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INTEGRATING MULTIPLE DESCRIPTIONS IN SIMULATION MODEL DESIGN: A KNOWLEDGE BASED APPROACH

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ABSTRACT

Because manufacturing and business systems are complex systems encompassing different sub-systems and because different domain experts design, implement, and maintain these sub-systems, it is becoming imperative that descriptions from different domain experts are captured, stored, and used to design realistic simulation models of manufacturing systems. This paper presents the concept of multiple descriptions and its applicability in manufacturing systems modeling and simulation and presents a knowledge based approach to support the integration of multiple descriptions in designing valid simulation models.

1 INTRODUCTION

Today's manufacturing and business systems encompass many different sub-systems such as production process, material handling, material storage, shop floor control, and order release. In most organizations, domain experts often view a system from a perspective that is heavily conditioned by their roles in the organization, and they may have detailed knowledge involving only some aspects of the system. It is therefore becoming more and more imperative that the descriptions from different domain experts are captured, stored, and used toward designing realistic simulation models of manufacturing systems. Manufacturing and business systems today are complex enough that attempting to capture descriptions from a single domain expert or from any one point of view cannot guarantee a complete model.

1.1 Background

The importance of multiple views in information systems related disciplines has been recognized by several authors. For instance, in software engineering literature, the need to use multiple views of the software architecture (system developer and system user views) has been emphasized by Ross (Ross and Schoman 1977). Database management system (DBMS) researchers, in particular, have explored the concept of multiple views in great detail (Date 1981). In the context of modeling and simulation, Zeigler's work on multi-faceted modeling is significant (Zeigler 1984). His system entity structure based approach organizes models in model bases so that they can be readily retrieved and employed to support diverse objectives. The simulation tools that are available today provide support (although limited) in modeling some sub-systems (like process systems and material handling systems in AutoMod), but they do not provide support for modeling a system from different views or at multiple levels of abstraction.

There are two primary advantages in the use of multiple descriptions in generating simulation models.

1. Models generated from multiple descriptions tend to be more realistic and efficient in answering questions about the system. This is because multiple descriptions provide more information than a single description and highlight biases in a domain expert's understanding of a situation. The way a problem is viewed drastically influences the way a problem is solved.

2. Multiple descriptions facilitate the model design process itself. Because multiple descriptions provide more information than a single description, they will greatly aid the conceptual model design process.

Our approach in attempting to unify multiple views is unique in the sense that it is *description-driven*. This approach is based on the premise that problem situations drive the capture of descriptions about the system and the set of questions that needs to be answered. This evolving system description base will be maintained by a knowledge based tool allowing facts about the system to be captured and then carried over or shared between analysis situations. This approach shifts the focus to reuse of the *facts* on which the model is based, instead of the *models* themselves. The description-driven approach toward building simulation models is based on the Air Force IDEF3 method (Mayer et al. 1993).

1.2 IDEF3 Overview

A limitation of existing simulation technology is that domain experts who know and can describe in detail how their systems operate have been unable to take advantage of simulation modeling. The development of IDEF3 is based on the observation that domain experts often communicate by relating an ordered sequence of activities that describes "how things work" in their domains. One of the primary mechanisms people use when describing elements of the world is to relate their descriptions as a story in terms of an ordered sequence of events or activities (Mayer 1988). IDEF3 was motivated by the need to distinguish between *descriptions* that record an agent's perceptions of how a system works and *models* that provide an abstract idealization of how a system works (Mayer, Menzel, and Mayer 1991).

The IDEF3 Process Description Capture Method provides a mechanism for collecting and documenting processes. IDEF3 captures precedence and causality relations between situations and events in a form natural to domain experts by providing a structured method for expressing knowledge about how a system, process, or organization works. IDEF3 captures the behavioral aspects of an existing or proposed system. Captured process knowledge is structured within the context of a *scenario*, making IDEF3 an intuitive knowledge acquisition device for describing a system. There are two IDEF3 description modes: process flow and object state transition. A process flow description captures knowledge of "how things work" in an organization (e.g., it captures the description of what happens to a part as it flows through a sequence of manufacturing processes. An object state transition description summarizes the allowable transitions an object may undergo throughout a particular process. Both the Process Flow Description and Object State Transition Description contain units of information that make up the system description. These model entities, as they are called, form the basic units of an IDEF3 description.

The IDEF3 term for elements represented by boxes is a Unit Of Behavior (UOB). Each UOB box represents a real world process. Each UOB can have associated with it both "descriptions in terms of other UOBs" and a "description in terms of a set of participating objects and their relations." We refer to the former as decompositions of a UOB and the latter as an elaboration of a UOB. IDEF3 provides this capacity by allowing multiple decompositions of the same UOB.

The IDEF3 based descriptions captured from domain experts are used to automatically generate simulation code in a target language using PROSIM™, an intelligent simulation modeling tool developed at KBSI (Benjamin et al. 1993). PROSIM generates simulation code from a description of the system and the user concern in the form of a question to be answered. By taking a description-driven approach, PROSIM significantly reduces the time and cost required to do simulation modeling and analysis. The current version of PROSIM has the capability to generate simulation code in WITNESS™ language from single descriptions.

1.3 Research Goal

Our research goal is to provide intelligent assistance to the designing of a simulation model system from a collection of descriptions and questions to be answered. This idea is illustrated in Figure 1. The descriptions about the real world are captured from domain experts in IDEF3 language. An organization will have a collection of such descriptions in a repository. These descriptions could be describing the different sub-systems or could be describing the same system from multiple viewpoints. The decision maker is interested in a set of questions to be answered about the real world and would like to build a simulation model to answer his questions. Depending on what question (or set of questions) needs to be answered, a model system will be generated.

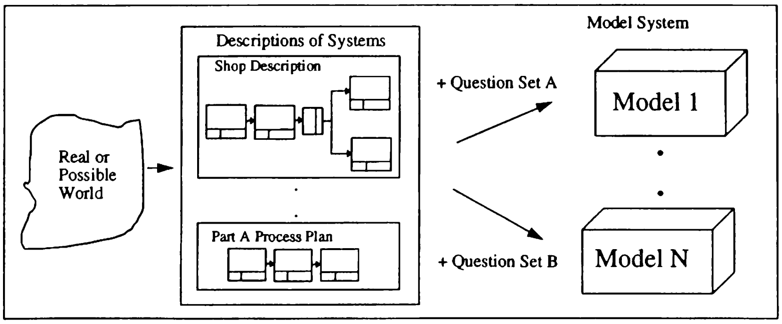

Figure 1: Generating a Model from Multiple Descriptions

2 MULTIPLE DESCRIPTIONS

Difficulty in describing the courses of events by a domain expert leads to the existence of multiple descriptions in an organization. At least three situations that lead to multiple descriptions have been discovered:

1. Domain experts often view systems from a perspective conditioned by organizational roles, so domain experts involved in the design and maintenance of different parts of a system describe the same system differently. They are sometimes required to perceive the same system in several ways to understand its multiple facets. Figure 2 shows the schematic diagram of a shop with a Kardex storage system (K), two machine tools (M1 and M2), and three conveyors (C1, C2, and C3).

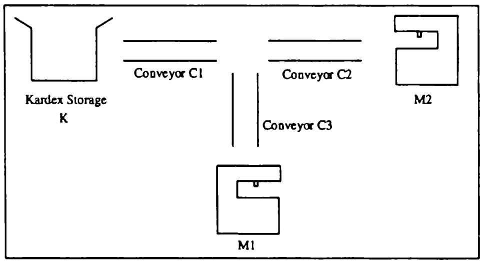

Figure 2: Schematic Diagram of a Shop

A process planner might describe the operation of this shop from a 'parts' viewpoint. An example is illustrated in Figure 3 in which the part is stored in K, moved to M1 to be processed, and moved to M2 to be processed again.

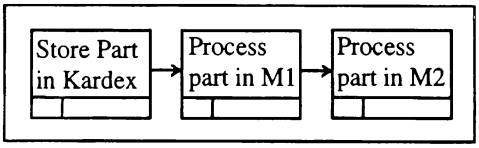

Figure 3: Process Planner View

So, process planners view systems from a perspective of how parts visit equipment according to process plans.

Figure 4 illustrates the description of a shop floor manager (shop view). The shop floor manager, being responsible for managing all the operations in the shop floor, describes the operation of the system as a whole, including the material handling system, and independent of any single part flowing through the system. As shown in Figure 4, parts get stored in storage system K, parts are conveyed through conveyor segment C1, and when parts reach the end of the segment C1, they can either get transported through segment C2 or C3, depending on whether the next processing is on M1 or M2. The junction shown is an XOR junction, where the decision logic to route the part could be based on the part type. The different part types will follow one of the two routes depending on where they are to be processed next.

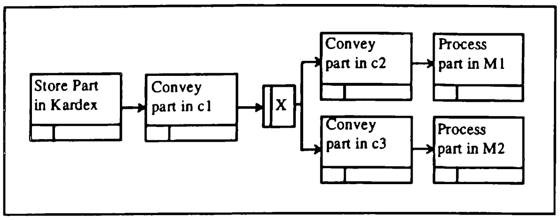

Figure 4: Shop Floor Manager's View

2. Multiple descriptions also arise from describing different sub-systems. As manufacturing systems are becoming more complex, different domain experts are typically involved with the different sub-systems. For example, there could be domain experts involved with production processes, material handling sub-systems, order-entry sub-systems, etc. Domain experts' expertise is typically restricted to the part of the system for which they are directly responsible. So, there is a need to interview many domain experts in order to capture all aspects of the system. The following example illustrates multiple descriptions that arise from different domain experts describing different sub-systems. Figure 5 shows a schematic diagram of a wafer fabrication facility with four bays. Each bay has three pieces of production equipment connected by the intra-bay material handling system and a stocker. The stockers of all the bays are connected by an inter-bay material handling system.

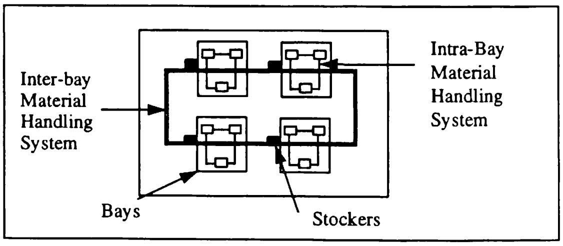

Figure 5: Schematic Diagram of a Wafer Fabrication Facility

Figure 6 captures a description of production processes in a semi-conductor wafer fabrication facility. This diagram illustrates the series of wafer processing steps associated with a mask level.

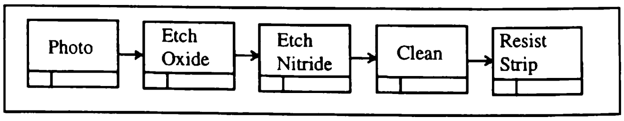

Figure 6: IDEF3 Description of the Production Process Sub-System

Figure 7 is a description of the material handling sub-system including the inter-bay and the intra-bay systems.

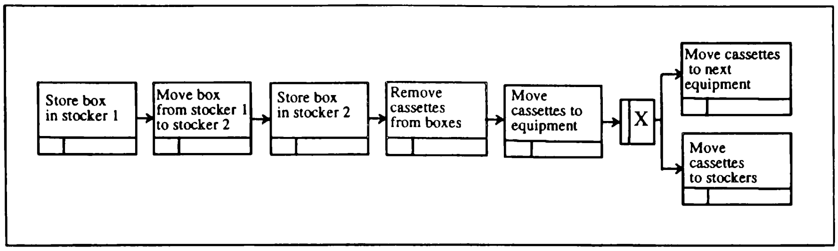

Figure 7: IDEF3 Description of the Material Handling Sub-System

3. Another way to describe a course of events is by different levels of granularity. For example, in the wafer fabrication facility example, the operation of the fabrication could be described as shown in Figure 8, a higher level of abstraction than those in Figures 6 and 7.

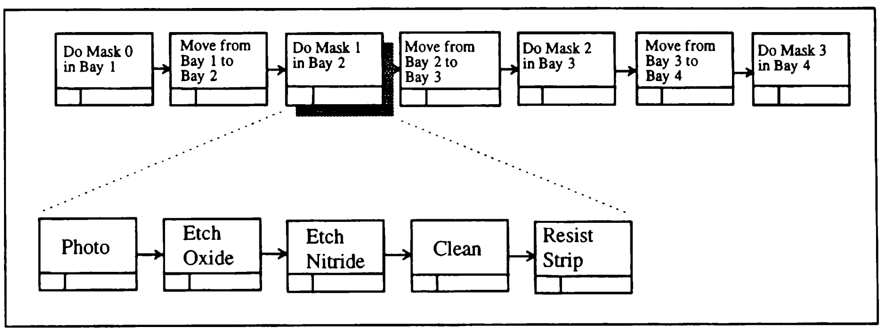

Figure 8: IDEF3 Description of the Entire Wafer Fabrication Process

3 AN APPROACH TO INTEGRATING MULTIPLE DESCRIPTIONS

In the preceding section, we showed three different ways that multiple descriptions can arise. Now we will show how this is a basis for integrating the descriptions.

3.1 Model Design From Multiple Descriptions

Figure 9 illustrates how an intelligent assistant would support the process of designing a simulation model from multiple descriptions. The collection of descriptions of the organization is captured and stored in the description repository. Decision makers express concerns and questions they want answered. Users' concerns and questions would determine relevant descriptions and the performance measures of interest (Erraguntla, Benjamin, and Mayer 1994). Relevant descriptions are determined based on the level of abstraction (granularity required of the different systems or sub-systems), the scope and boundaries of the model, and the viewpoints of interest. The next task is to integrate the selected descriptions using a knowledge-based approach. Validation tests are performed during the selection and the integration tasks. Key in this process is determining the adequacy or completeness of the selected descriptions, relative to the questions to be answered. During the integration process, inconsistencies between different descriptions will be identified using qualitative reasoning methods.

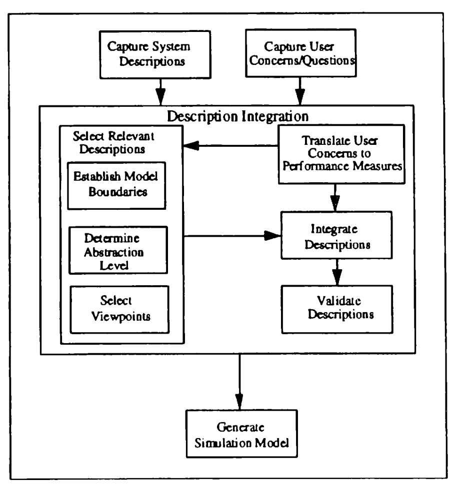

Figure 9: Conceptual Model of the Design Process

We'll next illustrate the activities involved in determining the level of abstraction, establishing the model boundary, and translating user concerns to simulation performance measures using the wafer fab example described earlier. If the user is concerned about the stocker capacities (WIP levels) in the different bays, it may not be necessary to model the material handling system in great detail and it can be treated as a black box. However, the production system needs to be modeled in sufficient detail. On the other hand, if the user is concerned whether the monorail system can handle the vehicle traffic, the user may need to study the material handling system in more detail and can probably treat the production system as a black box. If the user is concerned about studying the material handling system, descriptions about the order entry system or a process planner description may not be relevant to generating the simulation model. Similarly, a concern about meeting production requirements might translate into measuring the throughput of the system as a performance measure.

3.2 Methodology

In this section, we describe the method by which questions about the system guide the selection of relevant descriptions and the strategy for integrating the descriptions. As stated in Section 2, descriptions about the system are categorized along three dimensions, based on: 1) system/sub-system relationship, 2) the viewpoint of the description, and 3) the level of abstraction. This categorization also forms the basis for the organization of descriptions, as shown in Table 1. D1, for example, describes the material handling sub-system from a part-flow viewpoint and highest level of abstraction.

Table 1: Organization of Descriptions

Descriptions	System/sub-system	Views	Abstraction
D1	Material Handling	Part Flow	Highest level
D2	Material Handling	Layout	-
D3	Production Process	System	Detailed level

A table which maps user concerns or questions to the relevant descriptions is constructed. For example, if the user is concerned about the WIP levels in the different bays of a wafer fab, the user might want to study the production process sub-system in great detail while treating the material handling sub-system as a black box (Table 2).

Table 2: Mapping of Concern About WIP Level to Descriptions

Sub-system	Views	Abstraction
Material Handling	Part Flow	Highest level
Production Process	System	Detailed level

Once the relevant descriptions are selected, then, based on the combination of descriptions, we choose a method to integrate the descriptions. The actual integration step is thus based on the combination of descriptions. A method to integrate the shop description of two adjacent sub-systems could be as simple as concatenating these descriptions. At the same time, it can get a lot more intricate as in integrating the production process description with a material handling description, which would involve figuring out the connection between the material handling system components with the process system descriptions. These methods are currently being developed.

3.3 Architecture

The architecture of a knowledge-based system integrating multiple descriptions is described in this section. The figure was not included because of space restrictions. The architecture supports the conceptual model of the design process illustrated in Figure 9. The knowledge acquisition tools are responsible for capturing the knowledge about the end-user's system. This consists of three components:

1. Process description acquisition module, for capturing and organizing system descriptions.

2. Ontology acquisition module, responsible for capturing knowledge about the domain-specific knowledge (Benjamin et al. 1994). It will aid in such tasks as capturing the taxonomy of the system, organizing the descriptions, and mapping between questions and descriptions.

3. User concern/questions acquisition module, responsible for acquiring the concerns of the user. The description manager is responsible for selecting, integrating, and validating the descriptions. The conceptual model designer is responsible for designing a

conceptual model of the design process as illustrated in Figure 9. The query analyzer is responsible for 1) analyzing the user questions about the system and translating it to appropriate performance measures, and 2) selecting the descriptions of interest. The code generator will generate simulation code in the target simulation language based on the model design. The experiment designer designs tactical and strategic experiments for determining the performance measures that are of interest. The knowledge repository includes domain knowledge, simulation expert knowledge, a description base that stores the descriptions captured, and heuristics/algorithms required in the process of generating the model.

4 CONCLUSION

This paper presented our findings thus far on the concept of multiple descriptions, and our approach to integrating multiple descriptions in designing and generating a simulation model. A strong motivation to use multiple descriptions is that they provide more information than a single description and highlight biases present in a single domain expert's understanding of a situation. Acquiring domain knowledge from the user, using qualitative reasoning mechanisms to map the questions to choosing relevant descriptions, and developing a generalized knowledge-based approach to integrate descriptions are potential areas for future research.

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