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DATA DRIVEN DESIGN AND SIMULATION SYSTEM BASED ON XML

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ABSTRACT

Implementing a highly flexible manufacturing approach, like mass customization manufacturing, demands an integrated design and simulation system. This system must be able to cope with difficult issues such as a high level of product variety, uncertainty in the product demand forecast, and the reconfiguration of manufacturing resources to support the introduction and integration of new manufacturing capabilities. In this paper, a data-driven design and simulation system to support flexible manufacturing is presented. A neutral model of shop information, based on the eXtensible Markup Language, is used to describe the important information about the manufacturing facilities and processes, to configure simulation models and to exchange data between simulation and other manufacturing applications. When demand changes, the simulation model can be quickly modified to perform analysis according to the new demand. Manufacturing capabilities and production processes can be adjusted, layout reconfigured, and resources reassigned according to the analysis results.

1 INTRODUCTION

In the next decade, competition in the dynamic global manufacturing marketplace will be fierce and unpredictable, driving manufacturers to provide mass customized products, and to deliver them rapidly while keeping costs down. This can mean embarking on "Mass Customization Manufacturing"(MCM) (Alford et al. 2000).

Adopting MCM implies the ability to dynamically reconfigure available manufacturing resources to execute the right production processes to produce any possible product (Bourke et al. 1999). Because establishing a new production line requires a considerable investment, the existing line has to be able to produce a huge number of different variants, often with unequal capacity requirements. With increased frequency, the production line will need to be reconfigured to keep up with new product designs. The supporting manufacturing system is expected to be flexible enough to be able to adjust manufacturing capability by reconfiguring the system, including the developing and integrating of new functions needed to implement the reconfiguration. The challenge for manufacturers is to design and operate integrated manufacturing systems that can accommodate the accompanying increase in variety and uncertainty, without affecting lead-time, cost, or quality.

2 ADDRESSING THE INFORMATION INTEGRATION PROBLEM

To develop a system that integrates design and simulation of flexible manufacturing systems, such as those needed for MCM, a critical problem that needs to be solved is information integration. The information needed by simulation is often scattered in various sources like databases, product data management (PDM) systems, hand or computer generated drawings, flat files, and spreadsheets on different computers in the facility. Commercial off-the-shelf (COTS) and custom-built applications may be used to create and maintain this information, leading to situations where the needed information may be incomplete, or in different, incompatible formats. Similar information may have different functions. This leads to problems with storing, retrieving, and exchanging information between simulations and other manufacturing applications.

Advances in several areas of research are required to address the information integration problem. In the area of manufacturing simulation, the development of standard interfaces for exchanging data between simulations and other manufacturing applications is needed. Also, better methods need to be developed for efficiently reusing existing simulation model data (Nicholson 1999). Developing simulation models is time-consuming work that often must be repeated to undertake different simulation studies. Simulation models contain several kinds of information including information about the manufacturing system layout, processing logic, routing logic, and stochastic information about the manufacturing processes. Manufacturers urgently need to reuse existing models by modifying them based on current information.

To address those issues, the National Institute of Standards and Technology (NIST) is developing an information model and eXtensible Markup Language (XML)-based exchange file format that facilitates the exchange of manufacturing information between simulation applications, other manufacturing applications, and data sources (McLean et al. 2002). XML was chosen as the encoding mechanism for the exchange file format, hereafter referred to the Shop Data File (SDF), for several reasons. XML allows for the definition of documents that are both human and machine interpretable. XML documents can be exchanged easily between applications as text files using basic communications mechanisms. Several mechanisms are available for defining the allowable content of an XML document, which in turn, enables the capability of automated validity checking for XML documents. Many free and low cost tools exist that support the definition, creation, modification, validation, and display of XML documents.

The Shop Data Information Model describes the content of a Shop Data File (Lee and McLean 2003). It contains descriptions of the important elements of manufacturing operations, the attributes of those elements, and the relationships among the elements. Two equivalent methods are being used to create the Shop Data Information Model. Both Unified Modeling Language (UML) static structure diagrams and XML Schemas are being used. The static structure diagrams provide a graphical description of the model, while XML Schemas provide a textual description of the model that facilitates the creation of the XML instance documents, i.e. the Shop Data Files. For validity checking, the XML Schema for the Shop Data Information Model can be stored within, and exchanged with, a Shop Data File. It can also be stored on a web server for reference over the Internet.

The Shop Data File provides a mechanism for sharing data between simulation and other manufacturing applications. The file contains not only executable or computable data to be processed by the simulation, but also descriptive text intended only for human interpretation. It also contains a network of cross-reference links between the various types of data required to plan and manage operations within the shop. It supports references to other external computer files and/or paper documents that provide more appropriate mechanisms or standards for encoding or representing data (e.g., part drawings). Subsets of individual data types, i.e., substructures, may be created, stored, and/or exchanged using the file.

Many different kinds of manufacturing data can be described by the Shop Data Information Model and stored and/or exchanged in a Shop Data File. The information model contains representations for, but is not limited to:

- Orders *and* order status information (such as customer, purchase, shop floor, move, shipping orders)
- *Manufacturing* planning information such as process, routing, operation plans, schedules (long range and short term), and demand forecasts
- *Negotiation* related documents, such as request for quotes, invoices, quotes, and product inquiries
- *Resource* information (such as manufacturing line layout, machine characteristics, tool & fixture definitions, operator capabilities, material handling and storage requirements, etc.)
- *Management* and control systems definitions for factories, shops, production lines, work cells, etc.

While the scope of the information described above covers many areas of manufacturing operations, the focus and reason for developing the Shop Data Information Model is to facilitate the exchange of simulation-related information between simulations and other manufacturing applications through the Shop Data File.

3 ENABLING FLEXIBLE MANUFACTURING SYSTEM DESIGN WITH DATA DRIVEN APPROACHES

In Figure 1, a conceptual data-driven manufacturing design and simulation system is presented. The intent of this system is to be able to rapidly create and modify system designs based on the changing manufacturing requirements. It also enables verification of those designs to meet new requirements through simulation. The design and simulation of these manufacturing systems will be based on real data drawn from existing manufacturing applications.

There are three major parts of this system. The information management part contains manufacturing applications from which data can be extracted, in accordance with the Shop Data Information Model, to describe the manufacturing problem to be solved. The scenario creation part contains a scenario management application that can input a Shop Data File and allow a user to define and regroup manufacturing capabilities based on the concepts of function groups and Petri Nets (PN). This application can also generate the simulation model and support files necessary to run the simulation. The final part is the verification and analysis part. It includes a simulation engine that can execute a simulation using the model and data generated by the Scenario Manager.

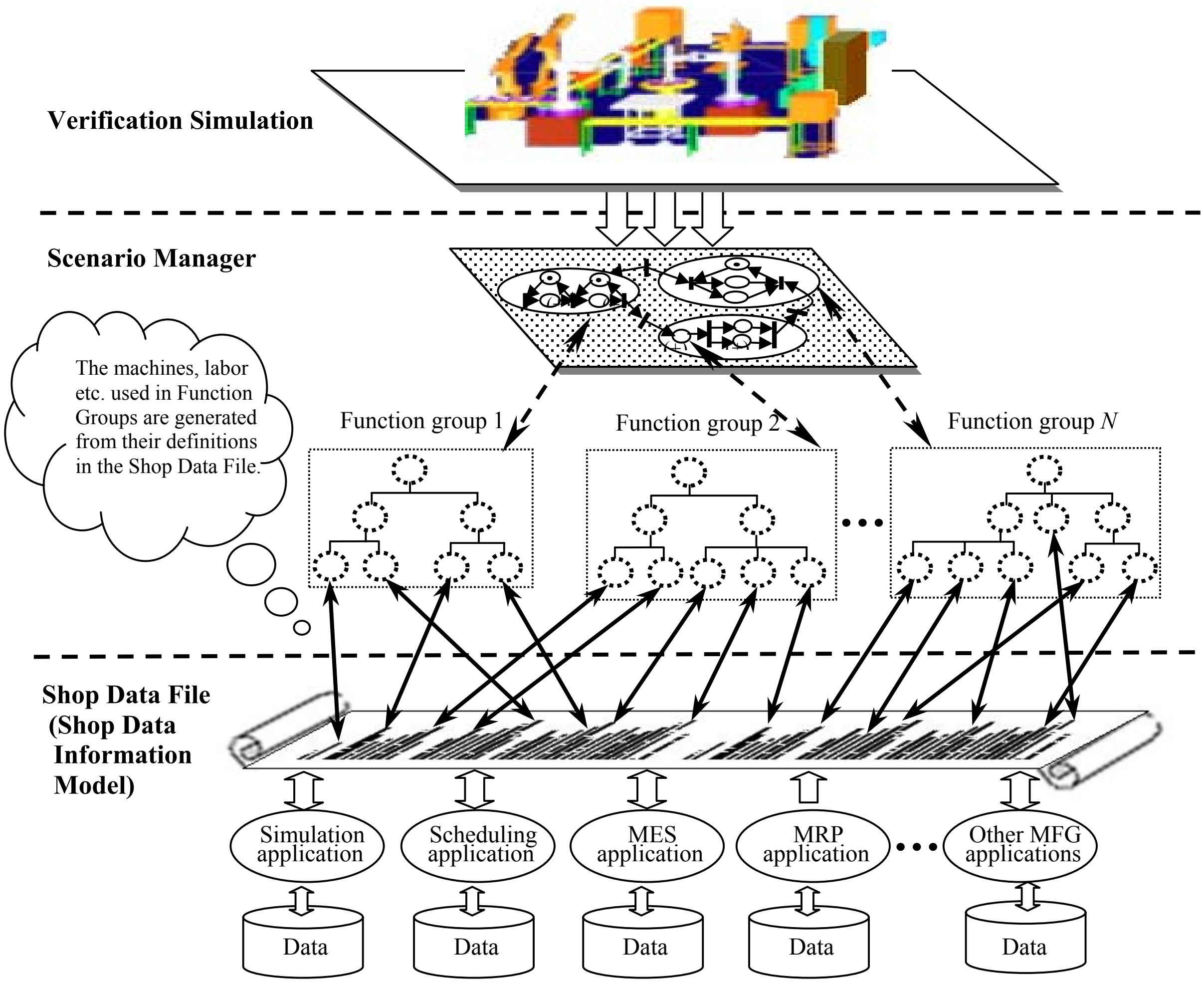


Figure 1: Conceptual Data Driven Design And Simulation System

3.1 Shop Data Information Management

At the bottom of Figure 1, several manufacturing applications that have been enhanced with the ability to export and/or import information based on the Shop Data Information Model are depicted. By enhancing these applications in this way, many problems associated with exchanging manufacturing information can be mitigated. This will reduce the time and complexity included in developing integrated applications suites to manage manufacturing operations and to design new manufacturing capabilities.

To support the Scenario Manager, data describing potential manufacturing system layout designs will be extracted from the existing applications (such as simulation application, scheduling application, manufacturing execution systems (MES) application, and manufacturing resource planning (MRP) application, etc.) and encoded in the Shop Data File. By enabling data-driven simulation in this way, many more layout design scenarios can be examined than would otherwise be possible.

3.2 Scenario Manager

The Scenario Manager manages function groups. Each function group represents a typical manufacturing capability, e.g., fabricating a specific component, a unique welding method, or a testing operation (Gilmore and Pine 2000). The machines, labor, tools, etc. used in a function group are generated from their definitions in the Shop Data File, which is an input to the Scenario Manager. The more diversity among the function groups associated with a system design, the more capability the system possesses to satisfy different manufacturing requirements. Function groups can be combined or reconfigured by the Scenario Manager to form new manufacturing capabilities according to the requirements.

The establishment of a dynamic network among the function groups of a system is critical to support the ability to rapidly reconfigure the system. The goal is to quickly identify required changes and use the changed data to support model reconfiguration. In this system, the valid Petri Net methodology is employed to reach this goal.

Each function group is modeled using a valid Petri Net. The PNs are used to analyze and optimize the manufacturing process.

One issue with using a Petri Net methodology is that it is hard to verify the validity of the PN model, especially when the model is very complex (Jiang et al. 2003). The validity of a PN model is defined by three properties:

- *Bounded* indicates the absence of overflow in the system model. This characteristic allows for the specification of a limit on the number of tokens that may be in a place at any time.
- *Live* implies that there is no possibility of deadlock.
- *Reversible* indicates that the system can return to its initial state from any current state. This characteristic is very important for error recovery.

To be valid means the model developed is reliable, without overflow, deadlock or conflicts. The approach used here is to develop valid PN models of a complex system by extending simpler valid models whose validity is easy to prove (Qiao et al. 2002). This approach uses the PN valid extension theorem. This theorem and its proof can be seen in (Zhou and DiCesare 1991, Wu and Zhou 2001). It states that, if valid PN models are combined in accordance with the connection rules that are defined in the theorem, then the entire combined PN model is valid.

According to this theorem, first, a set of valid PN models of basic serial and parallel systems, buffers and shared recourses are defined. A complex manufacturing system can be broken down into different functional cells described by these valid PN models. Rearrangement and insertion of new function groups is easily accomplished by using the PN valid extension theorem.

The model developed is flexible enough to handle problems of dynamically inserted schedules, system changes, and other unpredictable situations. It offers not only a means to model discrete-event systems graphically and mathematically where concurrency, synchronization and co-operation exist among subsystems, but also can be easily converted into computer control code for manufacturing processes control. The information from the Shop Data File and PN model are used by a simulation generator component to create the simulation model and support files necessary to run the simulation.

3.3 Simulation Verification

The output of the Scenario Manager is used by a discrete event simulation tool to execute a verification simulation. Based on an analysis of the output of the simulation, the Scenario Manager can be used to modify the simulation scenario and generate a new simulation model and support files. These new files can then be used for a new simulation execution. In this way, simulation studies can be done using a data-driven approach without making repeated, tedious modifications to the simulation for each simulation replication. As requirements change or if different analysis results are desired, the simulation model can be quickly modified to perform analysis according to the new requirements.

4 A DATA-DRIVEN ASSEMBLY SIMULATION EXAMPLE

Below is an example of how a data-driven simulation that facilitates the analysis of a manufacturing assembly line could be implemented. In this example, DELMIA QUEST is the target simulation tool, although a similar approach could be used with other discrete event simulation products.

In today's competitive environment where modification and reconfiguration of manufacturing lines are needed with increasing frequency, an efficient and flexible manufacturing system design is very important. The data-driven system described above can be used to rapidly build layout models for analysis with simulation.

A Shop Data File containing the resource, layout, and process information for an assembly line can be created from the available manufacturing data sources. This is the input for the Scenario Manager. It uses the information to generate Batch Control Language (BCL) and Simulation Control Language (SCL) files. These files can be directly executed by DELMIA QUEST.

Figures 2a and 2b are examples of two BCL files that could be generated from Shop Data Files. Figure 2a represents the initial layout that can be used to create the simulation depicted in Figure 3a.

Since the layout model is created from a Shop Data File, modifying the layout can be easily accomplished by changing this file, and then generating a new BCL file and QUEST simulation model. For example, in the Shop Data File, the location of a buffer can be changed and a new machine can be created (as shown in red color codes of Figure 2b). Figures 2b and 3b represent the BCL file and QUEST simulation generated from the changed Shop Data File. Using this approach, different simulation scenarios can be built quickly.

Information needed for process control is extracted from the Shop Data File, and incorporated into the BCL file to facilitate the analysis of both layout and process. An example of this is shown Figure 4. This system contains three parallel processes: a main assembly line, an inspection and test workstation, and a repair workstation.

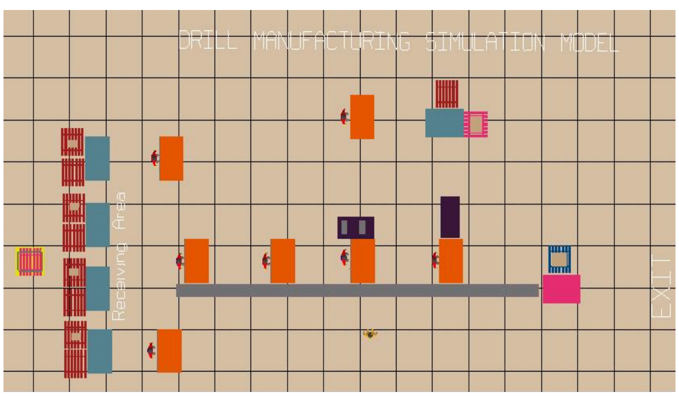
```
SET UNITS TO inch

CREATE    PART_CLASS    'MotorAssy'    DISPLAY
'C:/deneb/putmodel/PARTS/Drill_MotorAssy'
SET PCLASS 'MotorAssy' PRIORITY TO 1
SET PART_CLASS 'MotorAssy' color to $Purple
SET PART_CLASS 'MotorAssy' RENDER TO $SMOOTH
  ⋮
CREATE BUFFER CLASS 'CG_Pallet_Buffer'
SET 'CG_Pallet_Buffer' COLOR TO $color24
LOCATE ELEMENT 'CG_Pallet_Buffer_1' AT -651,
-187, 0
  ⋮
CREATE MACHINE CLASS 'Pack_CG_on_Pallet' GEO
'..\QUESTlib\PARTS\MACHINES\table_2'
SET 'Pack_CG_on_Pallet' COLOR TO $color27
LOCATE ELEMENT 'Pack_CG_on_Pallet_1' AT -612,
-211, 0
ROTATE   ELEMENT   'Pack_CG_on_Pallet_1'   to
0,0,90 in 1
  ⋮
```

a) BCL File For Original Layout

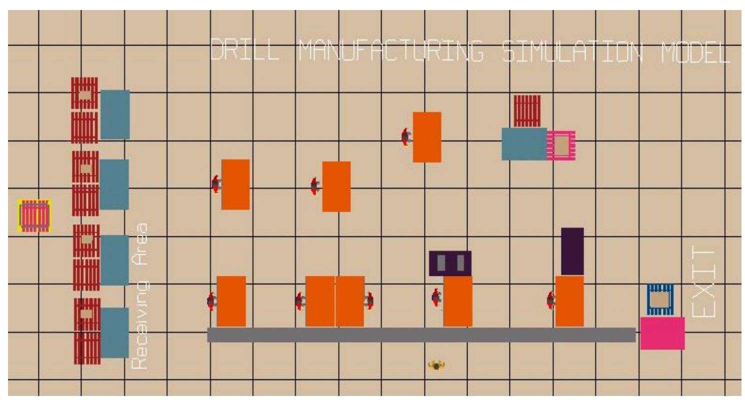
```
SET UNITS TO inch

CREATE    PART_CLASS    'MotorAssy'    DISPLAY
'C:/deneb/putmodel/PARTS/Drill_MotorAssy'
SET PCLASS 'MotorAssy' PRIORITY TO 1
SET PART_CLASS 'MotorAssy' color to $Purple
SET PART_CLASS 'MotorAssy' RENDER TO $SMOOTH
  ⋮
CREATE BUFFER CLASS 'CG_Pallet_Buffer'
SET 'CG_Pallet_Buffer' COLOR TO $color24
LOCATE ELEMENT 'CG_Pallet_Buffer_1' AT 1022,
287, 0
  ⋮
CREATE MACHINE CLASS 'New_CG_on_Pallet' GEO
'..\QUESTlib\PARTS\MACHINES\New_CG_on_Pallet'
SET 'New_CG_on_Pallet' COLOR TO $color27
LOCATE ELEMENT 'New_CG_on_Pallet_1' AT 1022,
111, 0
ROTATE   ELEMENT   'New_CG_on_Pallet_1'   to
0,0,180 in 1
  ⋮
```

b) BCL File For New Layout

Figure 2: XML And BCL File For Layout



a) Top-view For Original Layout Model



b) Top-view For New Layout Model

Figure 3: Top-view Of Layout Model

5 CONCLUSION

Based on this data-driven design and simulation system, highly flexible, rapidly re-configurable production lines can be designed in detail and analyzed using discrete event simulation technology. Utilizing the Shop Data file based on the Shop Data Information Model, when requirements change, the simulation model can be quickly modified to perform analysis according to the new scenario. Potential manufacturing processes and factory layouts can then be planned and optimized.

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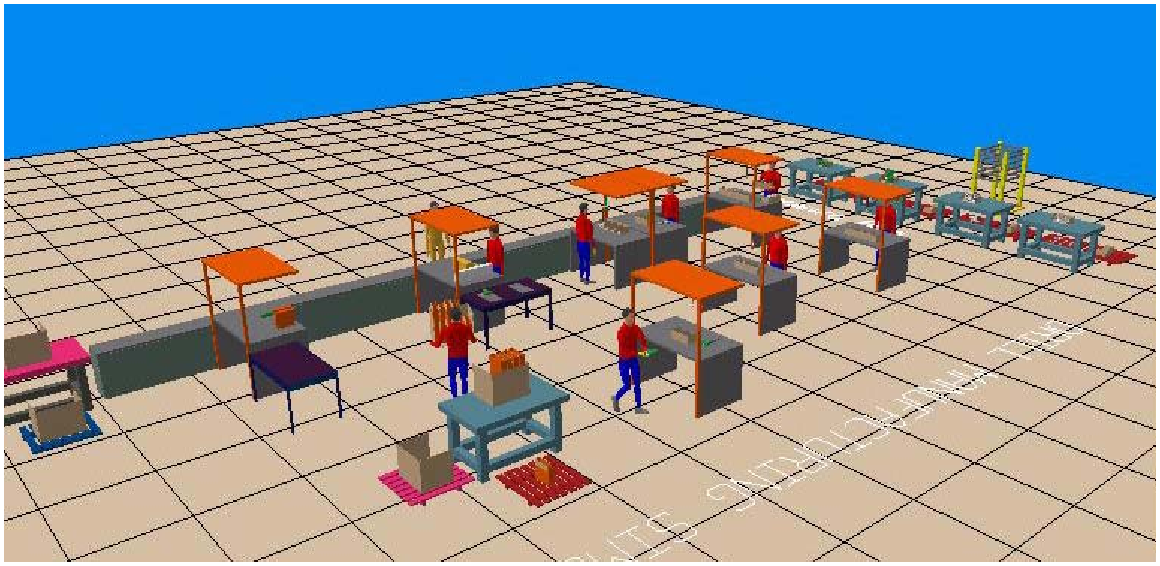

Figure 4: Assembly Line Example

Insertion Demonstration and Evaluation Program (SEI TIDE) Program. SIMA supports NIST projects applying information technologies and standards-based approaches to manufacturing software integration problems.

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