Process Control and Logistics Management for Mass Customization Manufacturing

Guixiu Qiao, Roberto F. Lu*, Charles McLean

Manufacturing Systems Integration Division
National Institute of Standards and Technology
Gaithersburg, MD 20899-8260
U.S.A.

*** Commercial Airplanes Material and Process Technology**
The Boeing Company
Seattle, WA 98124-2207
U.S.A.

Abstract

The emphasis on increasing product variety and individualization has created a strong demand for a new strategy of Mass Customization Manufacturing (MCM). A competitive and flexible manufacturing system must be developed to respond to small batches of customer demand. In this paper, problems of highly flexible process-control and logistics-management methodologies are addressed to meet MCM needs. The integration of manufacturing information with suppliers is developed. This integrated system information relies on open interfaces for data exchange with neutral data formats – the NIST Shop Data Specification, adopting XML. Additionally, process - resource planning, and component push - pull logistics are also discussed.

Keywords
Mass customization manufacturing, process control, logistics management, information integration, simulation

1. Introduction

Today's competitive industry environment is characterized by unpredictable and changing world-wide markets. Mass production can no longer capture market shares and gain higher profits by producing large volumes of standard products. Companies are forced to search for sustainable strategies for surviving and thriving within the global competition. Mass customization has received much attention.

Mass customization is the use of flexible processes and organizational structures to produce varied and often individually customized products and services at the price of standardized, mass-produced alternatives [1]. It seems to be an unreachable ideal until recent advances in product design, e-manufacturing and information technologies made this change possible. Those enabling technologies significantly enlarge the application field of mass customization in many ways. A wide range of industries including textiles, automotive, engineering, aerospace, consumer products, food, as well as firms in distribution and logistics, have been influenced by this innovative strategy. It not only changes the way customers make purchases, but also has strong influence on how products can be made. Mass customization has been viewed as a new business paradigm that can be used as a cornerstone for a new strategic approach. Business Week 2000 said, "The mass market of the 20th century is giving way to a market of one: mass customization."

The realization of mass customization implies an integrated system, as depicted in Figure 1. Design For Mass Customization (DFMC) is based on the concept of Product Family Architecture and postponement of product variety, which involves delaying activities throughout the supply chain until customer orders are received with the intention of customizing products [2]. Success in Mass Customization Manufacturing (MCM) is achieved by swiftly reconfiguring operations, processes, and business relationships with respect to customers' individual needs and dynamic manufacturing requirements. A new level of information integration is required both within the organization and with external parties. It means sharing of information to deliver value to the customer all the way from distribution back through manufacturing and design.

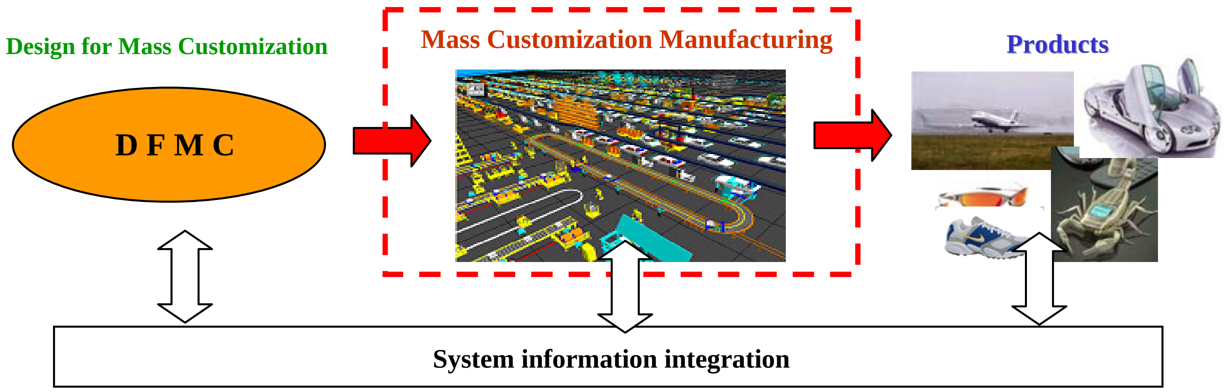

Figure 1. New strategy of manufacturing -- mass customization

Few literatures were published talking about critical technologies to enable MCM, especially for complex products like aircraft. Every commercial airplane is customized with different customer preferences and requirements, which associated manufacturing and logistics systems. The application of an MCM system in the aircraft industry faces challenges in achieving the goals of reduced lead-time and production cost. Critical MCM related technologies in process control and logistics management must be studied, to enable the integrated manufacturing system gaining capacities to change quickly. This paper presents a perception of an MCM technology in the aircraft industry.

2. Why process control and logistics management are critical MCM technologies

Implementation strategies must be analyzed to identify what are critical technologies demanded by MCM. There are two manufacturing-related MCM implementation strategies: optional MCM and core MCM[3]. Their characteristics, realization approach etc., are analyzed and listed in table 1 below:

Table 1. Analysis for MCM implementation strategy

Implem-entation strategy	Characteristics	Realization approach	Typical application example	Critical enabling technologies
O P T I O N A L M C M	It provides more varieties by providing pre-designed, standard options to customers. Customers can select limited options from the list and request them to be assembled.	Optional customization divides the manufacturing process into two stages: 1) Fabricating and storing components, and 2) Assembling these components into final products according to current demands.	The optional MCM is the most popular implementation strategy used by many companies. Typical products made using this strategy are computers. It needs to deal with frequent changes of manufacturing batch quantities and the aggressive delivery time demanded by MCM.	• DFMC • product configuration • process control • logistics management
L E V E L I	It allows customers to choose their products based on choices of product attributes, which is significantly different from the optional MCM.	Adjusting functional modules of manufacturing line to satisfy product attributes changes. The layout of manufacturing modules remains unchanged.	In apparel manufacturing, different style of clothes can be cut by the same laser-cutting machine. What needed to adjust are machine programs. Customers can design their own clothes styles.	• modular manufacturing arrangement • process control • logistics management

Table 1. Analysis for MCM implementation strategy (continued)

Implem-entation strategy	Characteristics	Realization approach	Typical application example	Critical enabling technologies
LEVEL II	It is the final goal of MCM. This strategy starts from the idea that: a) we cannot accurately predict who our customers will be, and b) we have the ability to provide demanded services from customers.	Building a parallel factory. Company builds two factories: mass production and mass custom. Most line workers are employed by the mass-production factory and only a few of the best skilled line workers work at the mass-custom factory to produce the high-end, custom-made products.	The National Bicycle Industrial Company (NBIC) works in this way. Although NBIC's customized bicycles only account for 2% of total production, the high-end Panasonic bicycles now contribute 27% of total revenues. For the first time, NBIC became the industry's second largest manufacturer of high-end bicycles [4].	• highly flexible workshop • process control • logistics management
		Reconfiguring production line to adjust production capabilities. This approach can produce extra features to satisfy unexpected customer demands. Layout is re-configurable. Needs to make the physical factory reconfigurable.	The General Motor's Michigan Electronic Vehicle assembly factory. It has been equipped with movable workbenches that can be adjusted efficiently according to manufacturing requirements. This factory can change swiftly to meet new demands. It's expandable throughput ranges from 2000 to 100000 cars per year [5].	• generalized production line platform • layout re-configuration • process control • logistics management

From the above analysis, process control and logistics management are two critical problems that need to be addressed for all efforts in MCM. They are also urgent problems that need to be solved in practical industry applications.

3. Process control for MCM

The process control for MCM can become very volatile with smaller batch size, higher variety, faster response and irregular insertion of new orders from customers. Discrete event simulation is a powerful tool that can help to quickly identify problems and derive optimized solutions. Traditionally, building process control information in simulation models is a painful task. Actual process information in industry usually comes in the form of spreadsheets, Gantt/PERT charts, and even some draft notes. Tens, even hundreds, of processes need to be manually established in the modeling practice. When a new scenario needs to be developed, modification of processes in simulation models must be done manually one at a time. In such a situation, it is challenging to handle process control information efficiently in getting alternative results upon making necessary scenario changes.

To address those problems, an approach to process control that is driven by an XML-based shop data file has been developed. Another concern of process control and simulation is how to organize resources. Mass customization, by definition, requires different products or services each time. This simulation modeling yielded more optimized resource utilizations and improved system efficiencies.

3.1 XML based information integration for MCM data driven and reconfiguration

The shop data file developed by the National Institute of Standards and Technology (NIST) is an information model in eXtensible Markup Language (XML)-based exchange file format [6]. The shop data file can facilitate the integration of manufacturing information between simulation applications, drive, and reconfigure simulation model executions. The shop data file contains four major supporting data structures and fifteen major manufacturing data structures.

Supporting data structures in the shop data file include: time-sheets, probability-distributions, references, and units-of-measurement. Manufacturing data structures include: organization-directory, calendars, skill-definitions, operation-definitions, resources (containing stations, machines, employees, cranes, tool-catalog, and fixture-catalog), layout, parts, bill-of-materials-group, inventory, process-plans (containing routing-sheets, operation-sheets, and machine-programs), work (containing orders, order-items, jobs, and tasks), purchase orders, schedule, maintenance-requirement-definitions, and setups.

Simulation models of a manufacturing system can be created and reconfigured, driven by this shop data file. An example of practical utilization in a Boeing case study is given in section 3.2. The XML-based shop data file contains standardized and interchangeable manufacturing information, which can be exchanged easily between applications as text files. By combining XML with the use of a scenario management system that automatically creates simulation models using the shop data file, companies can improve the collaborative processes, gaining information reuseabilities, and ease the information distribution to multiple applications. The use of the shop data file in exchanging manufacturing information is applied as a steady stream of information to coordinate and control activities in manufacturing processes.

3.2 Process control based on XML-base shop data file

An example of a part of a case study addresses a possible future process in one of the Boeing manufacturing facilities [7]. Information concerns about process control include: shift information, incoming part loading time, setup time, cycle time, part requirement, labor requirement, labor work positions, produced product, crane requirement, routing information, logistics, process logics, and cost. They are stored in an XML-based shop data file as shown: below:

```
…
<machine-processes quantity-processes="2">
<machine-process type="CYCLE PROCESS”
identifier="ProcRHPosB" number="1">
    <name>ProcRHPosB</name>
    <process-number>CYCLE PROCESS 1</process-
number>
    <process-time>28800</process-time>
    <product-mode>
    <part-keys>
        <part-key separator=",">
            <class>PartLH</class>
        </part-key>
    …
    </product-mode>
    <part-requirements>
        <part part-requirement="1">
            </part>
                <part part-requirement="1">
                <name>PartRHCart</name>
            </part>
    </part-requirements>
    <labor-requirement>
    <employee-keys>
        <employee-key labor-quantity="6">
            <employee-identifier>
             lbrMechanics</employee-identifier>
        </employee-key>
    </employee-keys>
    </labor-requirement>
</machine-process>
…
```

An example manufacturing operation is shown in Figure 2 and its coordinated process control modeling is illustrated in Figure 3. In Figure 2, incoming parts arrive at the buffer 2 via the only overhead crane in the system. The part will then be processed through the line. An external process is positioned outside the physical sequence of the main process

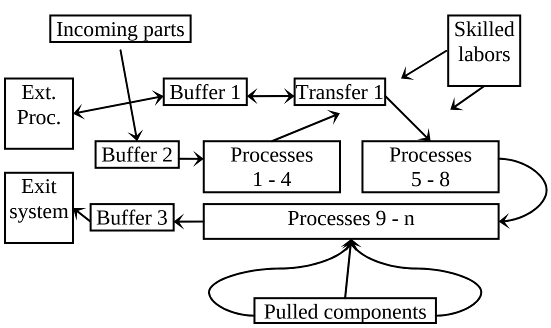

Figure 2. An assembly manufacturing process

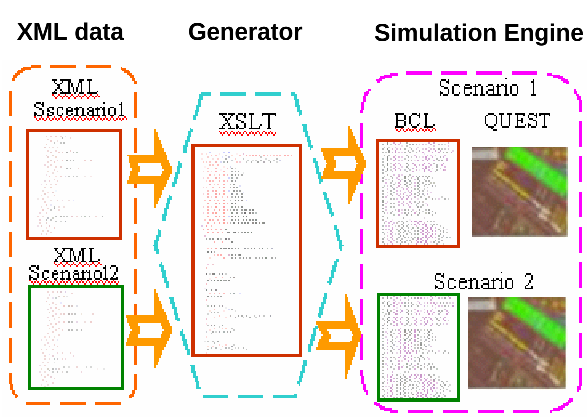

Figure 3. Data driven process planning

flow. It requires additional resources and crane movements. Different combinations of certified and highly skilled mechanics are needed at different process area within the system. These various processes and entity types, such as crane, buffer, labor, machine, etc. in this example manufacturing system are coded in an XML-based shop data file. Thus there exists a means of controlling manufacturing processes. The overall system schema of such an architecture is displayed in Figure 3. Pulled components are mostly produced by remote suppliers, which are not part of the main system flow. Feasible and efficient logistics management in pulling components into the given process needs to exist to support the overall system integrity. More discussion in the pull-push logistics management is included in the next section.

As shown in Figure 3, process information can be encoded in the shop data file. An XML Style Sheet Translate (XSLT) template is developed to translate the shop data file into Batch Control Language (BCL) and Simulation Control Language (SCL) files. These BCL/SCL files can be executed directly in the QUEST simulation software. Modifications of different scenarios can be done directly inside the shop data file, and the entire update can be automatically mirrored in the simulation model. This is different from traditional methods in modifying modeling processes. This generalized approach enables much faster process realizations from demands (XML data) via translations (Generator) to process modeling (Simulation Engine) [8]. Manufacturing capabilities, production processes, layout arrangements, and resource configurations can be more dynamically reconfigured according to simulation analysis results.

4. Logistics management for MCM

The traditional mass production model is a planning-based model. It is an explicit linear flow associated with the value chain model as typically depicted in Figure 4. In comparison, MCM model has some noticeable distinctions as shown in Figure 5. MCM system begins with a customer order that forces companies to take different approaches to organizing the workflow. Many activities in MCM model are being done simultaneously.

Figure 4. Traditional mass production model

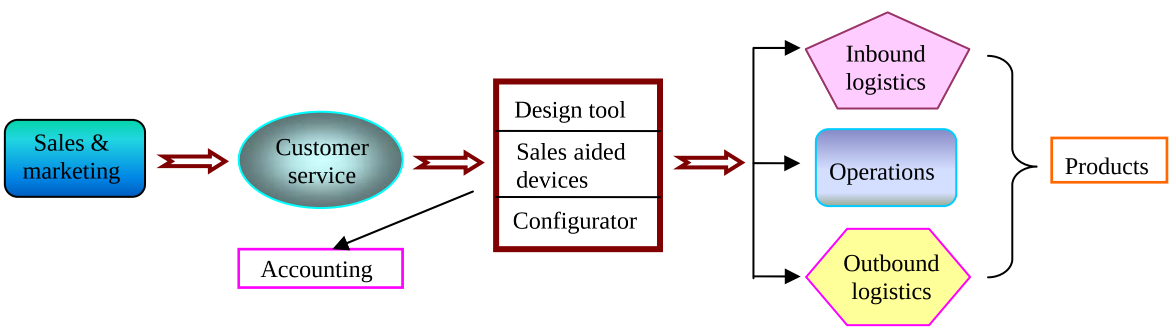

Figure 5. MCM system model

Moreover, compared with traditional manufacturing practices, which execute the push more than the pull processes, MCM exercises both push and pull processes. Yücesan and Groote[9] indicated simulation experiments with load-dependent order release mechanisms yield superior performance even in an environment with a high degree of uncertainty. Desired dynamic coordination among these pulled and pushed processes is often a challenge to practitioners of limited confidence level in relevant domain knowledge. Bonney et al [10] mentioned that when forecasting in a multi-product situation with long lead-time items, the problem becomes more complex. Transitions and linkage logics among sub-systems of long-lead items are part of the challenges.

Since both pull and push side of the production systems operate on their own respective schedules, even though both schedules are associated to each other, simulation modeling can be conducted independently for each side. Same type simulation modeling components can be applied to both the Assemble-To-Order (ATO) – pushed and the Make-To-Order (MTO) – pulled systems. This practice is applicable to processes within the ATO and / or MTO systems.

The time between releasing an ATO event and pulling an MTO event is mainly a function of the component manufacture time. The pushed ATO process generally has high visibility and continuously accumulated product value. The overall time span is largely contributed by the pulled component MTO processes. An integration of push and pull systems which implies that one part of the lead time is pushed and the other part is pulled. There are occasions that an ATO process has committed to push a product through its processes and yet had to wait for the corresponding pull orders to be completed from MTO processes, whilst some other MTO processes went ahead of others with extra inventory in buffers.

Kim and Tang [11] presented that reducing lead time, response time combined with product development cycle time would contribute to lower inventory level, increasing customer satisfaction, and better strategic planning. A methodology is utilized by reducing or eliminating non-value added activity, to work on just what is needed, and to streamline responsiveness in a lean/pull manufacturing solution. It has been generally true that the smaller the MTO lead-time and process time, the more time customers can have to change their options within an order that had already been committed to the system. Existing methodologies might not reach perfect solutions. It is favorable to have a process approach, which can make logistics management performances of all objects in an MCM system visible and controllable.

5. Conclusion

Mass customization is bound to become an important part of industries, from car, furniture to apparel [12]. Research on MCM is still early in its development as compared with other conceptual development for mass customization. In this paper, two critical MCM enabling technologies: XML-based process control and logistics management are studied. One of the future work possibilities may involve supply chain management in MCM.

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