Information Modeling and Model Implementation

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ABSTRACT: Today's manufacturing industry greatly relies on computer technology to support activities throughout a product's life cycle. Effective and efficient information sharing and exchange among computer systems have been critical issues. Formal information modeling languages that describe information requirements unambiguously is an enabling technology that facilities the development of a large scale, networked, computer environment that behaves consistently and correctly. Manufacturing systems are often costly to develop and operate. Simulation technology has been demonstrated to be an effective tool for improving the efficiency of manufacturing system design, operation, and maintenance. Standard interfaces could help reduce the costs associated with simulation model construction and data exchange between simulation and other software applications -- and thus make simulation technology more affordable and accessible to a wide range of potential industrial users. A machine shop information model has been developed at the National Institute of Standards and Technology (NIST) as a part of system interoperability efforts. This paper describes the concept of information modeling and implementation methods with a real-life information model, a machine shop information model.

1. Introduction

Today's industry is faced with global competition. Simulation technology can reduce cost, save time, and improve quality. A manufacturing system is composed of a large number of distinct processes that all influence product cost, product quality, and productivity. The interactions among these various facets of a manufacturing system are complex, and decisions made concerning one aspect have ramifications that extend to the others. Interoperability between manufacturing software applications and simulation is currently extremely limited. The need for an integrated and automated information system has emerged as a result of the reorganization and expansion of companies when a factory wants to move towards computer integrated manufacturing. Information models play a key role to integrate information and share data in industry. Information integration and sharing require a united and neutral information model.

Currently, small machine shops do not typically use simulation technology because of various difficulties and obstacles associated with model development and data translation. Small shops typically do not have staff with the appropriate technical qualifications required to develop custom simulations of their operations or custom translators to import their data from other software applications.. NIST is working with a number of industrial partners and researchers to develop neutral formats for machine shop data to facilitate simulation and modeling activities. A machine shop data model, as a neutral interface format, has been developed to support both NIST's System Integration of Manufacturing Application (SIMA) program and the Software Engineering Institute's (SEI) Technology Insertion Demonstration and Evaluation (TIDE) Program. SIMA supports NIST projects in applying information technologies and standards-based approaches to manufacturing software integration problems.

2. Information Modeling

An information model is a representation of concepts, relationships, constraints, rules, and operations to specify data semantics for a chosen domain of discourse. The advantage of using an information model is that it can provide shareable, stable, and organized structure of information requirements for the domain context.

2.1 Modeling Methodologies

Information modeling is a technique for specifying the data requirements that are needed within the application domain. There are different practices in developing an information model. The underlying methodologies for the modeling practices are based on three approaches: the entity-relationship approach, the functional modeling approach, and the object-oriented approach.

Choosing an appropriate modeling methodology is a judgment that must be made at the beginning of the modeling work. In general, an information model, developed in any methodology, is a representation of entities, attributes, and relationships among entities. However, each information model has a different emphasis. The emphasis is often depends on the viewpoint associated with the model. Occasionally there are multiple viewpoints for the model. The viewpoints of the model help to decide the type of information modeling methodology to be used. For example, the object-oriented approach is a better selection if data requirements are at the higher levels of detail. In the case where functions are more important and more complex than data, the functional approach is recommended. The object-oriented approach, however, may provide better extensibility and may be more compatible with the intended implementation environment. The disadvantage of the entity-relationship model is its lack of preciseness in supporting the detailed levels. Very often the data requirements of the application may need to be changed and most changed are function related; if the information model was developed using the functional approach, these changes may lead to a major modification to the model. Finally, the major obstacle for using the object-oriented approach is that the approach requires a critical paradigm shift in thinking compared with other data modeling approaches.

2.2 Modeling Languages or Tools

Quite a few information modeling languages or tools, for different methodologies, have been developed or are under development. These information modeling languages provide various ways of formally representing an information model. In general, the languages are presented in two forms: graphical form and textual form. The former is represented by diagrams that are formed by graphic symbols. The structure of the latter is specified by a context-free grammar that includes formal language syntax and semantics. The graphical form is designed primarily for humans, while the textual form is for both humans and machines.

The Integrated Computer Aided Manufacturing (ICAM) Definition Language 1 Extended (IDEF1X), EXPRESS, Unified Modeling Language (UML), and Extensible Markup Language (XML) are most often used by the manufacturing enterprises for information modeling. IDEF1X is a formal graphical language for relational data modeling, developed by the U. S. Air Force (Appleton 1985). EXPRESS (ISO 10303-11 1994) was designed to meet the needs of the STandard for the Exchange of Product model data, commonly called STEP (ISO 10303-1 1994), and it has been used in a variety of other “large-scale” modeling applications. UML is a graphic representation for artifacts in software systems, and is also useful for database design (OMG 2003). XML is a format for structured documents and it helps make possible information exchange in a globally distributed computing environment (W3C 2000).

2.3 Modeling Process

The initial phase for developing an information model starts with the definition of the scope of the model’s applicability. The scope specifies the domain of discourse and the processes that are to be supported by the information model. It is a bounded collection of processes, information, and constraints that satisfy some industry need. The scope statements include the purpose as well as viewpoints of the model, the type of product, the type of data requirements, the supporting manufacturing scenario, the supporting manufacturing activities, and the supporting stage in the product life cycle. A well-defined scope should be accurate, unambiguous, viable, and meet the industrial need.

After the scope is defined, the next phase is to conduct a requirements analysis. There is no standard method for collecting information requirements. However, requirements analysis may be accomplished by: literature surveys, standards surveys, domain expert’s interviews, industrial data reviews, and state-of-the-art assessments. As the result of the requirements analysis, information requirements are captured and documented. The data requirements are then transferred into a conceptual information model.

Conceptualizing information requirements starts with grouping concepts, which is to identify the model’s units of functionality. After that, an abstraction process will be performed to establish the model’s structure for each functionality. This abstraction process, which structures information requirements into entities, objects, or classes, may include generalization, specialization, aggregation, classification, and association. Once the structure of the model is established, the model is then laid out according to the syntax of the selected modeling tool/language.

2.4 Implementation methods

Three types of implementation methods are currently used by the manufacturing community:

- Data transfer via a working form, which is a structured, in-memory representation of data. The method uses a mechanism that accesses and changes data sequentially without actually moving the data around. All shared data are stored in memory.
- Data transfer via an exchange file, which is a file with a predefined structure or format. This method requires a neutral file format for storing the data. The application systems read and write from files.
- Data transfer using a database management system. This method uses a database management system where information is mapped onto and retrieved from databases.

These implementation methods can be accomplished through programming languages and database management systems. The selection of an implementation method is heavily dependent on the target environment where the application system resides. While the relational database is generally desirable for data transfer, the traditional file-oriented systems are being used continually by many manufacturing applications.

3. Effort to Develop a Real-life Model

McLean 2005 describes an interface information model, developed at NIST, to represent machine shop data for manufacturing simulation. The primary objective is to develop a standard-data-interface structure for exchanging shop data among various manufacturing software applications, including simulation. The information model, when completed, will satisfy the following needs:

- to support data requirements for the entire simulation of manufacturing life cycle
- to enable data exchange between simulation and other manufacturing software for machine shops
- to provide for the construction of machine shop simulators
- to support testing and evaluation of machine shops' manufacturing software

NIST's machine shop data model has been developed with two goals in mind: (1) to support the integration software applications at pilot facility, the Kurt L. Lesker Company's machine shop, and (2) as a standard data interface between manufacturing simulators and other manufacturing software applications. The model contains twenty major entities. They are: organizations, calendars, resources, skill-definitions, setup-definitions, operation-definitions, maintenance-definitions, layout, parts, bills-of-materials, inventory, procurements, process-plans, work, schedules, revisions, time-sheets, probability-distributions, references, and units-of-measurement.

3.1 Information Model

NIST's machine shop data model is presented in both graphical form, in UML, and textual form, in XML. The model has been developed with two goals in mind: (1) to support the integration software applications at pilot facility, the Kurt L. Lesker Company's machine shop, and (2) as a standard data interface between manufacturing simulators and other manufacturing software applications. The model contains twenty major entities. They are: organizations, calendars, resources, skill-definitions, setup-definitions, operation-definitions, maintenance-definitions, layout, parts, bills-of-materials, inventory, procurements, process-plans, work, schedules, revisions, time-sheets, probability-distributions, references, and units-of-measurement. Figure 1 illustrates some of major elements of the conceptual information model and their relationships to each other.

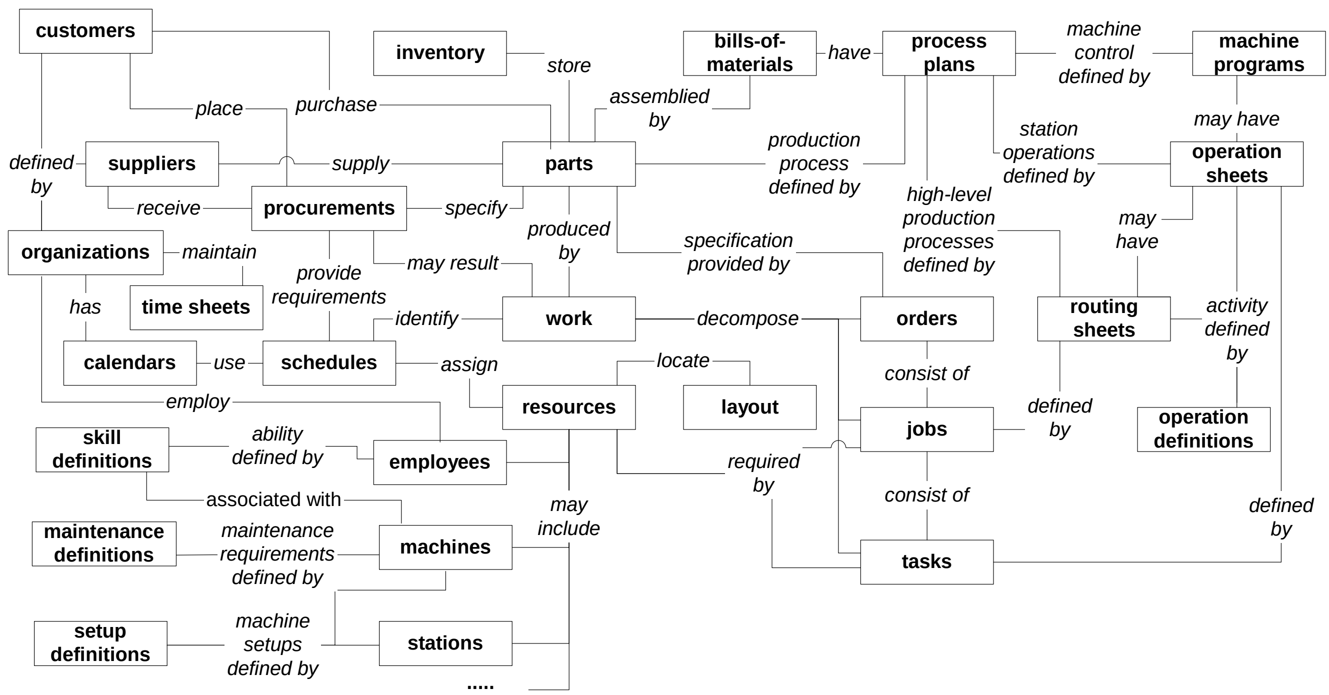

Figure 1: Concept for the Machine Shop Information Model

The primary objective is to develop a structure for exchanging shop data between various manufacturing software applications, including simulation. The idea was to use the same data structures for managing actual production operations and simulating the machine shop. The rationale was that if one structure can serve both purposes, the need for translation and abstraction of the real data would be minimized when simulations are constructed. The mapping of real world data into simulation abstractions is not, for the most part, addressed in the current data model. It is also recognized that maintaining data integrity and minimizing the duplication of data were important requirements. For this reason, each unique piece of information appears in only one place in the model. Cross-reference links are used to avoid the creation of redundant copies of data.

3.2 Database Model

A machine shop database implementation, which generates relational database tables from the information model, has been developed at NIST. The database model will be used to support the integration of manufacturing application and simulation in the shop environment. A database model has been developed to map onto the XML model's entities. The database provides the possibility of data sharing in a distributed simulation environment. There were three major objectives of the database implementation:

- to demonstrate the feasibility of the information model
- to develop a pilot database system and then to migrate to a large database management system
- to support the integration of manufacturing applications and simulations used in machine shops

Shop-data is the database model's very top level, thus the model's first level relationship expresses the connections between entity *shop-data* and the other major entities. About 500 tables and relationships have been developed.

Database management systems such as Oracle, DB2, and Access, have been used to manage enterprise data for many years. Nevertheless, custom translators are needed to transfer data between an existing database system and an XML representation of that data.

The design view of the *shop-data* table is presented in Table 1. Each element in the machine shop information model is represented as a table in the database model. Attributes and child-elements of an element are presented as fields in the corresponding table. Cardinality relationships are specified with the fields. Currently, there are about five hundred relational tables included in the machine shop database model.

Table 1: Data structure of *shop-data*

Field	Data Type	Description
INDEX	Number	[1], system use
type	Enumeration	[0..1]
identifier	Number	[1]
number	Text	[1]
name	Text	[0..1]
description	Text	[0..1]
REFERENCE-KEYS	Text	[0..1], reference-keys.SOURCE
REVISIONS	Text	[0..1], revisions.SOURCE
ORGANIZATIONS	Number	[0..1], organizations.SHOP-DATA
CALENDARS	Number	[0..1], calendars.SHOP-DATA
RESOURCES	Number	[0..1], resources.SHOP-DATA
SKILL-DEFINITIONS	Number	[0..1], skill-definitions.SHOP-DATA
OPERATION-DEFINITIONS	Number	[0..1], setup-definitions.SHOP-DATA
SETUP-DEFINITIONS	Number	[0..1], setup-definitions.SHOP-DATA
MAINTENANCE-DEFINITIONS	Number	[0..1], maintenance-definitions.SHOP-DATA

LAYOUT	Number	[0..1], layout.SHOP-DATA
PARTS	Number	[0..1],parts.SHOP-DATA
BILLS-OF-MATERIALS	Number	[0..1], bills-of-materials.SHOP-DATA
INVENTORY	Number	[0..1], inventory.SHOP-DATA
PROCUREMENTS	Number	[0..1], procurements.SHOP-DATA
PROCESS-PLANS	Number	[0..1], process-plans.SHOP-DATA
WORK	Number	[0..1], work.SHOP-DATA
SCHEDULES	Number	[0..1], schedules.SHOP-DATA
TIME-SHEETS	Number	[0..1], time-sheets.SHOP-DATA
REFERENCES	Number	[0..1], references.SHOP-DATA
PROBABILITY-DISTRIBUTIONS	Number	[0..1], probability-distributions.SHOP-DATA
UNITS-OF-MEASUREMENT	Number	[0..1], units-of-measurement.SHOP-DATA

3.3 Data Transfer

To demonstrate the data exchange role of the machine shop information model, prototype implementations are being performed at NIST. Different simulation systems use different modeling constructs and distribution methods. While demonstrating data exchange, only machine shop operation related data are addressed and those data specially defined for a particular simulation system are ignored.

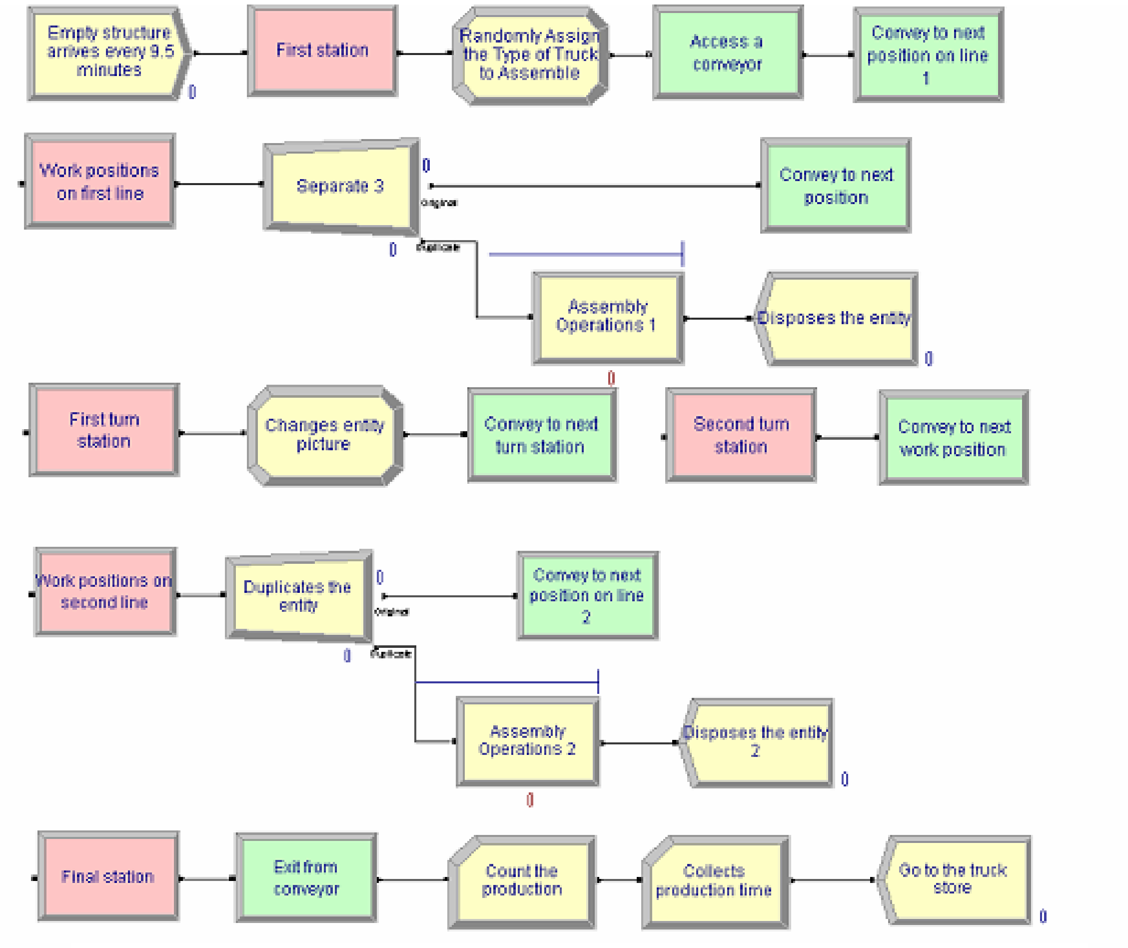

Figure 2: A simulation model of a truck assembly line

A prototype based on the Rockwell Software's Arena, Version 5.0 is introduced here. We selected the truck assembly line model from the Arena sample models library. New truck chassis enters the line at a constant rate. They are conveyed down the line from one work position where five processes are performed: *arrival, assembly-line-1, turn, assembly-line-2,* and *exit*. Each process has two to fourteen activities. The *arrival* process executes every 9.5 minutes. *The assembly-line-1* process performs operations related to axes, air tanks, etc. The *turn* process performs turning operations at two turning stations. *The assembly-line-2* performs operations related to bumper, radiator, engine, etc. The *exit* process completes assembly activities by exiting from conveyor, delivery to truck store, and collecting statistics data. An XML instance document, which contains *parts, work, resources, operation-definitions, schedules, units-of-measurement,* and *process-plans* is manually generated to support this truck assembly line operation. The XML document is then loaded into an Arena model database using the customer-built Arena utilities mentioned previously. As a result, an Arena simulation model can be generated dynamically from the model database using internal ActiveX dynamic link libraries. Figure 2 presents a screen capture of the described Arena simulation model.

4. Conclusion

A manufacturing system is composed of a large number of distinct processes that all influence product cost, product quality, and productivity. Manufacturing systems tend to be complex and expensive to construct and operate. The industry is becoming more aware of the potential benefits of an integrated manufacturing environment. Interoperability between manufacturing software applications and simulation is currently extremely limited. This paper describes a concept of information modeling. It also presents an information model for transferring machine shop data between a traditional database and XML files. The data transfer mechanism is based on Document Object Model, XML Path Language, and Open Database Connectivity database engines. The machine shop information model has recently been transferred to the Simulation Interoperability Standards Organization (SISO) for standardization. The standard is for the modeling and simulation community in the manufacturing industry.

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