# SIMULATION SYSTEM FOR THE CONTROL OF MANUFACTURING LINES

J. Beaudoin
G. Feldmann
P. Massotte
Advanced Techniques Group Dept 1510
European Manufacturing Expert System Center
IBM France, Montpellier Plant

## Abstract

LMA (Line Manager Advisor) is a hybrid application to perform process control and scheduling in a manufacturing system. It combines both procedural and declarative approaches. The simulation model embedded in LMA enables to study the behavior of the target system and to determine the different critical parameters. It is used for the design of the target system as well as for the evaluation of the decision actions. This paper describes the concepts and the features used in the simulation model and how they have been implemented.

## 1. Introduction

The present evolution of the manufacturing lines and production systems already well visible in some highly competitive industries is oriented toward flexibility (market change, customer demand variations, etc.). This means that the manufacturing operations are business driven. Furthermore, manufacturing line logistics is becoming more and more complex in order to meet, as closely as possible, the variation of demands involving several products, and to follow multiple processes which are activated on a single manufacturing line. The transportation systems between tools, shop floors or departments must also be totally flexible (2). For instance, such multi-products lines are appearing in different industries such as car building, crude oil refining, and computer building where the flexibility is expressed in terms of product variation. In addition, the manufacturer may be confronted by huge volume variations. For example if the demand for a given product explodes, the line should be working 24 hours a day, 7 days a week for that product, without additional resources. In any case, this means either that all equipments must have a very high reliability, and that a back-up must be quickly and easily available, or that the manufacturing line should be reorganized. Consequently, the manufacturing line must be "self adaptive" to the external environment.

Due to the time constraints and environment complexity, there is no room for a time consuming evaluation of a new manufacturing line configuration or new policy. Also a simple formula cannot be used mainly in complex environment.

This demonstrates that there is a need for the manufacturer, to have a versatile tool, in order to simulate, possibly on a real time basis, every new configuration of its flexible production lines: he needs to simulate the production line every time he is making a significant change. For instance the manufacturer needs to know if its solution is viable in following cases:

- Addition, suppression or modification of the existing resources either from an equipment or human view point.
- Production commitment to the customer, from a quantity and cost stand point.
- Ability to deliver a new or specific product on time.

## 2. Decision Support System Concept

In order to achieve the above objectives, a project called LMA (Line Manager Advisor) has been designed for improving the process control and scheduling of a manufacturing line. Briefly, LMA can be described as follows in Figure 1. See also references (5 and 6) for more details.

As seen in Figure 1, LMA contains three main phases to describe and study a manufacturing line. These three phases take place for:

- The description of a manufacturing line in terms of objects and the definition of appropriate tools for establishment of models and their simulation. (16, 14)
- The determination of an optimum production line profile (11, 2) matching the current profile of a simulated line.
- The modification of the manufacturing line (structure or behavior) function of predefined constraints (9).

The simulation model is used to study the design or the modification of a new system or project, but also to predict future events of the real system. A simulation model is used in conjunction with diagnosis and control models to analyze the model and determine decision actions.

In addition, modeling of a complex real system involves a great amount of manpower and knowledge. Considerable time is spent in system investigation, data collection, model design, analysis and programming. These tasks must incorporate the knowledge of an expert in each area and generally it is wasted with the completion of a simulation project. The aim of the simulator is to provide a flexible and dynamic environment to the decision maker but also provide the means to store the knowledge base and the results of previous modelling sessions, to benefit future sessions but also to save time and reduces efforts and duplication of resources. The contribution of AI techniques is then crucial. (1, 3, 8) They will be used in an integrated environment to:

- Provide facts on entities.
- Provide facts on results.
- Assist in algorithm selection.
- Assist in statistical analysis.
- Assist in model selection and creation.
- Assist the user in decision making.
- Explain the rationale behind a certain decisions.
- Implement self learning capabilities based on associative memories/neural nets.

In the following, we will address only the modelling and simulation modules of LMA.

## 3. Architecture of the Simulation System

Before starting the simulation itself, it is necessary to determine the simulation environment (4, 15), that is to say the parameters which will control the simulation run:

- External context described by the input part servers to supply the line with the incoming parts.
- External environment described by the output product servers for the manufacturing deliveries in line with the orders.
- Definition of the rate (frequency and duration) of the equipment breakdowns, giving the parameters for the failure and repair distributions.
- Actual status of the line: work in process, queues, and stocks.

For the later item, we can choose one of the following alternatives:

- First, it should be useful to take into account the production line history. So, we can start the simulation run from a loaded line and observe during a given time its evolution deduced from the environment.
- Otherwise, we can start the run from an empty line state and observe towards which new stable state the simulation ends up, thus giving visibility to eventual line bottle necks.

We now introduce the various parameters used to control the simulation. In the same way, we can go deeper in details and see the capability of the simulation model. We first remark that the simulation system was designed using object oriented concepts. The main interest in using an object oriented approach for the simulator is that the communication between the functional modules is quite easy and precise with the activation of methods. In addition, it gives more flexibility to collect and compute statistical data extracted in a predefined format from the simulation.

The manufacturing line model initialization is quite important because the end user wants to see how the production line will react under given conditions of production. Hence, some interactive tools to facilitate the determination and acquisition of those parameters have been developed:

1. A tool to define the work in process parameters. It allows the simulation to be started with an empty or loaded line.
2. A tool to select parts from among the existing input queues of the operation nodes.
3. A tool to generate potential breakdowns on the operation nodes.
4. A tool to define the type of server.

## 4. Simulation Principles

Based on the work we have done the two past years (13, 5, 6), we used an object oriented approach to develop our simulation system associated with knowledge based systems (12). Those new techniques give real advantages such as quick modelling of complex production lines and overall, their easy alteration during line monitoring phase (9). The idea is to make a hierarchical description of the production line (10). The basic object is the node (workcell for example). It is characterized by variables (workcell states, performances for example) and behavior (procedural attachment in this case). We have defined a family of nodes with inheritance characteristics attached to this approach. All the nodes are available in a library. Then we have defined the connections using the same principles. One connection being the link between the output of node "n" and the input point of node "n + 1". These connections are managed by rules that allow or block the part/lot transition from one node to an other. To have some connection activated, or to have some operation done on a work cell, sometimes requires the use of some additional resources: a transportation system for a connection, or a specific tool for an assembly robot, for example. To manage these situations, we have developed both a dynamic and a static resource allocation system, based on the same concepts. The parts/lots are moved from station to station with respect to local or global production rules, such as LIFO/FIFO or emergency, for example. We also introduced the notion of operation group. This notion enables us to consider a group of operations as a single node. This means that the simulation can be seen at a higher level: for example plant or department/area levels. The part of the program that gives life to the model, as defined above, is based on an event driven mechanism. It can be activated for a given number of elementary times, or for a given number of parts/lots to be manufactured.

# 5. Model Generation

Automatic model building is needed to implement dynamic modelling of a target system: this model building will be used each time we have to evaluate a decision action proposed either by other modules of LMA or generated by the decision maker. Then this part of LMA has to be integrated, flexible and efficient enough. This task includes the selection of features/objects, the initialization of the parameters/values and the routing inside the network of objects. This task will be made from the technical description and history existing for a given product and associated process. The user does not have to pay any attention to or spend time on this operation. It is integrated with the environment and is transparent to the user. It is done every time it is requested by any change or modification in the decision situation. The task of model building is based on information coming from:

- Product(s) specifications.
- Routing.
- Field bill of materials.
- Process descriptions.

Nevertheless it is highly knowledge intensive, and we use predefined knowledge to carry on these tasks:

- Combination of tools.
- Which elements are relevant to each process/product and how they have to be used ?
- How to simulate the behavior of some specific elements/cells ?

Such tasks require different forms of knowledge; therefore a unique representation like production rules cannot be used. We had to combine several techniques: some based on optimization algorithms, others related to KBS approach. In this way we were able to develop a tool flexible enough to represent dynamically the model of a target system.

# 6. Simulation System Outputs

### Numerical results

The simulation results are typically in the form of graphs displayed by the manufacturing line manager: he can request global information related to the WIP, the average TAT, etc. for the various products processed on its Manufacturing line. Some statistical values are also available relative to the parameters distribution (standard deviation, extreme values, etc.). The line manager can request local information such as the number of parts/lots in a queue or buffer, the workload of a specific workcell, etc. The program also gives data on the actual process time and resources consumption (when needed), and all the information needed by a pricing department. In case of any urgent part/lot to be produced, it is possible to evaluate the output date of that part/lot, and the impact of the priority policy on the rest of the production. For examples, see (6). Some results will be shown at the conference.

### Implementation of Results

Statistical data are collected within objects related to the operation nodes. They are used to compute the activity rate of the node, the length of the input queues and also the output throughput. Predefined methods were written to gather the statistical data in a given format and conditions so that only data variations are recorded along with the dates of variations. At the completion of the simulation we are also able to extract the distribution of the node outputs. Buffer or stock nodes result into different data which are the mean value, with its statistical distribution for both the buffer level and the time spent into the buffer. The computing module also delivers the standard deviations and the variance for each parameter.

### Simulation System Usage

In order to develop a fully integrated application, all the numerical results issued from the simulation are recorded in a standard history file, to enable their processing by the Diagnosis Module (not described here).

We have to insist thereby that LMA is devoted to define and to improve also the scheduling of a Manufacturing line. For that purpose, we need to associate, for a defined period of time, the processing date of a part/lot to a given workcell/equipment. Consequently, a module has been developed which produces a file associating the process date of each part/lot with the work cell visited. By this means, we have built a scheduling proposal for the next working period, corresponding to the evaluated time.

### Graphical Display

Even though it is not fully implemented yet, it is envisioned to perform a graphical display of the modelling line, to assist the user in understanding the model behavior as well as the simulation results. First a static display of the line representation will enable the user to check the adequacy of the model as compared to the real line. In addition, the possibility to display the statistical data over this line graphic representation, at a given rate during the simulation time, gives the user a dynamic view of the line parameter evolution.

## 7. Implementation

Since the purpose of LMA is to design and implement a decision support system for managing complex environments, real time and dynamic modelling have to be considered (7); this requires high speed computing facilities and an integrated computing environment. A prototype has been developed on a host system. The language initially used for knowledge representation was EMICAT.[1] The simulator itself was built in PROLOG. As EMICAT is an object oriented language based on PROLOG, we had a consistent environment. For several reasons, the discrete event simulation system required to be recoded. It is now being implemented in the "C" programming language without incurring the usual cost of developing an assembly language routine run time package. The simulator, integrated with the functional modules of LMA will be available on an Intelligent Work Station.

[1] EMICAT is a registered Trademark of Electronic Serge Dassault

## 8. Conclusion

The manufacturing line simulator described as above is based upon object oriented programming for modelling and event driven paradigms for simulation. It can be used in any modern manufacturing environment involving the CIM concepts. If the performance of such a simulator is comparable to other simulation model built with languages such as GPSS, RESQ, or SIMAN, a main interest of this new approach is the flexibility to enable a fast and dynamic generation and update of the model under study. As simulation is becoming a major factor in decision making, these modelling and simulation modules are integrated within the upper LMA application. This is done in association with a reasoning system able to analyze the simulation results and to determine the best decision actions in terms of product flow balancing and manufacturing line performances.

## References


1. Andersen M. An object oriented modelling environment. SCS Roma 1989
2. Biggs J A, Hall L M, Mixed model line balancing concept. IBM Technical Publication, TN45-4004, 1967
3. Bruck J, Sanz J, A study on neural networks. IBM Computer Science, RJ5403 (55354), 1986
4. Cavaille J B, Proth J M, SIPRODIS: Pratique de la simulation en production discontinue. Colection NOVOTIQUE. Edition EC2.
5. Chappaz E, Giambiasi N, Massotte P, PIAUL: a knowledge based system for process control and monitoring of a mfg line. SCS Nice 1988.
6. Chappaz E, Giambiasi N, Massotte P, Feldmann G, Antonsanti P, Simulator for control of manufacturing lines. SCS Roma 1989.
7. Fayex A M, Vanteenkiste G C, Simulation environments for process control and real time simulation. SCS Roma 1989.
8. Fogelman-Soulie F. Le Connexionisme, MARI 1987 Machines et reseaux intelligents COGNITIVA 1987.
9. Lewis W, Barash M M, Solberg J J, Computer Integrated Manufacturing system control: A data

flow approach, Journal of Manufacturing system, volume 6, Number 3.

10. Mc Gee B, Giambiasi N, et al. An adaptative and evolutive tool for describing a general hierarchical models based on frames and demons. Proc 22nd DAC Las Vegas, 1985.

11. Ohhata M, Line optimization by elimination of wastes. IBM Technical Report, TR81-0026, 1986

12. Ousslah C, Giambiasi N, Bath R, A framework for modelling and linking the structure of a system. IMAC'88, Paris, 1988

13. Stefik M, Bobrow D G, Object oriented programming: themes and variations. AI Magazine, 1984

14. Stendel H J, Simshop: A tool shop/cellular manufacturing simulator. Journal of Manufacturing systems. Vol 5, Number 3.

15. Annual Simulation Symposium. Edition S. TABAKA 1986.

16. Vaucher G, Views of modelling: Comparing the simulation and al approaches, P 3-7, Artificial Intelligence, Graphics and simulation. SCS publication, edited by Graham Birtwistle, 1985.

## Biographies

PIERRE MASSOTTE is manager of the Advanced Techniques Group within the IBM French Technical Services (manufacturing and labs). He participated in the development of the 3750 communication System at the IBM La Gaude SCD Lab during 1972. In 1977 and 1978, he worked in the IBM development Lab at Poughkeepsie. Since 1982 he has been the team leader, in French manufacturing, for modelling, simulation and AI. He is now responsible of the European KBS center of Competency in the Manufacturing area. He has an engineer degree in automation from the ENSEEIHT (Ecole Nationale Superieure Electronique, Electrotechnique, Informatique et Hydraulique de Toulouse). Furthermore he holds an engineers degree in Computer Science, a Management Business degree from IAE and a pre-doctorat diploma in Applied Mathematics from Montpellier University.

GUY FELDMANN is assistant to the Advanced Techniques Group manager within the IBM French Technical Services (manufacturing and labs). He has spent most of his career in the large system Engineering group, in the Montpellier Plant. In 1969 and 73, he worked in the IBM development Lab at Poughkeepsie. After a few years in the Product Assurance department as Manager of System Evaluation, he joined the Advanced Techniques Group in 1987, where he is in charge of modeling. He has an engineer degree in automation from the ENSEEIHT (Ecole Nationale Superieure Electronique, Electrotechnique, Informatique et Hydraulique de Toulouse).

JEAN BEAUDOIN joined the Advanced Techniques Group within the IBM French Technical Services (manufacturing and labs) in mid 1989. He spent ten years in the Product Assurance organization, as technical expert, then as manager for the tape drive evaluation. In 1981, he joined the Equipment department, and was responsible for managing the group that developed and installed on the Montpellier Manufacturing floor the first integrated robotics cell. In 1987, still in the Technical Equipments function, he was assigned to the French Robotics Center of Competence. He has an mechanical engineer degree from the ENSAM (Ecole Nationale Superieure des Arts et Metiers) and a Engineer-Doctor diploma in applied mechanics from the Paris University.

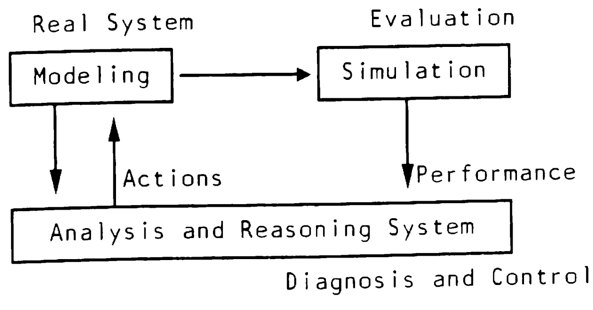


Figure 1. Figure 1. LMA Simplified Architecture