Knowledge Representation With Object-Oriented Modeling. Application To the Development Of Manufacturing Systems

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Abstract: The *Manufacturing System Design* requires a clear knowledge of the system and the Information System support (qualitative and quantitative) necessary for evaluating and deciding among different design alternatives.

A fundamental aspect during the design process is to develop a **model** which describes the system, with the required detail level, and in a formal, concise and suitable way, in order to study the impact of the decisions on the system performance, before its construction. Among different modeling methodologies applicable to Manufacturing Systems, Object-Oriented Methodology stands out for its capability of representing at once organizational, technological and human aspects involved in a complex production system, and of modeling its dynamic dependencies as well.

This paper shows a new way to develop a model using an Object-Oriented Methodology, called RCOO, developed by the IRIS Group of the Universidad Jaume I and the GIP Group of the Universidad Politécnica de Valencia, and apply it to develop a Reference Model of a Manufacturing System, that can be used to simulate different alternatives of a particular Manufacturing System.

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1. Introduction

The construction complexity of an Integrated Manufacturing System, whose design decisions are made by multidisciplinary groups with different needs and methods, requires the use of a **model** which: (1) makes the system understanding, **easier** (2) directs its **analysis**, **design** and **construction** integrating the four views composing it (functional, informational, decisional and physical) and (3) shows the **decisions impact** of the changes occurred in the model.

2. Model Levels

The proposed schema for designing Manufacturing Systems requires to create different types of models. They support the system design to accomplish the proposed objectives. Thus, there will be obtained, in this order, the **model hierarchy** as follows:

A **statical model** that describes the Manufacturing System from its four perspectives:

- a *functional view* in which the system activities are described
- a *physical view* that represents the resources necessary for carrying out the activities
- an *informational view* that collects all information needed to make and execute decisions on the system
- an *organizational view* that describes how the decisions of the system are made

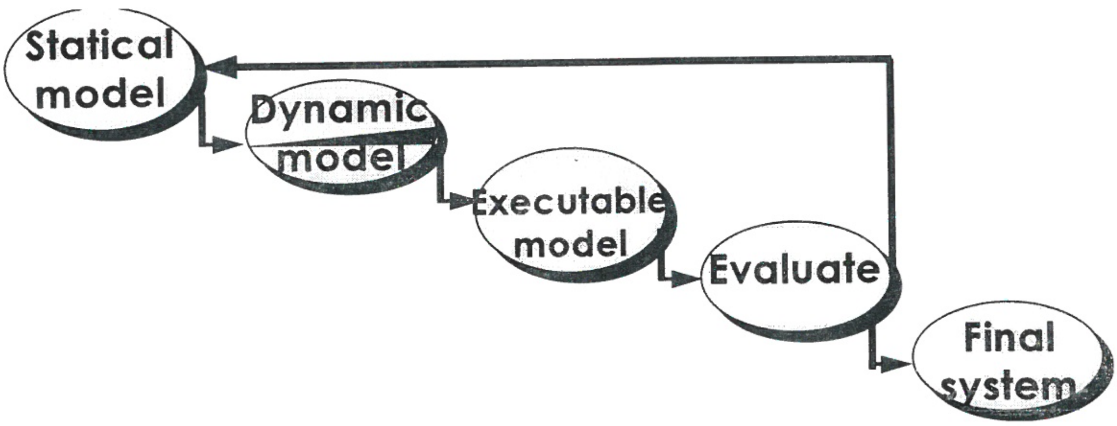

Figure 1. Development Paradigm Proposed

This methodology introduces a ***development paradigm*** which proposes to create the final system (the Manufacturing System) from the manipulation of the model. That is to say, from the gradual alteration and refinement of the model assisted by a computer in order to reach the desired goal. The key to do it is to obtain an ***executable model***. An executable model means a well-defined software representation of the system which allows its behavior analysis in order to obtain the system with the desired performance by successive refinements on the initial model.

A **dynamic model** that represents the process temporary behavior.

A **simulation model** (that is, a computer program), to be able to analyze the system performance.

The criterion which has been used for many years is that that different modeling techniques must be adapted to different useful abstraction levels at each stage. In this sense, a *variety of modeling techniques* exists and has been applied in industrial enterprise field. For instance, general purpose methods have been adapted to model systems (i. e. structured analysis and design techniques), and specific tools for the functional modeling (IDEFO) and the informational modeling (data and process oriented methods) have been developed.

These techniques cover different enterprise perspectives but no one can model the enterprise as a whole, nor does a method exist to group the partial models coherently generated by different methodologies either.

However, the connection among different hierarchy levels forces modeling methods and support tools to allow the integration of different models. The problem of integrating everything into a global model is not an easy task and, at the same time, it is essential to understand the Manufacturing System design process. Therefore, the so far used techniques and tools have not been suitable to generate a **Manufacturing System Integrated Model**.

3.Object-Oriented Methodology

Unlike the above techniques, the ***object-oriented methodology (OOM)*** offers the necessary features to properly carry out this process not only dúe its general application but because of many software tools which are being developed to support this methodology. The **OOM** can be used during all the stages of the models hierarchy. It allows to model every industrial function and resource. It permits to simulate them in order to analyze their dynamic behavior and it can be used to develop information computer systems. That is to say, the **OOM** integrates **statical** system modeling (considering all system perspectives), **dynamic** modeling and **simulation** modeling.

An application of this objects based modeling in production systems has recently been carried out. First references date from the years 1987-1988. Nevertheless, it is difficult to find detailed projects. For instance, one can mention [MIZE 91] who presents a production system simulation model based on objects , [GASP 91] who shows a system to sequence a real time implemented production using an object-oriented language, and [QUEL 94] where a mixed technique that combines Petri Nets and an object-oriented methodology to design information systems for production control, is shown. However, none of these references has reached the detail level of the Model proposed in this paper.

The Object-Oriented Methodology implies a radical change with respect to other conventional methods. Mainly, it requires a different way of thinking, developing and communicating during different project phases. However, no standard way of how to apply such a methodology does exist.

4. RCOO Methodology

Different object-oriented modeling techniques [YOUR 79], [BOOC 86], [RUMB 91] have been developed in the last years but none has been widely accepted and able to solve all problems occurring during its application in industry . For that reason, we have made an Object-Oriented methodological proposal of

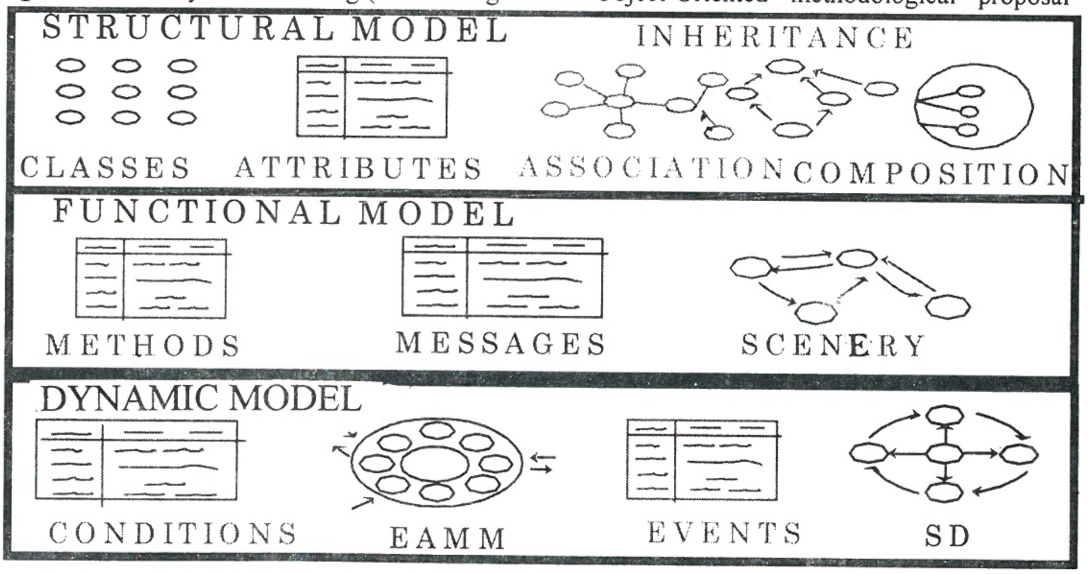

Figure 2. Graphic Tools of the RCOO Methodology

modeling, named **RCOO** [CHAL 96]. This methodology is an attempt at **standardizing** the system knowledge representation of object-oriented models.

The **RCOO** procedure application is structured in three phases. First, a **structural model** statically describes the basic system entities (objects which configure the system), their relations and attributes. The **functional model** represents the system according to the processes and their activities, which define a communication flow among objects. Finally, the **dynamic model** expresses the object internal dynamics through **events** that happen in the system and change the classes **states**. One must keep in mind that this modeling process does not take place sequentially but there is a continuous refeeding among the phases.

This methodology is quite formal, and uses many graphic tools that are very important in understanding the final model. Figure 2 shows the different graphic tools used to develop a model.

5. RCOO Reference Model of A Manufacturing System

We have used the RCOO methodology to develop a Reference Model of a Manufacturing System. The first step of this methodology is to establish the domain of the model.

Domain

Before starting the modeling process it is necessary to define the model (system) *limits* showing the **internal objects** that are included in the model, the **external objects** and the **linking objects** which connect external and internal entities. In case of modeling a specific production system, the entities would correspond to objects existing in the real system. However, in this paper the system to model is a conceptual one representing a generic production system. Thus, a first abstraction has already been made and, so, we consider classes, not objects.

The domain definition does not try to be an exhaustive stage in which all model objects/classes are determined but a first approximation to delimit what entities are going to be completely modeled (internal objects and linking objects) and what entities are only considered from the point of view of their influence on the system without internally analyzing (external objects). This domain view does not coincide with other more traditional points of view [TAYL 95]. Figure 3 shows the Generic Production System Domain that has been modeled.

Classes Identification

Once the domain has been established, the next step is to define the classes of the system. Object-Oriented modeling methodology **RCOO** allows us to structure a complex system in a hierarchical way, given the **scalability** property. Thus, at the maximum information aggregation level, the main entities of the system are only shown, indicating their properties. The selection of such entities must be made in accordance with the system analysis focus and the detail

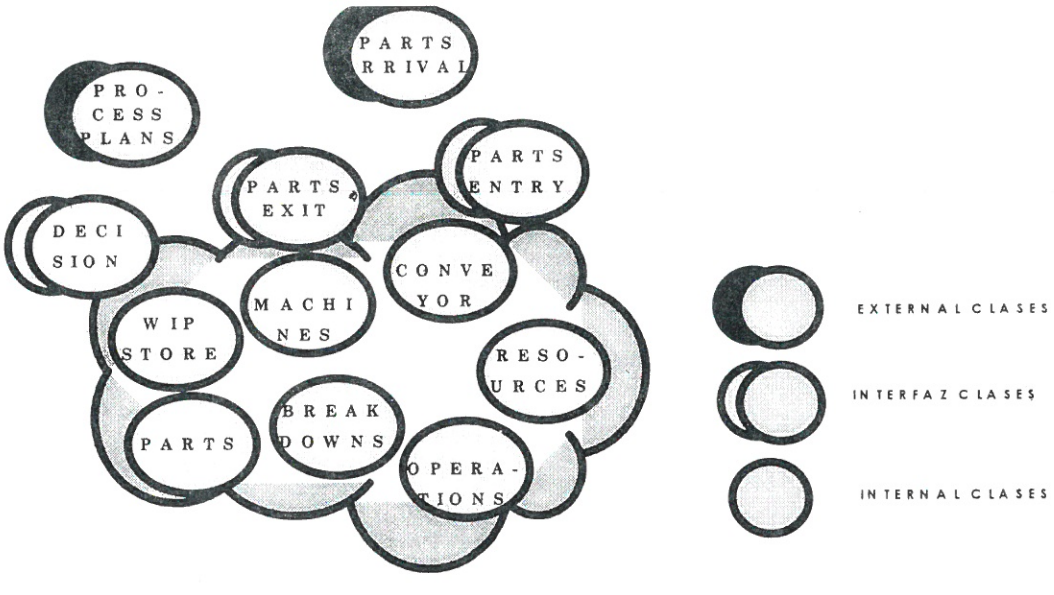

Figure 3. Domain of the Manufacturing System Model

level required. In a first approximation, the considered entities are reflected in the next literal model description:

"*Production system is considered to produce a set of final products through a set of elemental transformations (operations) of raw material (initial products) which are carried out in one or several machines. To regulate production is used storage areas, physical spaces where products are placed temporary. The movement or products flow into the system is carried out by transports. At last, to execute an operation, auxiliary elements are eventually required, named resources*" [PROT 95].

Therefore, the fundamental entities used in this model are **six object classes** as follows:

parts (including raw materials, work in process and final products)

stores (elements of temporal pieces storage)

machines (facilities to produce)

transports (elements to carry out pieces movements)

resources (material and human ones)

operations (transformation or assembly)

With this task, the first context expression is obtained. Successive activities give a more detailed model description. So, we have , following the RCOO methodology, established:

- The **Relations among classes**: Production system classes are not independent but a set of *Relations* among them can be defined. They can be classified in three categories: **Heritage**, **Association** and **Composition**.
- The **Attributes**: From relations among classes, the attributes of every entity are obtained. An attribute is any property or feature that all the objects of the same class have. Table 1 shows some characteristic attributes of storage class.
- The **Functional model**, that represents, through **sceneries**, the communication flow among classes.
- The **Messages and Methods** of the classes: Once the existing relations among objects in a system understood, by means of *sceneries analysis procedure*, the **messages** (elements used to communicate among objects) are determined, and the **method** which deals with them is identified and described.
- **The Dynamic model**: Due to the fact that the manufacturing system is not static but it changes in time, it is necessary to represent its temporal behavior in order to have a total understanding of the system. In **RCOO** Methodology, this task is carried out by means of modeling the **events** that happened in the system and the different states that occur in a class. A **class state** is defined as the value of its attributes in a specific time. Thus, state evolution describes temporary behavior of every class.

6. Model Uses

The developed model has **two main applications**. On the one hand, it covers suitable Information System Analysis and Design to support the management of the system. From this point of view, **attributes** are the *data* to incorporate into the database and **methods** constitute the software program *algorithm*. On the other hand, due to the fact that the model incorporates system dynamic features and there are Object-Oriented Information Technologies, it is possible to directly transform the model into an executable model, able to **simulate** it.

In this sense, the IRIS and the GIP Group have developed a software tool which acts as a **CASE-Simulator**, called **SIMGIP**. This application has a class library (software objects) containing the defined objects (with its attributes, methods and messages) of the above Reference Model and incorporating features of a simulator. So, the software program helps users to build a specific model of their manufacturing system, and at the same time, it is able to

Table 1. Some of the Storage Class Attributes

ATTRIBUTE	DESCRIPTION	INITIAL VALUE	TYPE
PULL	Define the PULL rule of the store (priority, by turn, and so on		variable
name	Define the name of the store		constant

simulate model behavior and to obtain a set of indicators about its performance.

Some specific examples on the interest of applying the Object-Oriented Modeling combined with a computer simulation program in the Manufacturing System Design Process are: to determine the personnel and equipments necessary for obtaining a specific production, to define suitable size and situation of storages in a production line or job shop, to detect and evaluate the bottlenecks in the production cycle, to estimate the repercussions of a machine breakdown, to set out preventive maintenance policies that interfere as less as possible in the production, to get a balance between material stocks and orders, and so on.

7. Conclusions

To construct a Manufacturing System is a complex task. Thus, it requires the use of a model to describe it in a formal and concise way, at the same time with a suitable abstraction level of the objectives. Then, from the system understanding and the decision impact analysis within the model, the system desired performance will be obtained through successive refinements.

However, modeling techniques used by companies have been viewed from different enterprise activity perspectives but none of them could model all at the same time. Nor does a method exist either to ensure the cohesion among the partial models generated through different methodologies. Suitable cohesion is an essential aspect to fully understand the whole system and to correctly analyze its efficiency and performance.

Contrasting with these techniques, **Object-Oriented Methodology** (MOO) allows to model *all enterprise activity views* including its *dynamic dependencies*. Besides, it admits other possibilities such as *operation concurrence representation*, *scalability* in order to obtain the desired detail level, model division into *modules* to facilitate its construction or to *hide information* in each entity. The possibility of relating, as a whole, all these properties notably facilitates the suitable model development.

In this paper, a methodology for the object-oriented modeling of complex systems, called **RCOO**, has been presented. The methodology has been applied to the development of a **Reference Model of a Manufacturing System**. This generic model is useful for an enterprise to develop a Particular Model of its Manufacturing System that can be simulated on computer.

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