Modeling Manufacturing Systems: An Information-Based Approach

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ABSTRACT
We describe an Integrated Simulation Modeling Environment (ISME) which utilizes an information-based approach for the description of manufacturing systems. Manufacturing systems are described as a higher level aggregation of the objects in the system. Such a description is stored in a relational database. Models are later synthesized from the description of the system. Experimental conditions are input to guide the analysis.

1. INTRODUCTION
In designing a new production system, or in modifying an existing production system, many issues need to be addressed. In a wide variety of design problems and cases, modeling and analysis tools have proven valuable in supporting the resolution of design issues through analysis. As production systems have become more complex with their components more interrelated, the positive impact of analysis on the success of design efforts should increase and, correspondingly, should the support provided by the modeling tool.

Many different types of models may be built during the design of a single production system. Typically, the models are built independently of each other which may be undesirable for the following reasons:

- **Redundant Models**—The description of the production system may be entered for each model. As models evolve, the consistency of system representation between models may become less and less. This may lead to inaccurate results and errors being propagated among many analyses.

- **Manual Information Transfer**—Information shared between models must be transferred manually. As models are analyzed in a iterative fashion, the clock time to evaluate alternatives may be too long and the process prone to manual transfer errors.

General purpose modeling languages are not always well suited to production systems because of the difficulty of model design. The modeler must perform the cognitive task of mapping between the objects in the production system and the constructs provided by the general purpose modeling language. This may require "guru" level expertise as the modeling constructs may not allow a straightforward representation of the complex interactions in a production system.

Alternatively, existing production specific modeling tools have suffered from lack of modeling power. From the modeler's view point, the tool provides a non-extendible (or difficult to extend) set of modeling constructs making the accurate representation of production systems difficult. Furthermore, the set of modeling constructs is based on a generic view of production systems and may cause the same difficulty of model design as a general purpose tool.

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We propose an approach for production system modeling that shows promise in relieving current difficulties and enhancing the production system modeling process. This approach integrates multiple types of modeling techniques, databases, and knowledge bases to jointly and concurrently help resolve multiple production system design issues. Modeling systems constructed using this approach should have the following characteristics:

- **A single data model for system representation** - All descriptive information of the system needed for all analyses is integrated and represented in one data model. Different views or subsets of the system may be selected (transparently) to support different analyses.

- **Adaptable functionality** - Modeling and analysis tools, including the set of model building constructs, must be tailorable and adaptable to the particular production system or class of production systems of interest.

- **Transparent information transfer** - Information generated is automatically and transparently captured and stored with the model for use in later analyses.

- **Gateways to external databases** - Needed information residing outside of the modeling system is accessible to support model construction, analysis specification, and for other purposes.

- **Support for multiple user types** - Users who build models, users who execute models for evaluating alternatives, and decision makers who need the information generated by models must all be supported by the system. Tools for tailoring the modeling environment to a particular production system or class of production systems must be provided.

The paper is organized as follows: Section 2 presents the background that motivated this study. Previous relevant work is also summarized. Section 3 describes the characteristics of ISME as well as relevant design and implementation issues for the realization of a complete ISME. Section 4 gives an example of using the information approach to build a simulation model. Section 5 summarizes the preliminary results of this effort.

2. BACKGROUND

Simulation modeling studies tend to be a low productivity activity. The traditional modeling life-cycle is very labor intensive and time consuming. The computer is used mainly for execution of the model while the design of the model, design of experiments to be run, and analysis of the results are, at least in significant part, shouldered by the modeler.

Progress in the field of knowledge representation and database management, especially the emergence of relational and object-oriented database technology, have resulted in opportunities for advances in production systems modeling. Expert systems (ES) and production systems models deal with large amounts of data that needs to be accessed and manipulated efficiently. The development of excellent database management systems and the evolution of sophisticated inquiry interfaces are natural adjuncts to data-hungry ES and modeling application programs.

The potential of expert systems and artificial intelligence (AI) has been explored by Shannon ([16], [18], [19]), Shannon et al. [17], Reddy [14] and O'Keefe [12] among others. Several simulation languages based upon AI methodologies have been developed. Adelsberger [1] explored the use of PROLOG as a simulation language. ROSS [11] and KBS ([14], [15]) are examples of simulation languages based upon AI concepts.

Databases have been used with simulation modeling previously. Must of these ef-
forts chose either the hierarchical or the relational data model to develop their own database management system. Ketcham [18], [19], [20]) developed IBIS based on a hierarchical database. A disadvantage of IBIS is that each program must know exactly how the data is stored, and the end-user must define the schema of each record type needed to describe the system to be modeled.

Codd's [3] relational data model is a simple and robust approach that offers possibilities to overcome the drawbacks of the hierarchical model. A relational database is "a database that is perceived by its users as a collection of tables (and nothing else but tables)" [5]. The relational model does not imply nor does it address specific physical approaches for data storage and retrieval. An early effort towards using a tabular data model is SDL ([20], [21]). SDL was a database system developed specifically for use in simulation that provided special constructs for organizing simulation inputs and outputs: time series, descriptive statistics, and histograms. The SDL query language provided for statistical computations and report generation including reports for alternative comparisons. TESS ([23], [24]) evolved from SDL and incorporates SDL's data organization and features. TESS integrates simulation, data management, graphics and animation on top of a relational database. TESS represents a new generation of software that integrates model building, model execution, analysis and presentation of results. Yancey [25] discusses the idea of a relational-based environment to properly collect and manipulate data generated by simulation runs as implemented in TESS.

3. ISME: CHARACTERISTICS

Modeling and analysis is a process which requires various types of knowledge, skills and tools as the study evolves. Thus, a modeling environment should integrate various tools, each providing support for a particular task of the modeling process. In designing ISME, we have taken into account some of the concepts of structured modeling as proposed by Geoffrion [16], [17]) and discussed by Shannon [19]. A simulation modeling environment (SME) should possess at least the following characteristics:

- a single model representation format
- independence between model acquisition and model execution
- a database of model elements, models and/or model results
- life-cycle orientation
- accessibility
- a well-designed interface

The first three characteristics provide the modeling flexibility needed for the analysis of manufacturing systems. These three characteristics suggest that models be constructed by viewing a manufacturing system as a set of interacting entities or objects. Description of the objects is based on the physical object's characteristics, not on the requirements of a simulation or other analysis tool. Thus, various types of models can be built from the object's encapsulated information. The fourth characteristic would permit capture of information generated during the formulation of the problem and the establishment of objectives. This information would then be used in guiding the modeling technique selection process as well as in documenting the overall project. The last two characteristics render a useful, non-isolated environment.

The design of ISME incorporates most of the above desirable characteristics. Figure 1 provides a graphical representation of ISME. Underlying the environment is a database. Information flows either through the database management system interface or through a net of knowledge-based tools. The flexibility and elegance of the relational data model made it philosophically the most suitable database model for the environment.
Figure 1. - ISME's global architecture
ISME’s database is managed by ORACLE, which is a robust and sound relational database management system (RDBMS) and portable across various hardware platforms. It also provides a set of tools to act upon the database. Among these tools are an integrated word processor, a spreadsheet, an interface for programming in a high level language such as C.

There are two main type of objects within ISME’s database: 1) the object a model represents, and 2) the modeling project itself. Within the manufacturing domain, the object for generic manufacturing facilities is called a station, and the object describing an entity that a station processes is a part. A station may represent a simple cell, an entire facility or any level of aggregation in between. Figure 2 shows the main characteristics of a station object and the relation that links a parent-station to its components. A station may represent a simple cell, an entire facility or any level of aggregation in between. Figure 3 shows the main characteristics of a part object and the relation that links a parent-part to its subassemblies. The level of aggregation a part represents varies from a basic component to a complex assembly. Parts move through the system by means of a material handling equipment (MHE) object. Different MHE types possess a different set of characteristics; however, they have some common attributes which allow the definition of a hierarchical generic MHE object. Attributes are added at lower levels of aggregation. Figure 4 highlights the main attributes of an MHE object and the lower level relations that allow the description of various types of MHE’s.

A project object is a structure that captures general information about the simulation study and owns a non-empty, finite set of model objects. A Model object is composed of a set of attributes that link it to the object station being modeled, to the parts to process, and to the experimental/analytic conditions under which the model is to run.

ISME contains various modeling support tools. An expert advisor provides guidance on how to go about conceptualizing a model to address a problem for the system under study. Depending on the modeler’s expertise, the expert advisor would behave as an expert instructor for the novice based on the knowledge of expert practitioners. For the experienced modeler, it becomes a reliable assistant that would perform routine operations unsupervised, fill in details after the modeler decides on a course of action, and be assigned to alert the analyst to significant changing events.

An analytical expert tool is capable of determining the most appropriate solution method for solving the problem at hand. Such a tool would extract the characteristics and assumptions of the model from the object-base, evaluate them, and trigger the generation and solution of the most appropriate model.

Valid inputs and model output are critical. ISME incorporates an expert statistician KBS which provides the necessary support in the analysis of input data as well as in the analysis of output results. An important element of this KBS is an simulation optimizer that will directly interact with the results of the simulation runs, and modify the experimental conditions until convergence to an optimal solution is achieved.

The transformation of information based description of a manufacturing system into an executable model is aided by a set of engines, one for each analysis technique supported by ISME. The Information to model translation process will be discussed for the modeling through simulation case.

As a first step, the modeler describes the system in terms of objects that are permanently stored in the database. During this model building process, the modeler is isolated from the simulation engine and from the simulation mechanism.
Figure 2. - STATION aggregate

Figure 3. - PART aggregate

Figure 4. - MHE aggregate
that would later be used for the execution of the models. Thus, the links and objects in the hierarchical structure of the system are part of the database not of a particular type model or of an analytic or simulation modeling language. Therefore, the manufacturing system description can be used to generate models of many types.

During a second step, the modeler links a model object to a particular system and inputs the experimental conditions under which the model is to be run. ISME has a transparent simulation engine that retrieves the components of a model and the links among them, and then transform them into an appropriate executable representation. Transformation results are accessible whenever necessary. The actual execution of the model is accomplished by the SIMAN simulation language.

4. BUILDING A MODEL USING THE INFORMATION APPROACH

As an example, consider the following problem. Two different jobs are to be processed within a Group Technology Machine Cell. The cell consists of one drill and two lathes. Jobs type 1 must be processed first on the drill, and then on the lathe. Jobs type 2 are processed only on the lathe. Jobs are processed on a FIFO basis. Further information establishes that jobs of type 1 arrive in batches of size 5 and only 12 batches are to be observed. Jobs of type 2 arrive in batches of size 8 and only 10 batches are to be observed. For type 1 jobs the inter arrival time is deterministic of 14 minutes, and for type 2 jobs, it is exponentially distributed with a mean value of 3.0 minutes. Type 1 are processed at the lathe uniformly between 2 and 3 minutes and deterministically at the drill for 3 minutes. Type 2 jobs are uniformly serviced at the lathe between 1 and 2 minutes.

Figure 5 shows the schematic layout of this facility and its three level of aggregation found in it. Under the information approach, the modeler begins by identifying the principal components in the system: 2 workstations (st12 & st11) in a single cell st10 which will be simulated at a level 2 of aggregation. For each object, relevant information is gathered as shown in Figure 5. After interacting with ISME, the user will choose to run the simulation engine for this particular model. The simulation engine will produce the SIMAN code shown below.

BEGIN;
; Creating Generic Customer 1
; CREATE,5:14.000000,12:MARK(1);
ASSIGN:A(4)=1;
ASSIGN:A(2)=1.000000;
ASSIGN:A(3)=3.000000:NEXT(st12);
; st12 QUEUE,1;
SEIZE:Drill#1;
DELAY:A(3);
RELEASE:Drill#1:NEXT(st11);
; st11 QUEUE,2;
SEIZE:Lathe#1;
DELAY:UN(A(3),1);
RELEASE:Lathe#1:NEXT(SALIDA);
; ; Creating Generic Customer 2
; CREATE,5:EX(2,1),12:MARK(1);
ASSIGN:A(4)=2;
ASSIGN:A(2)=2.000000;
ASSIGN:A(3)=3:NEXT(st11);
; SALIDA TALLY:A(4),INT(1):DISPOSE;
END;

BEGIN;
PROJECT,pj01_example 2,MACM,3/15/1990;
DISCRETE,99,4,2;
RESOURCES:1,Drill#1,1;2,Lathe#1,1;
PARAMETERS:1,2,0,3:0,2,3:0,3,1:0,2,0;
VALUES:1,Time Sys. pt10:2,Time Sys. pt11;
REPLICATE,1,0,0;
END;
Figure 5.- An example: GT Cell
5. CONCLUSIONS
ISME currently exists as a small prototype. The prototype includes a module for system description and model acquisition. It also includes a simulation engine that only knows SIMAN. In addition to these modules, an early expert statistician has been incorporated to ISME. A full development of ISME requires further research, especially in the area of the generation of models of multiple types. Nonetheless, ISME provides the necessary framework to be able to build various types of models from a unique description of a system.

In summary some of the benefits of developing a modeling tool such as ISME:

- **Hierarchical Modeling Flexibility:** Since a station exists as a set of hierarchically connected records, it can be analyzed at various levels of aggregation. A station can be viewed as a single time delay, or as a set of times delays representing each of the machines, operations and buffers comprising the station.

- **Environment Interfacing:** The modeling and analysis environment is capable of interacting with other manufacturing information systems. The information in the the database can be shared by non-modeling application programs; likewise, the modeling environment can extract information from existing corporate databases.

- **Facilitates Alternate Model Representations:** A system is always described in the same neutral format independently of the underlying analysis mechanisms. Several variations of the same type of model, i.e. several simulation models of the same system, and types of models i.e. analytical techniques as well as simulation can be supported.

- **Supports Use of Existing Software in Modeling Efforts:** ISME incorporates simulation languages, commercial data base management systems, and analytical tools to support new modeling procedures; thus, avoiding "re-inventing the wheel."

REFERENCES


