# A BUSINESS PROCESS MODELING APPROACH TO SUPPORT PRODUCTION SYSTEMS ANALYSIS AND SIMULATION

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## ABSTRACT

In this paper we propose a reference model conceived to simplify the development of production simulation paradigms as well as to support software houses in formalizing the main functions and properties of manufacturing systems simulation software. The proposed model results from a research project aiming to the design of a new manufacturing systems simulation tool, embedding the main production and logistics processes archetypes. Indeed, the designed tool natively entrenches several well-known production and inventory control policies on top of the greatest part of the typical processes and work methods in a manufacturing plant; the model is formally represented in Business Process Modelling Notation, which increases its clearness and the related benefits for industrial users.

The proposed reference model's architecture and working logic have been validated through a manufacturing company case study.

Keywords: manufacturing systems, reference model, simulation, software architecture

## 1. INTRODUCTION AND LITERATURE REVIEW

Simulation is considered as a useful tool to study and optimize production processes. Several authors agree on simulation potentialities in analysing dynamic and stochastic behaviour of manufacturing system, predicting its operational performance and pointing out its critical factors (Smith 2003; Hlupic 1999; Law 1991). However, a lack of a commercial software that merges the critical functions for modelling different manufacturing phases in a user-friendly way is reported in literature; despite simulation is always described as one of the best approach for improving system efficiency, these limits seem to prevent the diffusion of these tools in manufacturing enterprises (Rogers 1993, 2002).

At present, most of the simulation software available on the market implement a graphical modelbuilding approach - the so called "development environment" - where experienced users can model almost any type of process using basic function blocks; then, some user-defined statistical functions evaluate the whole system behaviour. Occasionally, formal metalanguages are used to describe the relationships among the components, such as resources, entities, etc. (Van Beek et al. 2008). The usage of multi-purpose simulation software requires, on top on advanced modelling and simulation knowledge and skills, great effort in translating the real industrial processes logic into the modelling scheme. However, strong competences in operations research or statistics have never been the traditional background of the analysts in industrial companies (Davis 1994). Several authors (Bodner and Mc Ginnis 2002; Narayanan et al. 1998; Mujtabi 1994) underline the need of a standard reference framework to model production and logistics processes as a success factor for wide spreading simulation software in manufacturing industry.

The definition of conceptual model and, specifically, the model requirements, the development methodology, the model representation and communication rules are important issues that need to be addressed at first (Robinson 2006). Thus, literature suggests to concentrate on a new reference model development for simulating systems that implements a structure and logic much closer to real production systems, and which may effectively support different kind of analysis of industrial processes.

Since the sixties, business process modelling has emerged as a practical solution for obtaining a better understanding of business processes with an approach similar to that used for representing physical control systems (Williams 1967). Nowadays, Object Group's Business Process Modelling Notation (BPMN) has become the de-facto business process modelling standard: BPMN is recognized to be an effective approach to model generic workflows in the companies (Chinosi and Trombetta 2011) either inside or outside production or supply chain management context, and to translate the result of the employees interviews on processes and procedures in a formal representation. It allows representing processes putting in evidence the differences among a present state ("as is") and an improved future state ("to be"), so it is particularly

useful to support the what-if analysis typical of simulation approaches. Keramati and al. (2011) have applied BPMN to model and simulate as-is and to-be situations of sale and distribution process for some Iranian companies. For simulation purposes, BPMN can be put at work in conjunction with XPDL (WfMC's XPDL), while WS-BPEL (OASIS's WS-BPEL) can be considered a possible choice for translating BPMN diagrams into directly executable code.

specific application, In this an Italian manufacturing company has been selected and BPMN has been used to represent its functions inside a reference model with the aim of defining a standard to represent resources interactions and their relationships in manufacturing systems. The reference model is useful to define how manufacturing systems resources relate to, one another, and how these can be modelled and which roles can be played by each one. The model has been used to support the design of a software simulation tool, called O.P.U.S. (the acronym stands for Optimizing Production Using Simulation), that allows to build and to simulate manufacturing process models in accordance to the main operations management theories, thus natively embedding various production and inventory control policies inherent the typical processes and operating methods in a manufacturing plant.

The choice of BPMN, which is strictly linked to business process but is directly translatable in XML format. has helped to simplify the implementation/coding of the simulation software, as well as to reach a further standardization level. The software could be easily written thanks to the fact that the java-objects could behave according to the modelled rules, e.g. a machine may send an item picking request to a stock buffer o may send a confirmation message for an item release to downstream resources. Thus the shop floor functions were directly translated from BPMN into the Java classes and methods of the related objects, in order to obtain a complete compliance among company business processes, real production/logistics procedures and tool simulation logic.

The remainder of this paper is organized as follows: section 2 presents the architecture framework. In section 3 the reference model working logic on which the kernel of simulation tool is based is described. In section 4 the company case study is reported, in order to highlight to software working procedure and to show the validation of the proposed reference model.

### 2. THE ARCHITECTURE FRAMEWORK

An architecture framework here indicates the general solutions for the design of models inside a given domain; in this case, production systems simulation software development. The reference model, build in accordance to the requirements of the architecture framework, includes standard design patterns to describe the operations. In this case, all the different functions, rules and procedures underneath the working logic in a manufacturing system are included.

The main problems in using multi-purpose simulation software to improve company processes reside in the contrast between the specificity of the application contexts and the generic high-level approach of these kind of tools. Significant approximations are always required to adapt the simulated model to the real context and this requires a lot of time on top of specific modelling competencies, which are seldom present in manufacturing companies. In order to solve this issue, the authors proposed an architecture framework dedicated to simulate only manufacturing production process. Despite the restriction of the application field, this approach results to be effective thanks to its clearness and the high intelligibility of the model for an operations expert rather than for an IT specialist. Thus, the pillars of the proposed architecture are:

- compliance between real-world objects and programming objects;
- separation of communication and production/logistics events;
- use of a discreet events simulation approach;
- existence of a single event handler.

Being dedicated to manufacturing systems, this approach helps in minimizing the use of artificial paradigms to model reality.

The dual-layer architecture, as well as the difference between production events and communication events, allows user to easily transfer to the model the most commonly used production algorithms and standards (e.g. MRP, lot sizing techniques, re-order level inventory management systems, etc.), relying on the fact that the interaction among the involved entities and resources will be automatically defined by the simulation engine.

The centralized event handler allows the simulation tool to build a single database, that can be queried to calculate the performance indicators and production cycles, namely the ones linked to the objects (machinery, resources, stocks) involved in the process. This solution drastically simplifies software development. The event handler manages all events thanks to the Future Event List (FEL), a sort of calendar that is progressively generated and scanned; this ensures the dynamic execution of the simulation.

A reference model based on these architecture pillars can easily:

- be used and understood from non-IT experts;
- embed operations logics and algorithms;
- embed performance indicators used in specific industries.

As a consequence, the simulation tools developed in accordance to this reference model will comply without difficulties to the main operations management theories:

- the only input comes from the typical manufacturing systems data structures: Bills Of

Materials, Master Production Schedules, Process Charts, etc.;

- basic production processes archetypes (e.g. setups, machine failures, etc.) are natively supported and no abstraction effort is required to the analysts;

- main production and inventory management policies (e.g. look-back and look-ahead material management policies, etc.) are natively supported;

- the distinction between information and physical layer is clear - considering that the data structure will provide all the required information to complete the physical flows (i.e. the items processing sequence information are already defined into the process charts).

## 3. THE REFERENCE MODEL

The architecture features presented in the previous section guarantees "ease of use", short development time and highly reliable simulation models: the user does not need to describe the basic functions logic because the conceptual archetypes of industrial production systems are embedded into the reference model.

The reference model structure replicates the exact manufacturing system dynamic: Master Production Scheduling or buffer replenishment requests initialize material flows. Depending on the Bill of Material (BOM) and process chart (item paths), "Picking request" and "Production order" flow upstream the production process in order to satisfy MPS orders or buffer replenishment requests. Indeed this structure evidences how the explicit definition of logic relationships among the objects of the model is not required, nor to define the process constraints.

The reference model basic elements are the machine object and the stock buffer object. Each of these objects has specific lists for managing the physical and information flows progress. Specifically, in the following table, a "communication function list" is reported both for the machine and the buffer objects; here, the coherence between the real manufacturing system dynamic and the proposed framework is put in evidence.

Table 1:Resources communication function list

Resource	List name List functions				
Buffer	Inventory on hand list	Controls items inventory stock: on its base, the simulation engine satisfies a picking request or sets out a replenishment request.			
	Picking list	Records picking requests from downstream resources. Pending picking request are fulfilled at the time of required materials are available.			
	Storage request list	Records storage requests from upstream resources. Pending storage request are satisfied when enough storage space becomes available in the storage destination.			
	Item release list	Records items ready to be transported to downstream resources. Depending			

		on production resources status – idle, busy, ecc – physical material flow is generated.
Machine	Production orders list	Records production orders requests from downstream resources.
	Items order list	Records items required to fulfil production orders.
	WIP list	Records working progress material on the specific machine.

The model works on an event based logic: both machine and buffer functions are triggered by an event occurrence. Ten main events have been identified to represent the typical manufacturing production process (Errore. L'origine riferimento non è stata trovata.).

Table 2: Events list

ID	Event	Description			
Ev1	Picking request	An item is requested to a buffer stock by some entity downstream (i.e. by another buffer, by a machine or by the Master Production Schedule in case of finite products)			
Ev2	Available item alert	An item, which has been previously requested, becomes available in a buffer or a in a machine			
Ev3	Supply order	An item is requested to a supplier outside the companies boundaries			
Ev4	Item release	An item is transferred downstream to a buffer stock			
Ev5	Production order	An item is requested to be produced by a machine in the process			
Ev6	Setup end	A setup is completed and the machine is ready to process another kind of item			
Ev7	Failure occurrence	A failure occurs in a machine and the machining phase is stopped			
Ev8	Reparation end	A machine is restored after the occurrence of a failure			
Ev9	Production end w/scrap	A machining phase is completed but the result is not compliant to quality requirements			
Ev10	Production end	A machining phase is completed and the result is compliant to quality requirements			

Thus the reference model is event-driven; each simulation cycle is performed in five phases which are:

- 1) advance the simulation time (clock);
  - 2) identify the events scheduled to the current time;
  - identify the elements to be activated (objects) along with the related functions (methods);
  - execute the selected functions and update the system values (variables);
  - 5) schedule the future events.

With reference to phase 3), activated resources manage information and physical flow through specific methods and this properly represents the simulation working logic. Each of the 10 previously presented events triggers the activation of certain objects, according to the following rules (Tab 3 -  $\bigoplus$  and  $\lor$  symbols stand for XOR and OR Boolean operators):

Table 3: Triggered resources by event

Event ID	Triggered resources
Ev1	Buffer
Ev2	(Buffer $\oplus$ Machine) $\lor$ Buffer
Ev3	No resource is triggered by Ev3
Ev4	Buffer ∨ Machine
Ev5	Buffer
Ev6 to Ev10	Machine

Then the FEL generation process is a consequence of each event. For instance, if at time  $t_{now}$  a *failure* occurrence event is recorded on the FEL for a certain machine, the simulation engine reads, on the input tables, the mean-time-to-repair (MTTR) data for the specific failure, on the specific machine. Then the engine returns a random number according to a prespecified distribution probability function with a prespecified standard deviation and MTTR as average. This number ( $\Delta t$ ) represents a single random occurrence of that time-to-repair. Thus, the simulation engine will write a *reparation end* event at time  $t_{now} + \Delta t$  on the FEL.

From FEL process generation BPMN diagram (see annex A, fig. 1) it should be clear that the proposed reference model embeds a look-back logic: Master Production Scheduling or buffer replenishment requests set off production process. Specifically, picking request event manages information flow propagation to the resources upstream in the production path: the buffer stock, once fulfilled the picking request on the base of the items inventory level, would propagate the replenishment requests. Thus, production order or picking request are triggered as a consequence of replenishment needs (this is the reason for the "look-back"). Buffer working logic, expression triggered by *picking request* event, is highlighted in the figure 2 that represent picking function.

In the next section a case study is presented to describe OPUS modeling process and to verify and validate the reference model proposed.

#### 4. THE CASE STUDY

The proposed approach here described was conceived as a result of a public funded research project carried on from 2007 to 2011 by the Italian universities of Rome "Tor Vergata" and of Salerno, related to the design and development of the prototype of a production/logistics processes simulation tool dedicated to manufacturing SMEs. Thus, the proposed architecture framework and the reference model have been validated on the case of an Italian manufacturing company that was selected to participate in the design and testing phases of the research project. Note that each resource method has been modelled with BPMN diagrams in order to facilitate communication both with the Italian manufacturing firm - that has been able to verify the reference model compliance to their real business and production processes – and with the software house that was encharged to the software OPUS coding, translating each resource function into java-method of the related objects.

The case study aims to show some of the features on which the OPUS architecture is based. In particular, the typical workflow of the development of a simulator starting from a real company is shown. In order to verify and validate information transfer mechanisms, UnisaGest management software (prototype of an ERP software developed by the Operations Management research group at the Department of Industrial Engineering, University of Salerno) was used which was connected to OPUS environment through a JDBC-ODBC connection that provides data transfer necessary for the operation of the simulator. The objective of the simulation is to verify the saturation of production resources for a given production plan for a period of 6 months. Therefore, for the validation of the model, media saturation data will be used for the machinery in manufacturing the product. The Execution Control is performed through a MES system continuously fed with data coming from the production environment. The company produces components for the automotive industry and it has several manufacturing plants in Italy.

For the construction of the physical level of the production environment to simulate, the OPUS architecture includes the ability to import the layout DWG and the placement of virtual resources on it. The metric environment makes it possible to drag the necessary objects, and once opportune scale adjustment operations are performed, to customize the objects so that they reproduce the machines actually present in the processing departments. The transport times of materials between resources will be proportional to their distance.



Figure 1: Layout Design

The data transfer will affect the components, the cycles and the Master Production Schedule for the production of the "brake pedal" (the subject of this

example). The Opus architecture makes it possible, as mentioned previously, to connect directly to the ERP system and collect data on:

- Bill of materials. This is done by selecting the finished products, possibly components and raw materials (in case you want to delete components of little interest to the analysis). The transfer allows you to automatically fill in the database of the simulator (Tab 4).

Table 4: "brake pedal" BO	М
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Lev	ltem	Description	UM	Q.ty	WS
1	64786693GR	ASS.PEDALE FRENO DX VER	PZ	1,00	w
.2	64786693GR1	ASS.PEDALE FRENO SALDATO	PZ	1,00	w
3	6478700	PEDALE FRENO GUIDA DX	PZ	1,00	w
4	64786709GR	PEDALE FRENO SCARICO MAT.	PZ	1,00	w
5	CUBC80X620	FE 430C F.TO 620X450X8	KG	5,592	Р
3	64787909	FORCELLA	PZ	1,00	w
4	64787909GR	FORCELLA GREZZA	PZ	1,00	w
3	64786009	TUBO DISTANZIALE	PZ	1,00	w
4	CIRC35X25	FE 360 CRUDO TRASF S/SAL	KG	0,15	Р
3	64786109	CIABATTA	PZ	1,00	w
4	FEEC40X56	NASTRO FE360D 56X4	KG	0,13	Р
3	64786209	PERNO MOLLA	PZ	1,00	w
.2	V420N00	VERNICE ARSONSIS	KG	0,025	Р
1	64899009	COPRIPEDALE	PZ	1,00	Р
1	SH655X800	SEPARATORI IN CARTA 655X800	PZ	0,0625	Р
1	SH450X1450	SEPARATORI IN CARTA 450X1450	PZ	0,0250	Р
1	BAG60	BUSTA PLURIBALL 270X470X60	PZ	1,00	Р
1	64786409	BOCCOLA 34	PZ	2,00	Р
1	13709003	SFERA-RB 11,906 TN 2481	PZ	1,00	Р
1	GR0990G1	GRASSO AL LITIA JOTA 2/S	GR	0,0005	Р

- Processing cycles. The operation takes place in an assisted manner making it possible to select the correspondences between the resources in cycles and those modelled in the previous phase. The figure 2 shows the processing cycle with integrated multi-level BOM of the 64786693GR1 component, as shown by UnisaGest.

Prodotto Finito	Livello I	a	Livello II	CI	Livello III	a
64786693GR1						
	10 SALDATURA	46				
	6478700	1				
			10 RITRANCIATURA FORI	150		
			64786709GR	1		
					10 TRANCIATURA A BLOCCO	105
					CUB80X620X450	3,59
	64787909	1				
			10 FRESATURA	88		
			64787909GR	1		
			20 BURATTATURA	88		
	64786009	1				
			10 INTESTARE	1		
			CIRC35X25	0,15		
			20 SMUSSARE	1		
	64786109	1				
			10 STAMPAGGIO PROGRESSIVO	1		
			FEEC40×56	0,127		
			20 BURATTATURA	1		
	64786209	1				
	20 SALDATURA	130				
	30 PUNTATURA FORCELLA	50				
	40 AHHUTUNDAMENTO	400				
	50 GRANIGLIATURA	450				
	60 HIQUALIHCA	75				
	70 HIBADITURA A CALDO	300				
	80 CONTROLLO	300				

Figure 2: "brake pedal" process path

- MPS. The transfer operation makes it possible to select the orders whose production you want to simulate in the virtual environment. In this case, the selection applies only to orders for the "brake pedal" part number (Fig 3).



Figure 3: MPS

Lastly, the configuration operations make it possible to change the standard settings of the buffer management policies, initial inventory and resource parameters. In the example buffer management policy was changed in order to simulate a recovery operation, an infinite level of stocks of raw materials was also set and lastly, a distribution of random type processing times was implemented.

The verification of the proper operation of the simulation model was carried out through an analysis at "step by step" mode. In this manner it was possible to display the arrows showing the transfer of information and materials between objects and events generated during simulation in the "Log" side window. This operation made it possible to verify that the model accurately reproduced the modelled work environment.

Instead, the validation phase was conducted by comparing (in the simulation environment) historical data (extracted from the MES) of saturation, obtained by creating the same production used as input for the virtual model. The results of the comparison are shown in the figure 4.



Figure 4: Validation analysis

The average saturation data, linked to all the resources used in the production (measured day by day), showed a mean value lower than the corresponding figure for the real plant. This difference is due mainly to the simultaneous presence of other components on the real plant that during the period of observation used the resources and were not considered in this example. The validation process can be achieved quickly by configuring the connection to the MES and comparing the results automatically.

The designing phases, execution of RUNs and analysis of the results are similar to those of traditional simulation environments. Even if the research group is designing an environment for result analysis integrated with the decision support system, to make the environment more suitable for supporting the daily choices of planners.

### 5. CONCLUSIONS

The authors proposed an approach that may be looked at as a reference for manufacturing system simulation tool development. The aim was to create a standard for both production system objects (entities, functions, items, data, etc.) and their relationships to one another. An architecture framework and a reference model were described: the latter was presented through the usage of Business Process Modelling Notation, in order to allow a better understanding to Companies, which differently from software developers - tend to think in term of processes instead of functions and procedures. On top of this, the basic functions of manufacturing systems have been embedded into the properties of the modelled objects, so that any simulation software the proposed reference model could adopting automatically inherit all the typical processes, procedures and operating methods of a manufacturing system: basic production processes archetypes (e.g. setups, machine failures, etc.), main production and inventory management policies (e.g. MRP, ROC&ROL policies, etc.), input data format (BOM, MPS, Process Charts, etc.). As a consequence, creating objects that behave according to the proposed design patterns, the work of engineers and developers who need to develop manufacturing systems simulation tools is made easier.

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## 7. ANNEX A



Figure 1: FEL generation process



Figure 2: Buffer picking function