EDI electronic documentation, mass customization, product family, industrial engineering

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DISTRIBUTION OF INFORMATION AND DOCUMENTATION FOR THE MANUFACTURING PROCESSES OF THE HIGH-VARIETY PRODUCTS – CASE STUDY

Abstract

In the last years the researches in engineering have moved towards customer-oriented manufacturing. The individual customer's requirements are very important for the company's activities. It results high-variety production. High-variety production like mass customization is facing the challenge of effective variety management. Applying methods of mass customization to the empirical process can improve product development process efficiency and reduce time and cost. The manufacturing process requires documentation of the production. Very often, the documentation process and the time of its formation is limited. The article includes an analysis of the modern manufacturing systems and answering the question: how is it possible to produce without having a documentation in paper form. The presented solution is used during the high-variety products manufactured in the SMEs. The method was validated in the conditions of best practice high-variety production.

1. INTRODUCTION

In the past the fundamental objectives for most companies were to produce as cheaply and efficiently as possible and to reach as large a customer group as possible with the same product (mass production philosophy). The customer orientation is one of the most essential strategies for every manufacturer.

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Previously the primary source of competitive advantage for manufacturing companies in many industries was related to price. Therefore, all manufacturing strategies were driven by attempts to reduce the cost of the product. Technological advances, in manufacturing as well as in information, have provided the impetus for change in many paradigms, including customer expectations. Customers have become more demanding and want products that can meet their specific individual requirements. Producing customized products at a low cost, which seemingly is a paradox, is the purpose of many enterprises. This main purpose, which is considered as fulfilling customer needs, results in production by unit and small batch process [2, 19].

For many companies, this implies a need of production, in short cycles while keeping a cost criterion. Reducing the time from the moment of customer decision to receiving product may involve many aspects: a presentation of an attractive offer, the acquisition order, the process of product data preparation and issue of manufacturing documentation, the manufacturing process and delivery of the product to the customer. In this article the author focused on the issues of product data preparation, documentation of the manufacturing process and its distribution. Currently, a very important issue is supervising changes in manufacturing processes and thus the emitted documentation. Printed documentation has the disadvantage. The change can be made when user finds documentation and all the copies.

Currently many companies use IT systems supporting the organization of the manufacturing process. However, to what extent the SME's can use existing IT systems to manage the manufacturing process using only documentation in the paperless form? This is a question that the author of this article want to answer.

The paper is structured as follows. First, the studied problem is shortly described. Then, an example to illustrate the problem is presented. The main part of the article consists of an analysis of variants of data collection, preparation of high-variety product data and manufacturing management using paperless forms of documentation. The article concludes with some summary remarks.

2. PROBLEM BACKGROUND

2.1. Product variety management

Past research on product variety management explored multiple solutions to overcome varies difficulties. Some scholars focused on integrated approach for flexible manufacturing systems [12] others on product structure and specification [6, 1], mass customization, part family manufacturing and group technology (GT). The concept of Mass Customization (MC) has received considerable attention in the research literature [3, 7, 23, 24, 27, 9, 15].

In the MC environment, customers are placing unprecedented pressure on manufacturers to deliver a highly customized product at a highly accelerated speed and at highly reduced cost. The companies are finding it extremely difficult to manage these conflicting priorities and they are looking for innovative ways to optimize their systems so that they can satisfy the demanding customer of today [12]. The fundamental modes of operation for mass customization were given in many publication among others [11, 26, 25].

The changing economy world has caused an increase in the use of just-in-time manufacturing, which results in a trend toward short-run, multiple-product manufacturing. The frequent product changeovers make it imperative to improve setup operations and shorten line changeover times.

2.2. Trends from a paper-based to a paperless factory

Paperless factory is not the main goal of companies. The goal is a response to the customer needs by improving quality and on-time deliveries, shrinking manufacturing cycle time, and minimizing waste. Over time a variety of technologies led to the development of an infrastructure that enabled the paperless factory. In [5] author presented a review of issues and technologies used currently in the paperless factory. Yao [8] and Porter [22] emphasized the effects of "wireless connectors" in manufacturing workstations to improve inventory control and the timeliness of real-time data. Li, et al. [10] described the application of some computer web-based technologies, such as visualization techniques, to establish a integration of product design with paperless concurrent engineering design.

Traditionally, data communication among various functional areas of a factory (Figure 1) has been made by the exchange of blueprints, routing sheets, inventory lists, shop floor travelers and so forth. Often papers occupied too much space and cost too much to process. Doing business on paper slowed the pace of the enterprise to the speed at which paper traveled in the factory. To improve their systems, some companies required that their operations function without paper. They used workflow automation to define paths for electronic documents to travel automatically [5, 20].

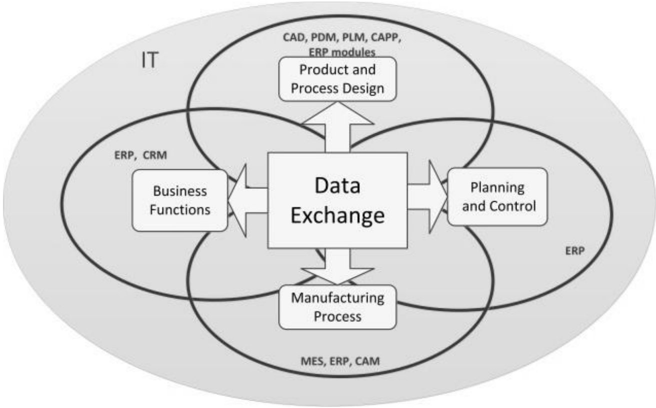

Fig. 1. Data Communication with IT systems [20]

Today, also in SMEs, to solve the problem of data exchange IT are used (Fig. 1). The dominant role in business activities play an ERP and CRM systems, in product and process CAx, PDM, PLM, CAPP and ERP modules, in planning and control ERP and in manufacturing process area MES, ERP and CAM systems [2, 13]. Largely in SMEs the heterogeneous solutions are used.

2.3. Model of high-variety products

A model of high-variety products is based on an analysis of the product's feature. The model is an abstraction of the real world product family that is specifically meant for configuration purposes. First thing to do is to specify attributes for the products, like colour, size, kind of drive, etc.

In this case solution on the basis AND/OR graph representation was implemented [14, 28]. Configuration space is represented as a AND/OR graph with the root indicating product family (PF on Fig. 5.). The product family is composed of possible configuration solutions $P = \{P_1, P_2, .., P_n\}$ with AND relation. Each solution $P_i|\forall i\epsilon[1, N]$ could be derived through configuring the configurable modules, $M = \{M_1, M_2, .., M_n\}$.

Each configurable module $M_i|\forall i\epsilon[1, K]$ may possess several available module instances $M_k^* = \{CA_{k1}, CA_{k2}, \dots, CA_{kL}\}$ with OR relation, among which, one and only one instance can be selected for a certain configuration solution. While customers always purchase products according to product performances, each module instance is characterized with corresponding product attributes $= \{a_{kq}\}$, and their values $D = \{d_{kqr}\}$ where d_{kqr} indicates the r^{th} value of the q^{th} attribute associated with the k^{th} module.

Besides the hierarchical relations among these compositions, there are other relations needed to be considered due to their influence on product configuration. They are exclusive and inclusive relations, which could be used to check whether there are conflicts involved in configuration solutions thus enabling to rule out the infeasible solutions in configuration solving.

In the configuration space, the inclusive relation between two compositions implies that when one of the compositions is included in a configuration solution, the other one should also be included. The inclusive relation can be represented as the "if-then" rule: if $C_i = p_{i1}$ then $C_j = p_{j1}$, where C_i and C_j refer to modules (or attributes) while p_{i1} and p_{j1} module instances (or attribute values) associated with $C_i$and C_j.

In the configuration space, the exclusive relation between two compositions means that these two compositions are not allowed to coexist in the same configuration solution if $C_i = p_{i1}$ then $C_j \neq p_{j1}$.

3. PROBLEM FORMULATION

The problem discussed in this paper concerns the paperless manufacturing of high-variety products. To solve this problem the point is to find an answers to the following questions:

- What data for configurable high-variety products are needed?
- What data and what algorithms are necessary for the automatic process of generating production documentation for configurable products?
- What knowledge bases to extend the ERP system for the production of configurable products is necessary?
- How to manage the distribution of information and paperless documentation of manufacturing process?

To illustrate the above problem a simple example is given.

4. ILLUSTRATIVE EXAMPLE

4.1. Product family

The example in this paper is the customization and production of product families for roller shutters manufactured in SME. Roller shutters are one example of family products.

The shutter can be made in many options. Product elements are given in Fig. 2. The main optional features are: system profile, dimensions: height and width of the blinds, color, drive type and others [21].

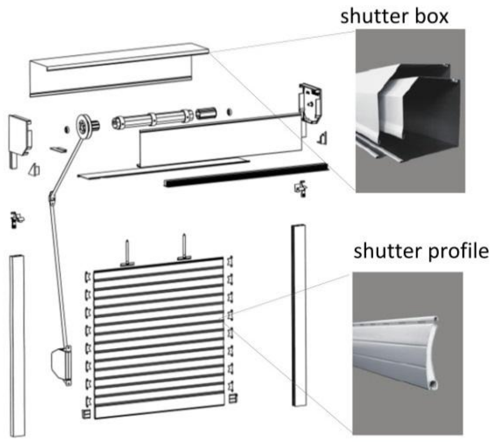

Fig. 2. Roller shutter's components [21]

4.2. Characteristics of the production process

A crucial role in waste-free manufacturing of roller shutters is played by the rollforming line. The production of the high-variety product (product family) (see Fig. 2) assumes zero waste of roller shutters. A crucial role in waste-free manufacturing of roller shutters is played by the rollforming line. It's possible to produce, in one process, a complete roller shutter curtain. The rollforming line is equipped with tooling suitable to produce the foamed roller shutter profiles in different sizes.

The process consists of foaming, punching and cutting to length operations. The line is designed for high density or low density foamed profiles. It is also possible to add a stacking bench to make packages or to cut to length curtains complete with side caps. Depending on the type of profile the line can reach a productivity of approximately 50-60 m/min. Unfortunately, the changeover time of the line is 2 hours. Until now, shutter manufacturing was based on profiles supplied in 6m sections. The profile was then cut to length according to individual customer requirements. The next stages of the process were the curtain assembly, the box cutting and the final assembly of other materials and components. Manufacturing from 6 m profile sections did not allow for waste-free production. It's possible only on the rollforming line with cutting to length according to individual customer requirements. The above line is computerized numerical controlled (CNC) and the controlling data are transmitted automatically by the manufacturing execution system (MES). The process can be implemented by alternative routes [16, 17].

5. SOLUTION METHOD

Below are presented the possible scenarios of solution with special reference to the high-variety production.

5.1. Business area

In the business area possibility of paperless documentation is largely determined by the law. Introduced in recent years, changes in the law have allowed the wider use of electronic signatures and electronic invoices. The data exchange between business partners is via e-mail or web portals. In the case of optional products a key role plays product configurator. Given a set of predefined components, the task of product configuration is to find a configuration solution satisfying individual needs of customers without violating all constraints imposed on components due to technical and economical factors. Configuration models describing all legal combinations of components include knowledge about the structure of products and knowledge about technical and economical constraints. Additionally, user requirements can be specified in the form of constraints, such as constraints on properties of a component.


```xml
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE supplier_order SYSTEM "bestellung_anwis.dtd">
<supplier_order>
  - <supllier_data>
        <order_date>2012-06-20:15.15</order_date>
      - <recipient>
            <![CDATA[AN A.G. ul. Wilcza 16/18 43-900 Bielso, Polen VAT No.
            PL8882896226]]>
        </recipient>
    </supllier_data>
  - <orders>
      - <plissee>
          - <order>
              - <customer_data>
                    <commission>P-389082- [JD895555]</commission>
                    <prename>Ralf</prename>
                    <lastname>Buck</lastname>
                    <ordernr>384282</ordernr>
                </customer_data>
              - <konfiguration>
                    <width>740</width>
                    <length>1130</length>
                    <quantity>1</quantity>
                    <stoff>BC_18</stoff>
                    <stoffseite>R</stoffseite>
                    <bedienung>R</bedienung>
                    <halterart>B</halterart>
                  - <profilfarbe>
                        <![CDATA[silber / grau]]>
                    </profilfarbe>
                    <system>VS2</system>
                    <neigungswinkel>ohne</neigungswinkel>
                  - <bemerkungen>
                        <![CDATA[Klemmtraeger]]>
                    </bemerkungen>
                </konfiguration>
                <dispatcher>DHL</dispatcher>
            </order>
```


Fig. 3. Order with configuration (XML file) [source: own study]

Currently, the front-end issue mainly focuses on interface for B2B partners. Think of configurable products as made-to-order products dynamically developed last years. An Internet created new possibilities for submitting orders directly by the customer.

The main problem is constituted into the interface for submitting orders. The interface must be clear, transparent, dynamic, graphical and in correlation to changeable requirements.

For a better idea on how a product configurator works, imagine at the following shopping scenario:

1. A customer navigates through an electronics online catalog until finding a roller shutter that he is interested in. At this stage a search engine of products is needed.
2. Since the chosen product is a dynamic kit, it needs to be configured through an configurator.
3. The customer selects the "*Configure*" link (or a similar link) to interact with the configurator. This interaction may be as simple as answering a series of questions or as complex as manually selecting detailed configuration options for the product. At this stage interface of configurator plays an important role.
4. When the customer has completed the interaction, the configurator returns a bill of materials that represents the grouping of items that make up the fully configured shutter. The customer can then decide to add this configured computer into the shopping cart.
5. The order is sent to the company by web page.

The company is confirming the order. The confirmation is visible on the web page. There is also sent alert about confirming or rejection the order [16, 17].

Electronic order example is shown in Fig. 3. In extension to the standard information for high-variety product the configuration options are required.

5.2. Product & Process design

Building the knowledge base for configurator is a real challenge. Not all companies managed to cope with that problem. A configuration of products based on the customer's requirements and defining requirements "a priori" are the point issue.

A configuration problem (CP) is formulated as [14]:

$$CP := \{C, P, Cr, R\} \quad (1)$$

where: C – set of options that may constitute a customizable product,
P – set of properties of options,
Cr – set of constraints imposed on components due to technical and economical factors,
R – set of customer requirements, which are usually specified in the forms of constraints.

A configuration Solution (CS) or a configuration is defined as:

$$CS := \{I, V, S\} \tag{2}$$

where: I – set of individuals, which are instances of components,
V – set of values, which are assigned to properties of individuals,
S – Boolean function defined as:

$$S : \{Cr, R\} \rightarrow \{T, F\} \tag{3}$$

The assignment of I and V makes the expressions Cr and R true. A configuration engine (Ce) is a function that maps a configuration problem CP to a set of configuration solutions CS:

$$Ce : \{CP\} \rightarrow \{a\ finite\ set\ of\ CS\} \tag{4}$$

Due to the number of possible options for process planning the generation process planning method is used. In this case DPE modules are prepared.

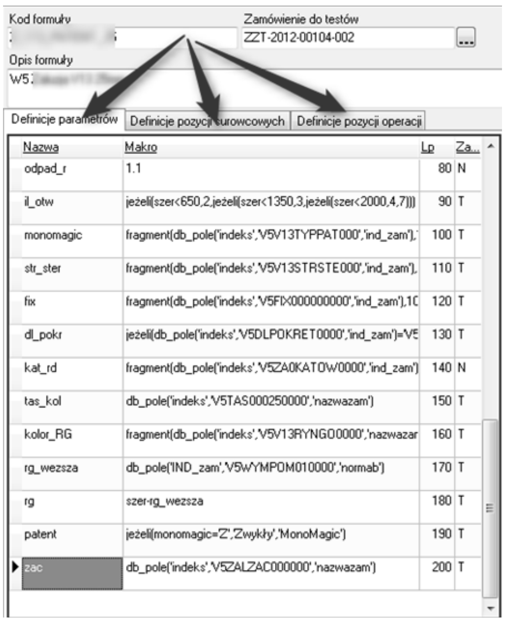

Fig. 4. Parameters definition for BOM and process routes [source: own study]

A data preparation engine (DPE) is a module that maps a configuration engine (Ce) to sets of BOM (Bill of Material) and route of production process. It consists from two functions: data preparation engine for BOM (DPE_{BOM}) and data preparation engine for route of production process (DPE_{RPP}) [14].

$$\mathrm{DPE_{BOM}} : \{Ce\} \rightarrow \{a\ finite\ set\ of\ BOM\} \tag{5}$$

$$\mathrm{DPE_{RPP}} : \{Ce\} \rightarrow \{a\ finite\ set\ of\ RPP\} \tag{6}$$

In practice, it comes down to define a set of formulas assigned to the product family. Every formula is composed of three elements: a set of parameters which values are mostly map of configuration parameters (Fig. 4), a definition of raw material or assembly unit, and definition of routing process.

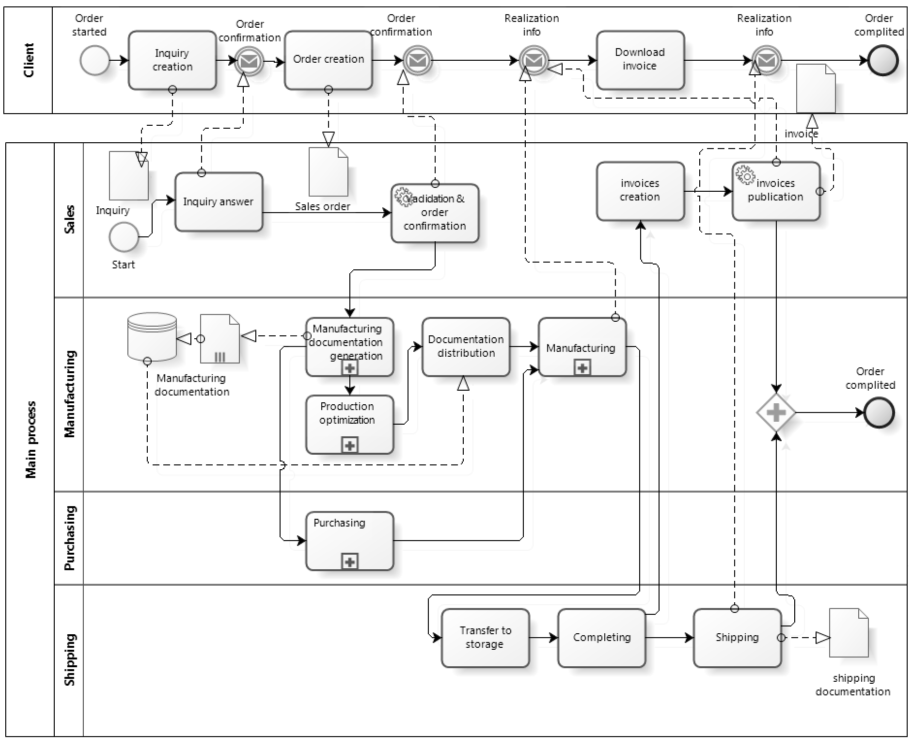

Fig. 5. Process flow in small and batch production [source: own study]

Planning and control take place according to the process shown in Fig. 5. One of the important problems to solve is the distribution of documentation. It is closely connected with the its functions: identification of the product, definition manufacturing routes and function of a carrier for data collection. Implementations of these functions must take the operator panels.

Unfortunately the disadvantage of this solution is the relatively high cost associated with the creation of a full network infrastructure for every workstation (operator panels, WiFi network). To reduce costs the hybrid solutions are implemented (Fig. 6). The hybrid solution is a compromise between the costs and the benefits from the work “on line”. Operator panels are installed only on the selected workstations. The criterion for selection is rather simple and it is associated with “bottlenecks” of the manufacturing process. Workstations which are bottlenecks are monitored and special controlled.

If the above workstation are ready to communicate with the machine via MES tools the solution is more cost-effective. Management system such as ERP gives the information about the job orders, gives the processing parameters (eg. CNC program number) and gets back information about performance. The process of data acquisition does not require human intervention and thus is much more reliable.

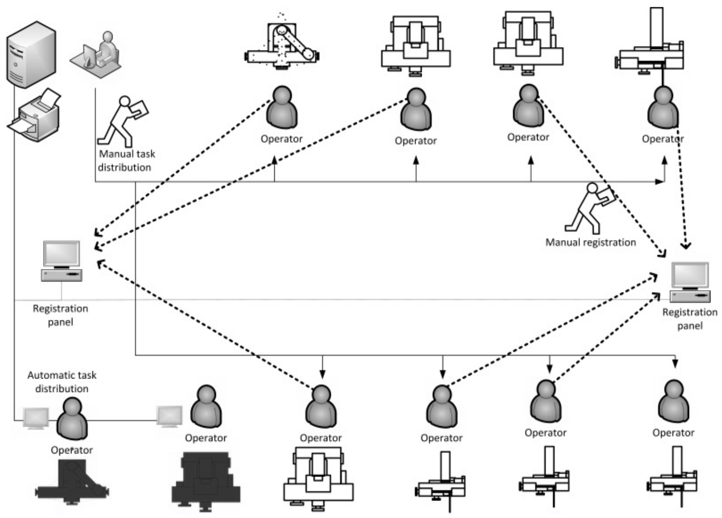

Fig. 6. Paperless workshop [20]

The next generation of factories could be a part of digital enterprises that collaborate around the world with their systems and business processes. In digital factory manufacturing could be more agile, responsive, productive, profitable, and humane than manufacturing in contemporaries enterprises is today. In an integrated systems, processes, manufacturing, and management personnel work collaboratively to prepare and release information to the factory floor. Simultaneously, factory workshop operators have simplified access to dynamic documentation that helps them do their job effectively.

6. CONCLUSIONS

The contemporary customer requirements, determine the production systems.

Today, paper form of documentation has not been eliminated. But, paper substitutes or representations require improving management processes in the factories. Operators panels provide the shop floor with operational status, and production control data such as work-in-progress and quality control charts.

The trend to change from a paper-based to a paperless factory has gained momentum over time. It was enabled by the application of the existing technology of wireless communication on the factory floor and the introduction of new technologies and concepts such as RFID and web systems.

However, implementing a true paperless factory is a challenge. In the case of configurable products it requires knowledge base preparation. It requires also improvement in data security, integrity and evolution of existing technologies.

Eliminating redundant documentation can, in many cases, significantly improve the organization of the production process. It can not be a goal in itself. The resignation of the documents in paper form improves the quality of management. In a high-variety production the management of change is very important, both in the process of the preparation of documentation and its distribution on the manufacturing workshop. Analysis of documentation emitted inside individual processes (business process, data preparation or production scheduling or control), show that there are fewer places where it is emitted unnecessary. The situation is worse if we look comprehensively at the entire enterprise. Often documentation is emitted to link business processes. To eliminate emission, unfortunately, quite expensive investments are needed. Fundamental changes are necessary in the processes of preparing production documentation. The static form must be replaced with the algorithmic form. Today, manufacturing systems need to be prepared for production as soon as possible. The best production cycle is cycle without the laborious process of preparation and distribution of documents in paper form. In addition, the machine control data can be sent directly from the planning system, and the timing and execution monitoring progress could be monitored by computer systems. Both studies and practice have shown usability of the proposed solutions.

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