Proceedings of DETC'04
ASME 2004 Design Engineering Technical Conferences and Computers and Information in Engineering Conference
September 28–October 2, 2004, Salt Lake City, Utah USA

DETC2004-57745

MANUFACTURING INFORMATION INTEGRATION IN PRODUCT LIFECYCLE MANAGEMENT (PLM)

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ABSTRACT

The research on manufacturing information integration in PLM calls for a new fundamental information technology to enable adaptive information representation and exchange between manufacturing applications. Four major problems are studied, including interchangeable common data representation, management of information access, information reuse, and disturbance reflection of information change. An information model for manufacturing simulation is built. A problem about the abstraction of real models to virtual models is also discussed. A neutral model of shop information, developed by NIST based on the eXtensible Markup Language (XML), is detailed in this paper with illustrations from industrial applications.

Keywords: manufacturing information integration, simulation, XML, PLM

1. INTRODUCTION

In today's economy, product lifecycle has been significantly shortened. All manufactures are faced with the challenge of making high quality products within a short product introduction time while reducing costs as low as possible. PLM is an emerging solution to address this challenge. PLM allows users to design, analyze, and manage company's products throughout all phases of the product lifecycle. The aim of adopting PLM is to improve the efficiency of product development processes and the capacity of a company to use product-related information.

PLM needs some enable technologies to make it happen. A lot of simulation software vendors have been endeavored to provide PLM via three scopes of tools: virtual product development (VPD) tools that provide the product solution, virtual manufacturing (VM) tools that provide the process and resource solution, and a product data management (PDM) system that provides the data and workflow management [1,2]. These simulation tools can help reduce the risk and costs of product development and shorten the time to put products to market.

Information integration is a core to integrate these scopes of tools. Without an efficient methodology to integrate data, those tools would only be isolated information islands and PLM would be impossible. A methodology is needed to provide a unified perspective for all elements in a domain. This methodology should also offer a sound strategy for integrating and re-engineering the business processes related to the product through its entire life-cycle, leading to reduced costs and faster times to market. Timely and accurate information is a prerequisite to obtain a competitive advantage to meet this challenge [3, 4].

The focus of this paper is on the development of an adaptive XML based information representation for manufacturing information integration in PLM, which provides a natural way to describe important information about the manufacturing facilities and processes, and enables information integration and exchange among different manufacturing facilities. An example of its practical utilization in a Boeing case study [5, 6] is given in this paper.

2. INFORMATION NEEDED FOR PLM

Information needed for PLM includes the entire product and manufacturing information throughout a product lifecycle, from early conception to eventual disposal of the product [7, 8]. An information-flow connects practical applications and simulation tools.

In the face of a huge amount of information, it is important to identify what is the necessary and adequate information to put into the information-flow for simulation and analysis purpose.

As show in figure 1, physical manufacturing process can be simulated and analyzed using virtual product development and manufacturing simulation tools. At the product design stage, virtual product development tools provide the capability of virtual design and assembly, which can help find out potential design problems before fabrication. Kinematics and dynamic characteristics of a product can be analyzed. Product designs can be viewed and evaluated by designers, decision makers and customers in three dimensional realistic geometry models or virtual reality models. Information needed for VPD includes product data, geometry, product bill of material (BOM) and costs etc. Those are also the input information for VM.

VM is characterized by the capability to analyze and optimize the dynamic, flexible manufacturing lines and processes. VM provides powerful tools to build virtual layouts, integrate virtual devices, and plan manufacturing processes. Compared with the relatively mature VPD technology, VM is attracting more and more attention as an important part to achieve the PLM goal. Modern manufacturing is featured by flexibility, and more focus on personality, namely mass customized products. Mass customization is a production philosophy to provide customized products while keeping costs at the mass production level. This implies more product variety must be able to fabricate quickly, maybe in the same production line, according to rush order requirement. More turbulence is introduced into production lines. And the complexity of the product variety will be transferred to the process planning eventually. These make it very complex for VM to obtain an efficient process and resource solution. Information needed for VM includes resources, such as machines, buffers, transformation tools, laborers, as well as process information and product information.

Based on VM, virtual enterprise helps to support cooperation among branches. Manufacturing is a global activity now. An enterprise may have several different factory locations in different countries. Supply vendors are scattered around the world. An efficient information integration and communication system is critical to coordinate those branches.

Because of the complexity of information needed for PLM, it is easy to lead to situations where the needed information may be incomplete, or in different, incompatible formats. Practical manufacturing data, including product data and production data, are usually scattered in various sources like databases, charts, spreadsheets, hand or computer generated drawings, and flat files, etc. Similar information may have different functions. This leads to problems with storing, retrieving, and exchanging information between simulations and other manufacturing applications.

3. ADAPTIVE INFORMATION REPRESENTATION FOR INTEGRATION

The research on information integration for PLM calls for a new fundamental information technology to enable adaptive information representation and integration. It focuses on four major problems: 1) achievement of a common data format for enabling product visualization and information distribution and enhancing data sharing between PLM software applications; 2) exploitation of web-based technology in production systems with the crucial ability to manage information access; 3) management of information components for reuse purpose and enabling dynamic assembly of customized documents; 4) development of a mechanism to enable reflecting the disturbance of information change and to create a feedback loop from production to design.

3.1 COMMON DATA FORMAT

We need a better way to manage the huge volume of data. There needs a common information infrastructure that can provide reliable sharing of information between systems on the manufacturing applications and other parts of the enterprise. It provides members with the opportunity to work together to develop common business practices around the specification format. For today's globally distributed manufacturing environment, visualization is also a key to effective collaboration and exchange of product data within the manufacturing supply chain. The common data format can provide a pipeline to become a collaborate hub for the enterprise's global network, including their vast supply chain [9].

3.2 INFORMATION ACCESS – WEB BASED MANUFACTURING

The future of manufacturing is heading towards a model where mass produced goods are tailored to individual customers - mass customization and web-based manufacturing. Web-based technology is important to enable the management of information access in production systems in this trend. This is going to be a direct consequence of phenomena like globalization and the internet [10, 11].

Jon Mainwaring [12] argues that the web-based product configurators will play a big part. Customers can access product information and place an order through web. Product configurators allow consumers to select the features of products they want to buy like cars, PCs and mobile phones. So custom orders can be identified as product features and transferred to product design to evaluate the possibility of assembly. BOM is achieved for this product and process plan. The manufacturing resource plan (MRP) can be done to inform supply chain's action. The information is feed back into the manufacturing system, where the cost of the product configured is determined and sent back to the customer, along with an estimation of how long it will take to assemble and deliver. From the time an order is confirmed, the whole manufacturing system is ready.

Timely information about product design, resource availability status, process plan, manufacturing schedule and supply chain components, etc. need to be accessed, gathered, transmitted, and updated. An understandable, standard information representation for all this is a necessity.

3.3 INFORMATION REUSES AND COMPONENTS MANAGEMENT

Information reuse is always a big concern in information technology. For manufacturing simulation application, reusable simulation model can save developers huge time and energy that means great improvements in efficiency.

There needs something called component manager for information reuse and reconfiguration. Information is broken into smaller information components for reuse purpose. When something needs to be revised or customized, changes can be made to just the components affected without having to redesign the whole document.

Information can be reassembled when it comes with the demand of customized information. For example, the same information is reused, but needs different presentation for different users, e.g., supply vendors; or different detail information for different level of users. The smaller and more specific the component is the more addressable and reusable it is. Unlike conventional document management systems, component management can demonstrate document files into their component parts. And manage these independently. Information can be searched for, revisions tracked, and assembled into new documents, for example, at the level of a specific section or even paragraph [13].

Components management can also be utilized to support the configurators mentioned in section 3.2. It can swiftly find out the available substituted resources if the necessary one is occupied and quickly reconfigure the production system.

3.4 DYNAMIC INFORMATION INTEGRATION

One of the difficult things for information integration is to reflect the disturbance of information change. A number of events may disturb the manufacturing task execution at different levels, thereby implying a non-optimal performance according to the initially prescribed plans, which may lead to unfulfilled customer requirements or/and increased costs.

Dynamics originating from new orders and varying costumer demands must be added to the existing production dynamics ranging from fluctuations in material process, the delivery performance of sub-suppliers to the breakdown of machines and other common daily failures.

A methodology needs to be developed to enable the reflection of information change and to create a feedback to react immediately and appropriately.

4. A SOLUTION – XML-BASED MANUFACTURING INFORMATION REPRESENTATION

With its ability to describe data and content, XML has added a new dimension to enable information access, reuse, and dynamic assembly.

XML can be a standard interchangeable information representation. It 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. Many free and low cost tools exist that support the definition, creation, modification, validation, and display of XML documents.

There are many ways to create XML. Some companies can author XML directly in an editor designed for that purpose. Others can convert existing content from proprietary publishing formats into XML. Still others can leverage existing web-accessed information and use XSLT to convert it into an XML document for delivery or interchange. As shown in figure 2, manufacturing-related information can be inputted in a XML document. Via parsing, it can be utilized as an exchangeable document among different manufacturing applications.

XML can make components. This makes it available for reuse purposes. XML makes it natural to work with information as a series of components, assign metadata and search within an information set. By combining XML with the use of a component management system that brings engineering efficiencies to the manufacturing process, enterprises can better manage the collaborative work, information reuses, dynamic document assembly, and easy distribution to multiple supply vendors or other manufacturing applications.

Another way XML adds value to information is through attributes or metadata. By adding “information about information”, users can further describe the information for repurposing [13].

A NIST developed neutral model of shop information, based on XML, is discussed in section 6. The purpose of the project is 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.

5. BUILDING AN INFORMATION MODEL FOR MANUFACTURING SIMULATION

Manufacturing simulation concerns all the aspects of product design, process plan, manufacturing plan and supply chain management. How all this information is organized into an information model for exchange is the topic discussed in this section.

As shown in figure 3, manufacturing plan is resource centered. From the information representation aspect, a manufacturing plan can be depicted as resources utilized in a production line and linkages between resources. Resources include machines, buffers, laborers, cranes, fixtures, transport tools, etc. To setup a manufacturing plan simulation, first of all, the layout of those resources is implemented. In a discrete simulation environment, after this step, models of the virtual production line can be visualized in a three-degree scenario, with all necessary resources located in predefined positions and orientations. Yet this is just the first step for a simulation analysis.

More information is needed to link these resources to perform simulation and analysis. Let’s use one of the resources, machine, as an example, information related with machine includes:

- Premise information, such as shift data;
- Process cycle, which is the combination of processes (results from the line balance calculation) performed on this machine;
- Other resources related, for example, laborer needed for an operation on this machine, or transportation tools needed for transporting finished parts;
- Part routing, which is used to define where the finished parts should go from the current resource to the next resource as the incoming of the future process. It is a necessity when the output of this resource is more than one;
- Linkage between resources: run after and run before.

Each resource is assigned a number of processes according to the complexity of the activities performed on it. Product information is linked to process plan. As shown in figure 3, basic information related with process plan includes:

- Cycle time;
- Input part or subassembly, which is the constraint for starting a process. This means the process cannot be triggered until all the part or subassembly requirements are satisfied;
- Output part or subassembly, which means what kind of product is produced through this process. It can be a new part or a new subassembly.
- Linkage between processes: run after and run before.

One of the consequences of increasing use of flexible resources is the explosive number of potential process plan alternatives for each unique product. Line balance calculation is needed to perform before a process is assigned to a specific resource. Other process-related information such as process logic also needs to be considered.

To simplify, figure 3 can be explained in this way: product information is linked to process; process information is linked to resource; resources construct a manufacturing plan. So finally, the manufacturing plan is where all information is connected. This means that manufacturing information integration, resource information, process information and processes information need to be fully integrated.

A simulation environment is an abstraction and mapping of the practical manufacturing environment. The typical correspondence between a concrete representation and an abstract conceptual value of an abstract data type object is a many-to-one function [14]. For simulation, there needs some specific information, most of them related to display, namely abstract information.

Using a very simple manufacturing simulation model as an example, as shown in figure 4, the model contains two machines, one laborer moving parts between the two machines, and one buffer. Resource information used to build this simulation model, including abstract information, is as follows.

Machine:
- Location
- Orientation
- Geometry: abstract information, for display
- Process definition: setup process: time
  cycle process: cycle time, input part, output part, logic etc.
- Labor point: abstract information, defining where the labor stand before the machine
- Stack point: abstract information, defining where the part is placed on the machine
- Stack axis: abstract information, defining the axis for stack point
- Part routing

Buffer:
- Geometry: abstract information, for display
- Color: abstract information, different kind of buffers can be set as different colors
- Location
- Orientation
- Labor point: same as explained in machine.
- Stack point: same as explained in machine.

Labor:
- Move time mode: defining how labor moves around.
- Display color: different labor levels can display with different colors
- Location
- Labor controller: defining default labor behaves logic

6. APPLICATIONS

This section discusses a NIST developed XML-based shop data specification, and a data-driven design and simulation methodology based on this specification.

To address the information integration problem, a neutral model of shop information, based on the XML Language, hereafter referred to as the Shop Data File, is developed by NIST. It 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 [15].

The Shop Data File provides a mechanism for sharing data between simulation, other manufacturing applications, and supply vendors. 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.

The shop data specification contains four major supporting data structures and fifteen manufacturing data structures. Supporting data structures in the shop data file includes: (1) time-sheets, (2) probability-distributions, (3) references, (4) and units-of-measurement.

Manufacturing data structures include:

- organizations
- calendars
- resources (containing machines, stations, cranes, employees, tool-catalog, and fixture-catalog)
- skill-definitions
- setup-definitions
- operation-definitions
- maintenance-definitions
- layout
- parts
- bill-of-materials-group
- inventory
- process-plans (containing routing-sheets, operation-sheets, and machine-programs)
- work (containing orders, jobs, tasks, order-items, maintenance-orders, pickup-orders, and tool-orders)
- procurement
- schedule

A data-driven design and simulation methodology based on this specification is utilized to build the simulation model of a Boeing aircraft major component assembly line. All information needed for that manufacturing simulation is encoded in the XML-based shop data file.

For example, the XML structure for the resource element is depicted as:

```
<resource type=””   identifier=”” number=””>
    <name/>
    <description/>
    <reference-keys/>
    <revisions/>
    <machines/>
    <stations/>
    <cranes/>
    <employees/>
    <tool-catalog/>
    <fixture-catalog/>
</resources>
```

This simulation model contains more than thirty complex processes on fourteen different machines. Most processes required a different number of laborers from various labor classes.

The shop data file is utilized as the input of manufacturing simulation. DELMIA QUEST is the target simulation tool, although a similar approach could be used with other discrete event simulation products. Via a parser, which could be DOM facility or XSLT, a QUEST executable Batch Control Language (BCL) / Simulation Control Language (SCL) file is generated. Different from the traditional way of building a simulation model manually, the simulation model is built and driven by a data file --- the shop data file. The model created is one hundred percent complete, including all necessary information for analysis, and ready to run.

Other than to modify process parameters manually in discrete event simulation tools, this XML based shop data specification enables simulation practitioners to manage modeling exercises, such as model reuse, reconfiguration, and process data integration more proficiently. 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. Details about this methodology and case study can be found in [5, 6, 16].

The shop data file contains standardized and interchangeable manufacturing information, which can be exchanged easily between applications as text files.

7. CONCLUSION

In today's information technology dominated world, a neutral data format, which can be exchanged among applications, has a broad utilization future. In the manufacturing simulation area, this methodology is an innovative approach toward manufacturing information sharing, which means the immensely reduction of simulation costs, for both simulation users and simulation software vendors. Application case studies have illustrated somewhat utilization potential. Yet the full potential for that is still needed to discover. The next step of this work will focus more on the supply chain.

ACKNOWLEDGMENTS AND DISCLAIMERS

The NIST portion of the project is funded by NIST's System Integration of Manufacturing Application (SIMA) Program. SIMA supports NIST projects applying information technologies and standards-based approaches to manufacturing software integration problems. Commercial software products are identified in this paper. These products were used for demonstration purposes only. No approval or endorsement of any commercial product by NIST is intended or implied.

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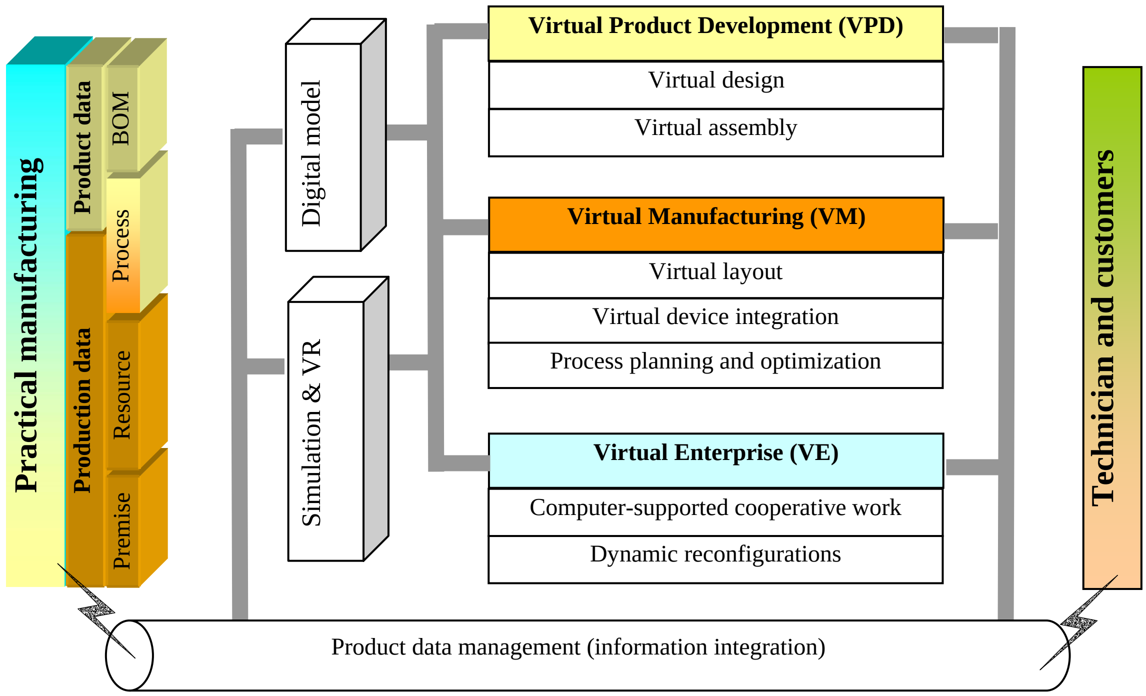

Figure 1. Information Integration for PLM

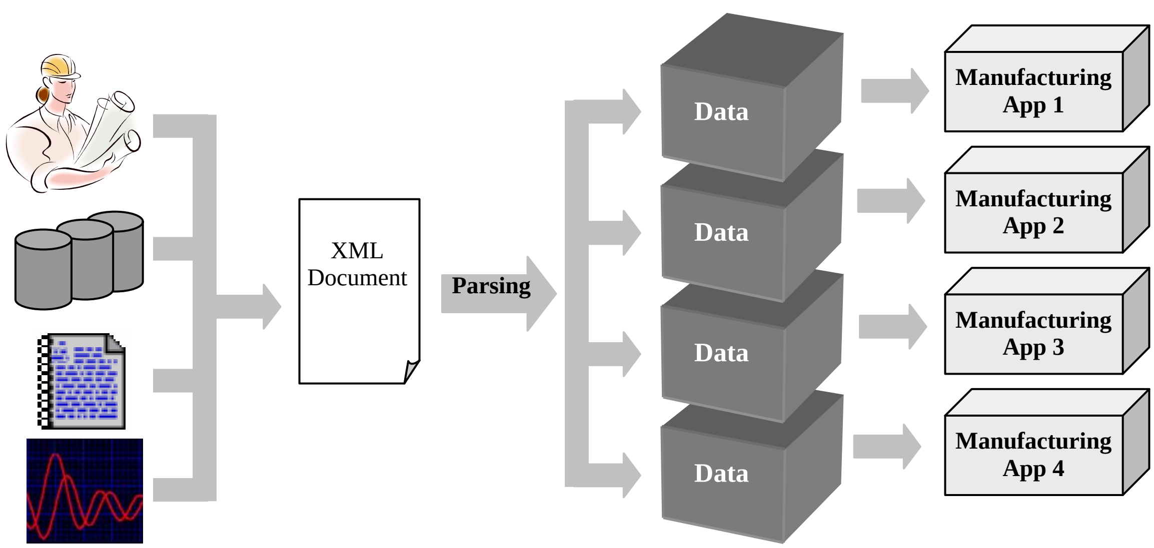

Figure 2. XML-based Information Representation

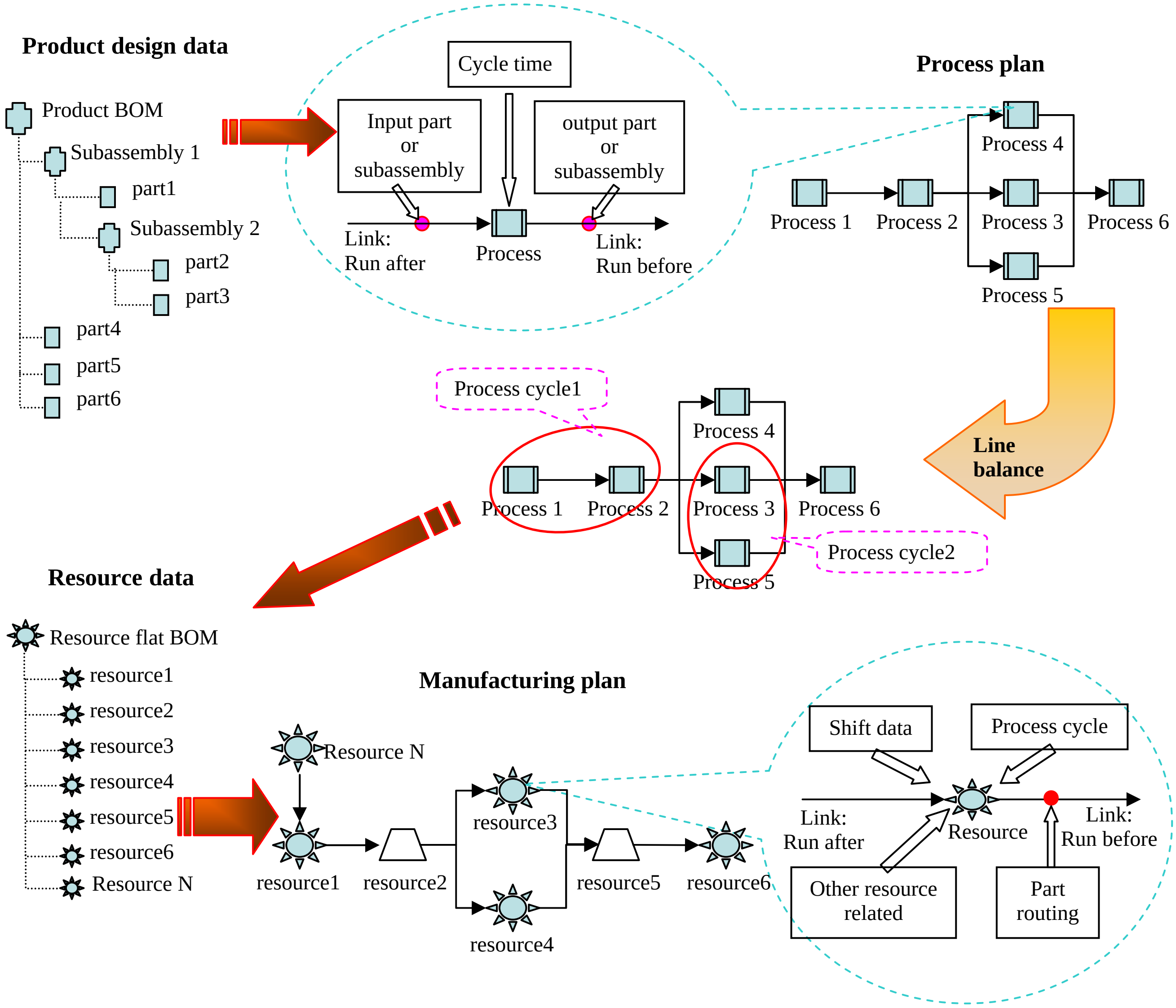

Figure 3. Information Model for Manufacturing Simulation

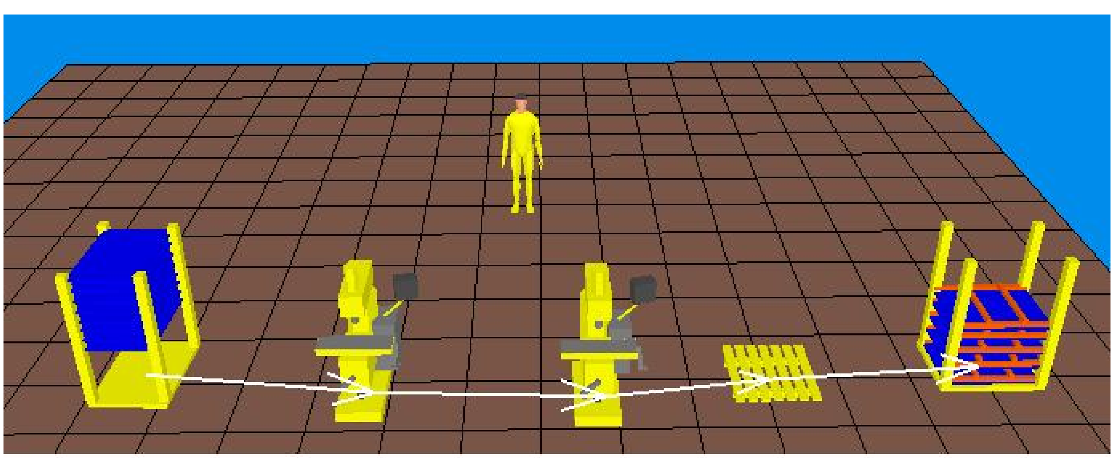

Figure 4. A Simple Manufacturing Simulation Model