies that celebrate the simulation as the best approach for analyzing, designing and improving manufacturing processes, highlight some important limits that prevent the diffusion of simulation tools outside universities and research centers boundaries. The literature review suggested to concentrate on the design of a new modeling framework for simulating manufacturing processes that implements a structure and a working logic much closer to real production systems. This paper presents some key elements for developing a standard framework for simulating and modeling manufacturing systems, showing how a different modeling approach can allow to reproduce the actual dynamics of a generic production process, natively replicating both information flow and physical material flow. Snapshot of a simulation tool, still in development, are presented as well.

Keywords: simulation, modeling, manufacturing systems

1. Introduction and literature review

Process efficiency is becoming definitively a critical factor for manufacturing enterprises in order to reduce operational costs and to optimize time to market. The literature review clearly shows how researchers and operations managers consider simulation as a useful tool to study and optimize production processes (Hlupic, 1999). It allows analyzing dynamic and stochastic behavior of manufacturing system predicting its operational performance and pointing out its critical factors (Smith, 2003; Law, 1991). The growing need to use simulation in industries as a decision support tool has resulted in stimulating software market in issuing lots of simulation languages and simulators.

Nevertheless, even the studies that celebrate simulation as the best approach for analyzing, designing and improving manufacturing processes, highlight some important limits that prevent the diffusion of simulation tools outside universities and research centers boundaries (Rogers, 1993, 2002). Lack of commercial software that includes all the strategic features to build and analyze a complex manufacturing plant in a user-friendly way is reported too.

At present, simulation softwares available on the market can be usually qualified as a development environment in which experienced users can model any type of process using formal meta-languages or defining relationships among standard components (resources, entities, activities, etc.) and then evaluating the whole system behavior through the application of statistical functions. Hence, the user must typically possess a very good knowledge and skills both in modeling and in simulation.

Some authors see in these strict requirements one of the main limit of simulation tools (Davis, 1994): in simulation software, and generally in process analysis environment, "ease of use" becomes critical when the user may not rely on a strong background in operations research or statistics – this is the traditional condition of nearly every analyst in industrial companies. Verma et al. (2009) distinguish two different types of simulation tools: softwares for educational purpose and packages for industry. The most important reasons are the differences in users' experience: it is clearly impossible to develop a unique tool directed both to expert modelers and first time users (Pidd, 1989).

Among several other elements, ease of use of software is linked to the number and the different kinds of "objects" available for model design; being real manufacturing environment particularly complex, a long time is needed to develop the relative model.

This is one of the main simulation's drawbacks; several authors (see Bonder and Mc Ginnis, 2002) propose to start formalizing simulation modeling in order to support the inexperienced users to study their complex systems. The lack of simulation frameworks suitable to easily model manufacturing system – and to study them both from the technical and economical point of view – is recognized as one of the primary drawbacks of the commercial tools: "none of the existing tools are directly

[1] Corresponding author: Claudia Battista, claudia.battista@uniroma2.it, tel./fax +39.06.7259.7164

applicable for building a simulation model at the enterprise level" (Mujtabi, 1994).

Moreover in their publication on object-oriented manufacturing simulations, Narayanan et al. (1998) indicate the need of a standard reference framework to model production and logistics processes as a success factor for spreading simulation software in manufacturing industry.

Literature review suggested concentrating on the design of a new modeling framework for simulating manufacturing processes in order to support industrial users in production planning, control and validation. Thus in this paper we propose a standard framework to model all the different production and storage policies, natively embedded in a simulation tool called OPUS (Optimizing Production [processes] Using Simulation). Thus, our goal is to design a simulation architecture that implements a structure and a working logic much closer to real production systems; which can support industrial users not only to evaluate business process re-engineering plans – the typical use of commercial simulation tools – but also as day-by-day activities such as master production scheduling, capacity planning, job assignment, etc. Moreover, communicating both with ERP and SCADA systems, the tool may quickly and reliably obtain the needed information on the processes states.

The remainder of this paper is organized as follows: section 2 analyzes the key features of softwares commonly used for industrial purposes. In section 3 we present the modeling framework on which the kernel of the simulation tool is based. Finally, section 4 concludes with future research directions.

2. Key features of a tool for simulating and modeling manufacturing systems

Besides functionality, reliability, efficiency, maintainability, portability, concerning the scope of this paper one of the most important aspect in evaluating software quality is usability (Marghescu, 2009), intended as "the capability of the software product to be understood, learned, used and attractive to the user, when used under specified conditions" (ISO/IEC 9126-1:2000 Software engineering – Product quality or see even ISO 25000:2005).

In order to design a high-usability manufacturing systems simulation tool is surely needed to preliminary identify which are the most appreciated features in the addressed domain (Shishir Bhat, 2008). A certain number of features has been identified by Hlupic et al. (1999) in a paper on manufacturing simulation software selection and evaluation; some others originates from the proposal of Brandolese et al. (1991) for a framework for the description of production processes. The combination of these two different visions on simulation software (respectively information technology versus operations management point of view) had led to the definition of three features typologies for a manufacturing systems simulation tool:

- general features, i.e. characteristics of the software layer;
- model features, i.e. characteristics of the modeling language;
- data analysis features, i.e. potentialities in processing simulation results and aiding the user in reaching its ultimate objective.

General Features
Manufacturing domain terminology and symbol notation
Capability to interface ERP/SCADA/MES/SFC systems
Ease in manual data input from the users
Model features
High number of types of production process that can be modeled
Capability to update master scheduling, resource and inventories status from the information systems
Capability to build the model in accordance to the physical layout of the plant and to keep automatically into account distances among the resources
Capability to easily model various criteria for inventory control and material management logics
Capability to easily model discreet/continuous transportation systems
Capability to adopt stochastic distributions for modeling time and production yields variables
Capability to easily model failures occurrence and repair/maintenance intervention
Capability to easily model resource set-ups
Capability to support cost measurement & management criteria
Data analysis features
Capability to manage experimental plans and scenario analysis
Capability to perform statistical analysis on results
Capability to report technical and economical key performance indicators
Capability to support the implementation of production process optimization procedures

Table 1: Key features for manufacturing simulation software

In order to develop a simulation tool suitable for manufacturing industry, on top of the adoption of the typical terminology and data structures used in this specific domain, the model features surely represent the key attributes: for this reason, a great importance should

[1] Corresponding author: Claudia Battista, claudia.battista@uniroma2.it, tel./fax +39.06.7259.7164

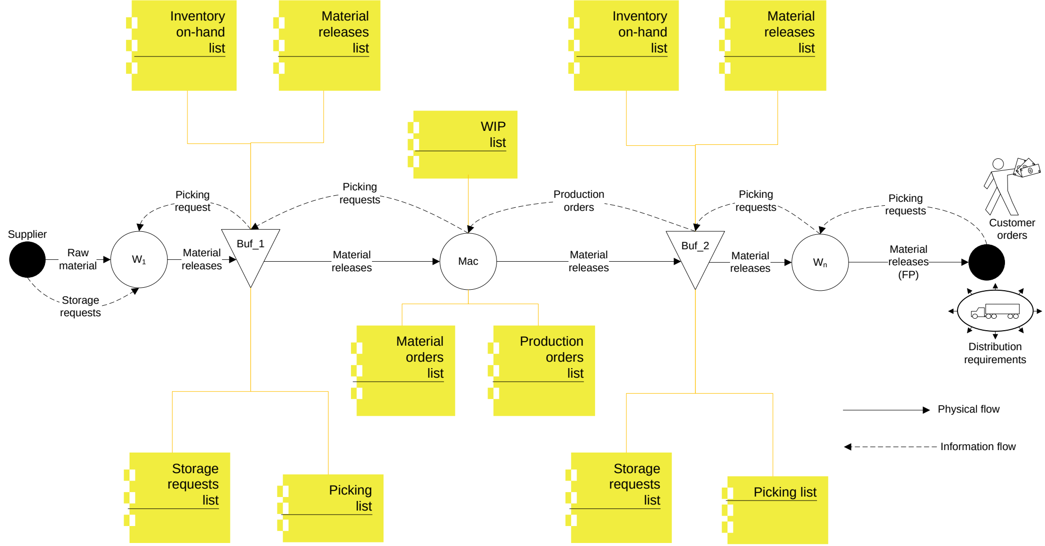

Figure 1: information and physical flows in an OPUS model

be given to the modeling framework which supports the logics embedded in the software kernel.

Basic archetypes from production processes should be embedded in the modeling framework. This would allow representing real manufacturing contexts in a simple way, natively. In example, in almost all the commercial softwares it is not so easy to model even the most commonly used logics for inventory control in a interoperations stock buffer: re-order level or re-order cycle criteria must be usually replicated through the use of several function blocks or, directly, written in the integrated programming language in a sort of "advanced mode" user interface. In both case a long time and a great effort is required. Similar problems are usually found in modeling resource failures and relative maintenance intervention planning, different set-ups in a single machine for different path-items, bills of material management, master production scheduling, material requirement planning, which are all common issues in any traditional manufacturing plant. Experienced users may even be able to replicate the dynamics of all these concepts with series of logic operators, but the resulting model gets very far from what is the real system.

Lastly, industrial users appreciate the possibility to read the classical manufacturing domain KPI in the simulations reports, i.e. overall equipment efficiency, scenarios generation and comparison, etc. Other important features are related to the opportunity to interface the simulation tool "upstream" (with the information systems which may automatically update master scheduling, resource and inventories status) and "downstream" (with optimization or statistical tools which are fed with the simulator results, i.e. bottleneck analysis, analysis of variance, etc.). Statistical confidence indicators should be not underestimated also.

3. A proposal for a standard framework for simulating and modeling manufacturing systems

In this section we present the modeling framework on which the kernel of our simulation tool is based. We stress the fact that it is designed in order to develop a simulation tool dedicated to manufacturing industrial companies. According to what has been outlined in the previous paragraph, the proposed modeling framework is founded on four main pillars:

- usage of data input forms analogous or compatible with the typical data structures of this specific domain, i.e. BOM structure, MPS, shifts calendars, process chart, etc.;
- native support to modeling basic production processes archetypes, i.e. set-up, machine failure, etc.
- native support to modeling all the different production and inventory management policies, i.e. ROL, MRP, JIT, etc.;
- clear distinction between physical and information layer.

Thus, unlike existing simulation tool, it is not required any abstraction effort in order to build a virtual representation of the real system: modeling of logic relations between system entities or process constraints is not required because the conceptual model is embedded into the simulation kernel. In example, in all the commercial simulation tools, the user is required to link the resources in order to depict the path that will be followed by the items to be processed; on the contrary, these paths should not be built dragging and dropping an "arrow" on the workspace, since it is clear that the processing sequence information are already stated in each item path in the process charts, which are typical ERP data forms. In other words, if the proper data structures are uploaded in the simulation tool, the user should not be required to do anything but representing eventual unusual information related to the plant layout.

Thus, material flows are correctly originated by Master Production Scheduling or buffer replenishment requests and not by any kind of virtual "entities generation nodes", which are typically present in commercial simulation

[1] Corresponding author: Claudia Battista, claudia.battista@uniroma2.it, tel./fax +39.06.7259.7164

softwares. Given a P/N code to be delivered in a certain day and quantity, depending on both components structure (BOM) and on resources involved in production process (process chart), "Material requests" and "Production requests" flows upstream along the production line. In this way, the exact manufacturing system dynamic is replicated (Figure 1).

The modeling framework is simply based on two main objects: machine and buffer. Each of them manages specific lists that guarantee the coherence of the physical and information flows progress. Note that these two objects are modeling structures either as java-objects in the software programming code. The various functions (i.e., a machine may send a material picking request to an upstream buffer o may send a confirmation for a material release to the downstream buffer) have been directly and straightforwardly translated into the java-methods of the related objects, in order to obtain a complete compliance among the represented model and the embedded working logic.

Additionally Opus simulation architecture is designed in order to communicate both with ERP and SCADA system: this allows obtaining the information needed on the processes status easily, quickly updating the input for the simulation model. Indeed, without a link among the simulator and the company's information and control systems, modeling time gets much longer due to the fact that the user must re-create the time-zero condition of the simulation model inputting all the parameters of the production processes. On the contrary, the capability to interface ERP/SCADA/MES/SFC systems allows the use of the simulation tool as a real decision support system for production planning, control and validation: at any time it is possible to perform a what-if analysis verifying the effect of each possible alternative (i.e. planning a Saturday morning shift, expediting or preempting a production phase, fixing some replenishment orders in the production plan, etc.) on product cost and production efficiency.

For these reasons, Opus simulation architecture has been conceived in four modules (Figure 2):

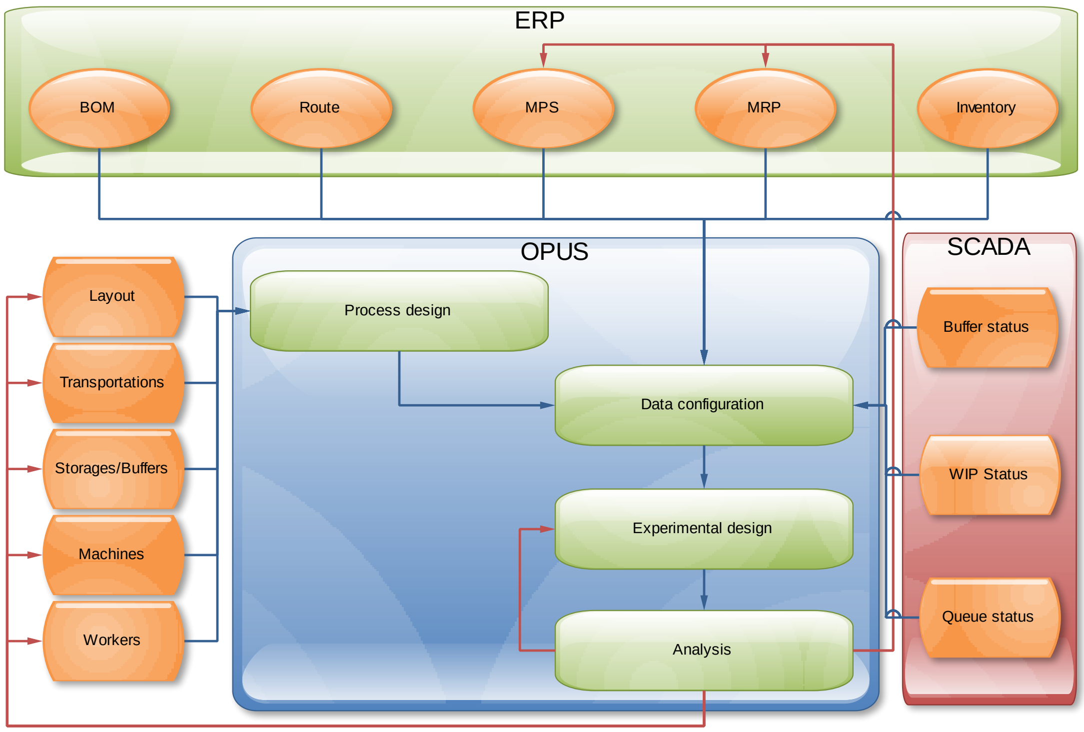

Figure 2: architecture of the OPUS simulation tool

- process designing module: here the user can represent the physical condition of the plant, i.e. plant layout, buffers and machine characteristics, transportation systems location or paths, areas in which the operators can move, etc.
- data acquisition module: here the user is requested to link the tool input form with the relative data set from the information system or, as an alternative, provide the input data in the same structure it is used in the ERP, i.e. BOM structure, MPS, process chart per each finite product, P/N codes and storage locations, etc.
- scenario management module: this module is conceived to support the user in designing the parameters of what-if analysis, in order to identify the influence of his decision on the

[1] Corresponding author: Claudia Battista, claudia.battista@uniroma2.it, tel./fax +39.06.7259.7164

performance indicators of the production process;

- simulations results analysis module: this module implements the data analysis and reporting functions of the tool, highlighting possible cause-effect relations among the scenario leverages fixed by the user and the performance indicators chosen to be maximized and supporting the user in choosing the best solutions and process configuration.

The scenario management model is designed on the basis of a design-of-experiment (DOE) approach (Montgomery, 2001): chosen one performance indicator and the decision leverages - among the various technical parameters in the model – along with their relative interval of feasible values, the tool will proceed in generating full or fractional experimental plans (depending on the confidence threshold specified by the user or on the maximum run time) and, consequently, in running them in batch. An Analysis-of-Variance (ANOVA) procedure will then determine which factors have a greater effect on the performance indicators, computing also the relative p-value and Fisher's confidence values, which allows to hypothesize or to identify eventual cause-effect relations.

4. Conclusions

Simulation remains one of the most widely used tools to analyze manufacturing system. As a matter of fact, however, almost all commercial softwares are used by researchers and the spreading among industrial companies is very limited. In our opinion, this is related to the high complexity of creating simulation models of real scenarios; this, in turn, is due to the distance between the modeling framework and the logic on which are based the operations in a manufacturing plant.

In this paper we outlined some elements of a standard framework for simulating and modeling manufacturing systems, which constitutes the foundations of a research project – still in progress – for the design and the development of a new simulation tool. This tool has been conceived to support industrial analysts – although without any simulation expertise – in taking the better choices as far as production planning and control is concerned. With this extent, it is of a critical importance to natively embed production logics and basic components in the simulation kernel (i.e. set-up events, machine failure events, MRP, JIT, ROL logics, etc.) and to interface ERP and SCADA system in order to provide real-time updating of the simulation parameters. On top of the completion of the tool in development, future research direction is certainly the formalization of the modeling framework with the aim of proposing a standard of representation and functioning of manufacturing production processes.

5. References

Bertoa, M. F., Troya, J. M., & Vallecillo, A. (2006). Measuring the usability of software components. *The Journal of Systems and Software*, 427-439.

Bodner, A. a. (2002). A structured approach to simulation modeling of manufacturing systems. *Proceedings of the 2002 Industrial Engineering Research Conference*. Georgia.

Brandolese, A., Pozzetti, A., & Sianesi, A. (1991). *Gestione della produzione industriale*. Milano, Italy: Hoepli.

Davis, L. a. (1994). Evaluating and selecting simulation software using the analytic hierarchy process. *Integrated Manufacturing Systems*.

Hlupic, V. a. (1999). Guidelines for selection of manufacturing simulation software. *IIE Transactions*, 21-29.

Hlupic, V., Irani, Z., & Paul, R. J. (1999). Evaluation Framework for Simulation Software. *International Journal of Advanced Manufacturing Technology*, 366-382.

Law, A. a. (1991). *Simulation modeling and analysis*. Singapore: McGraw-Hill.

Marghescu, D. (2009). Usability Evaluation of Information Systems: A Review of Five International Standards. *Information System Development* (p. 131-143). Galway, Ireland: Springer.

Montgomery, D. C. (2001). *Designs and Analysis of Experiments*. New York: John Wiley and sons.

Mujtabi, M. (1994). Simulation of Modelling of Manufacturing Enterprise with Complex Material, Information and Control Flows. *International journal of Computer Integrated Manufacturing*, 29-46.

Narayanan, S. e. (1998). Research in object-oriented manufacturing simulations: an assessment of the state of the art. *IIE Transactions*.

Pidd, M. (1989). Choosing discrete simulation software. *OR Insight*.

Rogers, P. (1993). Simulation for real time decision making in manufacturing systems. *Proceedings of the 25th conference on winter simulation*, (p. 866-874). Los Angeles, California, United States.

Rogers, P. (2002). Simulation of manufacturing operations: optimum-seeking simulation in the design and control of manufacturing systems experience with optquest for arena. *Proceedings of the 34th conference on Winter simulation: exploring new frontiers*, (p. 1142-1150). San Diego, California.

Shishir Bhat, B. N. (2008). Usability factors to be considered in a simulation tool while designing production system. *International Journal on Interactive Design and Manufacturing*, 225-232.

Smith, J. (2003). Survey of the use of simulation for manufacturing system design and operation. *Journal of manufacturing systems*, 157-171.

Verma, R. a. (2009). A critical evaluation and comparison of four manufacturing simulation softwares. *Journal of science*, 104-120.

[1] Corresponding author: Claudia Battista, claudia.battista@uniroma2.it, tel./fax +39.06.7259.7164