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MANUFACTURING DOCUMENTATION FOR THE HIGH-VARIETY PRODUCTS

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Abstract
In the last years researches in engineering have moved towards customer-oriented manufacturing. The individual customer's requirements are very important for the company's activities. It results in 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 the efficiency of product development process 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. One possible way to solve this problem is to automatically create documentation in electronic form. Then, without having to print, distribute them directly to the panel of the machine. In the process of creating manufacturing documentation, this method takes into account alternative manufacturing processes and the current availability of labor resources The article is an attempt at the analysis of the modern manufacturing systems and answering the question, how it is possible to produce without having documentation in paper form. The presented solution is used for the high-variety products manufactured in the SMEs. The method was validated in the conditions of best practice high-variety production.

Keywords
paperless factory, mass customization high-variety products industrial engineering.

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). 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 seems to be 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.

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 the 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. The process of automatic generation of manufacturing processes and related documentation, regarding the current availability of labor resources, is very important.

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 that a change can be made only when a user finds documentation and all the copies.

Currently many companies use IT systems supporting the organization of the manufacturing process. However, to what extent can the SMEs use existing IT systems to manage the manufacturing process using only documentation in the paperless form? This is the question that the author of this article wants 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 acquisition, preparation of high-variety product data, and manufacturing management using paperless forms of documentation. The article concludes with some summary remarks.

Problem background

Product variety management

Past research on product variety management explored multiple solutions to overcome various difficulties. Some scholars focused on integrated approach for flexible manufacturing systems [1], others on modular product structure and specification [2], mass customization, part family manufacturing, and group technology (GT). The concept of Mass Customization has received considerable attention in the research literature [3–9]. Customers are placing unprecedented pressure on manufacturers to deliver a highly customized product at a highly accelerated speed and a highly reduced cost [10]. 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 [1]. 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. Frequent product changeovers make it imperative to improve setup operations and shorten line changeover times.

Trends from a paper-based to a paperless factory

Paperless factory is not the main goal of companies. The goal is to respond 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 [11] the author presented a review of issues and technologies used currently in the paperless factory. In [12–13] the authors emphasized the effects of "wireless connectors" in manufacturing workstations to improve inventory control and the timeliness of real-time data. Li [14] described the application of some computer web-based technologies, such as visualization techniques, to establish an integration of product design with paperless concurrent engineering design.

Traditionally, data communication among various functional areas of a factory was realized by the exchange of blueprints, routing sheets, inventory lists, shop floor travelers, and so forth. Papers tended to occupy 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 [11].

Today, also in SMEs, IT are used to solve the problem of data exchange (see Fig. 1). The dominant role in business activities belongs to ERP and CRM systems, CAx, PDM, PLM, CAPP and ERP modules in product and process, ERP in planning and control, and in manufacturing process area to MES, ERP, and CAM systems. Heterogeneous solutions are largely used in SMEs [15].

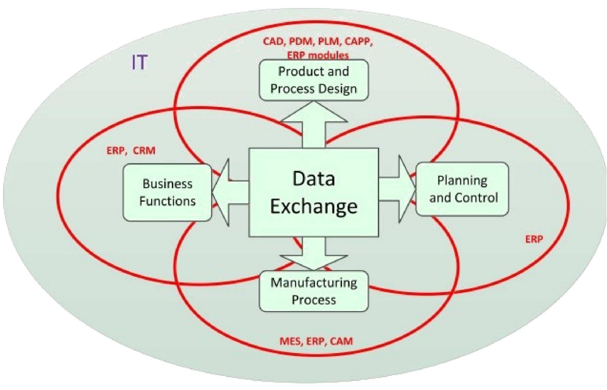

Fig. 1. Data Communication with IT systems.

Concurrent engineering is the computer integrated environment for design and manufacturing – the common platform for computer aided product development. The key condition for the effective concurrent engineering and cross-enterprise engineering is the computer integrated environment of design and manufacturing – the common platform for computer aided systems for product development [15, 16].

Model of high-variety products

Introducing modularity in product development as a means for dealing with increasing levels of variance within product portfolios has been widely and successfully applied by many companies. A model of high-variety products is based on an analysis of the features of the product. The model is an abstraction of the real world product family that is specifically meant for configuration purposes [17–18]. The first thing to do is to specify attributes for the products, like color, size, kind of drive, etc.

In this case, a solution on the basis of an AND/OR graph representation was implemented. As you can see on Fig. 2, configuration space is represented as an AND/OR graph with the root indicating a product family (PF on Fig. 2). The product family is composed of possible configuration solutions $P = \{P_1, P_2, ..., P_n\}$ with AND relation. Each solution $P_i|\forall i \in [1, N]$ could be derived through configuring the configurable modules, $M = \{M_1, M_2, ..., M_n\}$ [19].

Each configurable module $M_i|\forall i \in [1, K]$ may possess several available module instances $M_k^* = \{CA_{k1}, CA_{k2}, ..., CA_{kL}\}$ 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 $A = \{a_{kq}\}$ 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} are 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 $C_j \neq p_{j1}$.

The realization of configuration involves several mapping processes from customer order to the acceptable configuration scheme of realization.

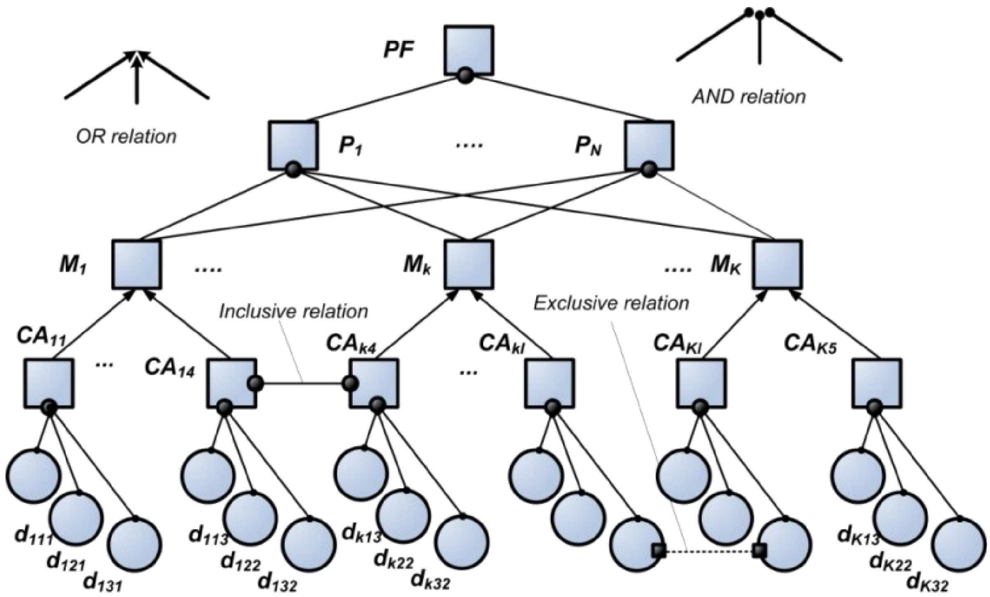

Fig. 2. Graph representation of configuration space.

Variant and generative process planning

Currently, in the process of automatic generation of the manufacturing processes, similarity methods are used.

Mathematics knows similarity, coincidence, identity, and equality of abscissas, triangles, sets, vectors. Two vectors are regarded as equal if they have equal elements in corresponding places. Sets are created from elements. The elements may have various form, as components, vectors, structures etc. If elements of two sets A, B are equal, we consider these sets as equal for congruency.

It seems that examination of mutual relations of two sets may explain the term of similarity. Let the set A be the pattern (the standard) and the set B the task to be solved.

Here they are (the 0 is the sign of an empty set, the frame contains the mode of approaches to process planning) [20]:

1. $A = 0$, $B = 0$ no practical meaning
2. $A \neq 0$, $B = 0$ no practical meaning
3. $A = 0$, $B \neq 0$ no pattern – fully generative
4. $A \neq 0$, $B \neq 0$, $(A \cap B) = 0$ no pattern – fully generative
5. $A \neq 0$, $B \neq 0$, $(A \cap B) \neq 0$ insufficient pattern – partly generative
6. $A \neq 0$, $B \neq 0$, $A \subset B$ insufficient pattern – partly generative
7. $A \neq 0$, $B \neq 0$, $A \equiv B$ identical set – standard
8. $A \neq 0$, $B \neq 0$, $A \supset B$ abundant pattern – variant access

Only the standard process plan is fully applicable. At variant access the abundant elements are omitted, in generative mode the missing elements or all of them must be completed.

In addition, due to the limited availability of resources, alternative manufacturing processes should be used.

Problem formulation

The problem discussed in this paper concerns the paperless manufacturing of high-variety products.

To solve this problem one has to find 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 are necessary to extend the ERP system for the production of configurable products?

How to manage the distribution of information and paperless documentation of manufacturing process?

To illustrate the above problem, a simple example is given.

Illustrative Example

Product family

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

The shutter can be made in many options. The main optional features are: system profile, dimensions: height and width of the blinds, color, drive type, and others.

Characteristics of the production process

The production of a high-variety product (product family) assumes zero waste of roller shutters. A crucial role in waste-free manufacturing of roller shutters is played by the rollforming line.

It is 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 (see Fig. 3). 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, box cutting, and the final assembly of other materials and components. Manufacturing from 6m profile sections did not allow for waste-free production. It is 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.

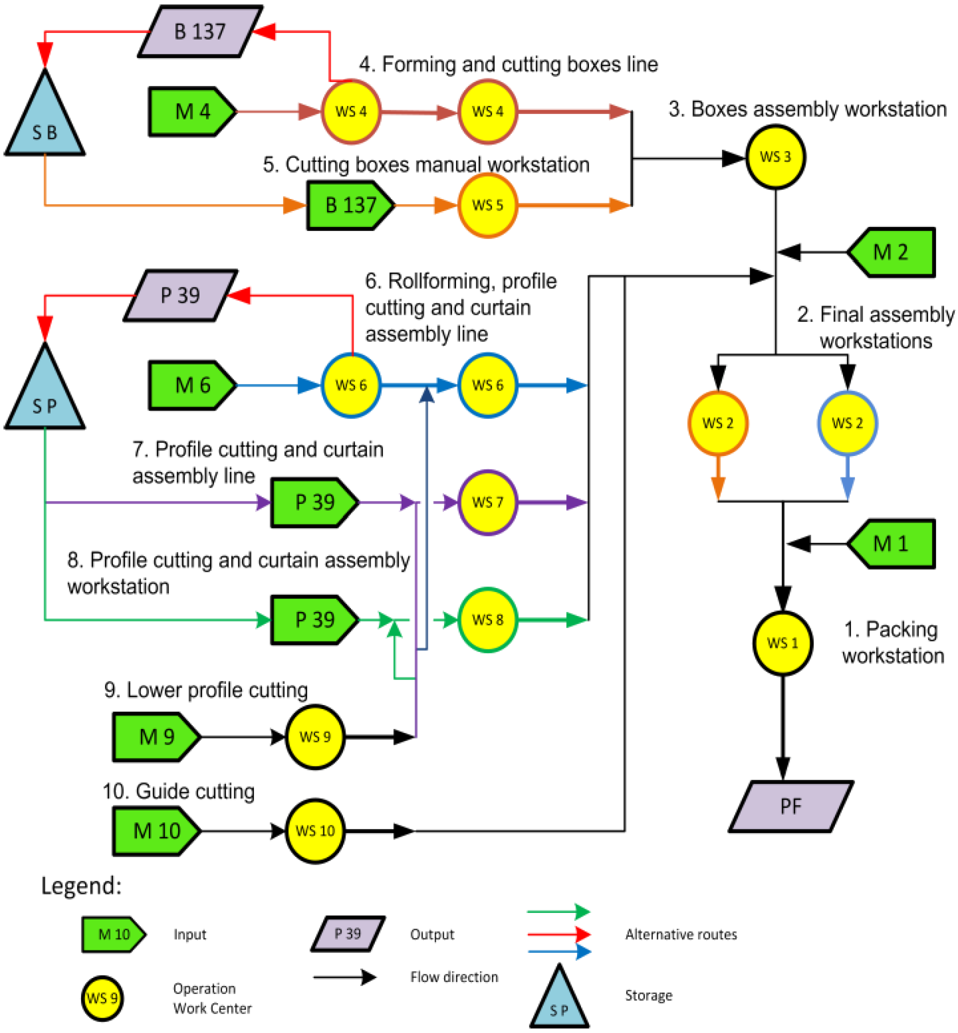

Fig. 3. Alternative routes of the manufacturing process.

Solution method

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

Business area

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

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

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

The company confirms the order. The confirmation is visible on the web page. An alert about the confirmation or rejection of the order is also sent.

An example of an electronic order is shown in Fig. 4. In extension to the standard information for high-variety product the configuration options are required.


```
<?xml version="1.0" encoding="UTF-8"?>
- <zamowienie>
    <klient>02674</klient>
    <id_zam>00210</id_zam>
    <nazwa_zam>test</nazwa_zam>
    <lok_alt>brak</lok_alt>
    <data>07-07-2014 22:49:26</data>
  - <produkt id="00469">
      <wyrob>MAR0619-0000-000-0</wyrob>
      <szer>550</szer>
      <wys>1900</wys>
    - <konfiguracja>
        <typkolor>malowanie</typkolor>
        <malowanie>RAL 1000</malowanie>
        <rodzajprofilu>cofniety</rodzajprofilu>
        <rodzajuchwytow>uchwyt9mm</rodzajuchwytow>
        <dodatkoweuchwyty>nie</dodatkoweuchwyty>
        <kolorsiatki>czarna</kolorsiatki>
        <szpros>tak</szpros>
        <kolorszprosu>malowanie</kolorszprosu>
        <malowanie>RAL 1000</malowanie>
        <nawiercanie>tak</nawiercanie>
      </konfiguracja>
      <cena>98.28</cena>
      <ilosc>1</ilosc>
    </produkt>
    <wartosc>98.28</wartosc>
    <rabat>40%</rabat>
  </zamowienie>
```


Fig. 4. Order of optional product.

Product & process design

Building the knowledge base for the 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:

$$CP := \{C, P, Cr, R\}, \tag{1}$$

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:

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

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:

$$Ce : \{CP\} \to \{a \text{ finite set of } CS\}. \tag{4}$$

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

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

$$DPE_{BOM} : \{Ce\} \to \{a \text{ finite set of } BOM\}, \tag{5}$$

$$DPE_{RPP} : \{Ce\} \to \{a \text{ finite sett of } RPP\}. \tag{6}$$

In this case, an algorithmic form of routing process can be defined.

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 whose values are mostly maps of configuration parameters, a definition of raw material or assembly unit, and a definition of the routing process.

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 of manufacturing routes, and the function of a carrier for data collection. Implementations of these functions must involve the operator panels (Fig. 6).

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. The hybrid solution is a compromise between the costs and the benefits from the "on line" work. Operator panels are installed only at 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 specially controlled.

If the above example, the workstation are ready to communicate with the machine via MES tools, so the solution is more cost-effective. A management system such as ERP gives the information about the job orders, provides 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.

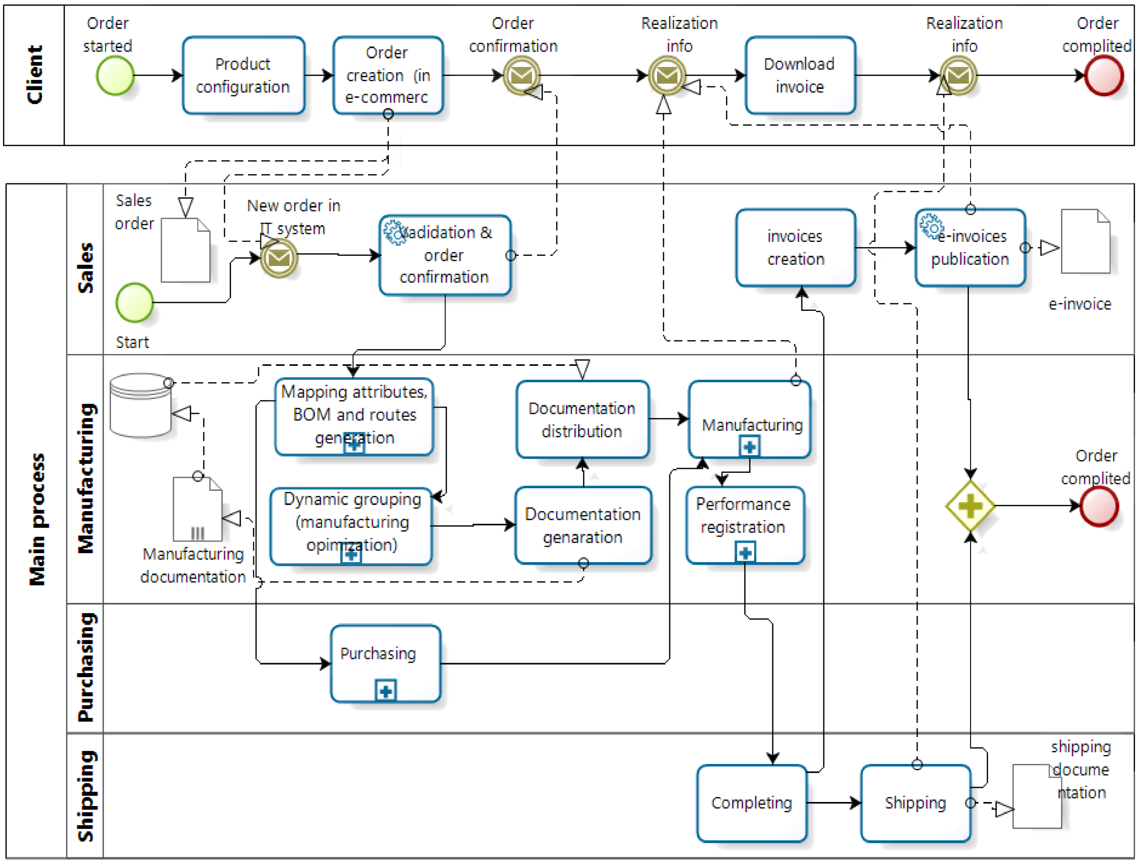

Fig. 5. Main process (BPMN notation).

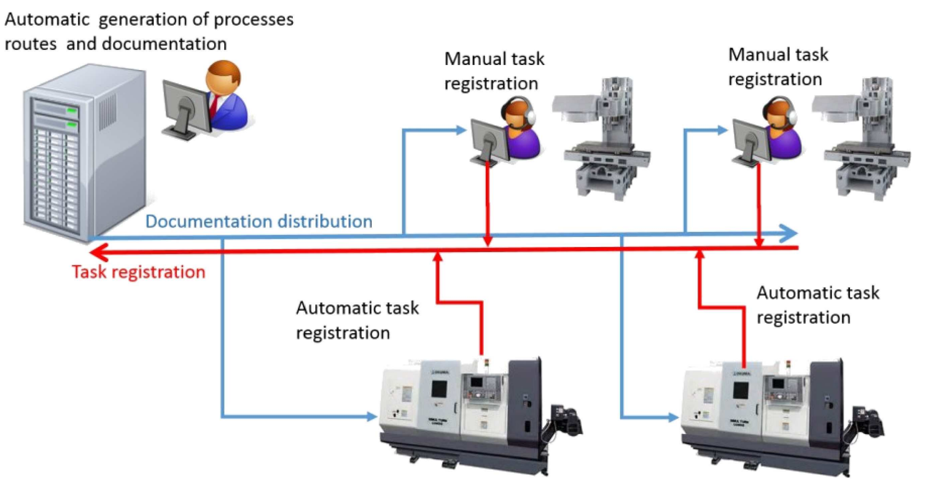

Fig. 6. Paperless workshop.

The next generation of factories could be a part of digital enterprises that collaborate around the world with their systems and business processes. In a digital factory, manufacturing could be more agile, responsive, productive, profitable, and humane than the manufacturing in contemporary enterprises is today. In 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.

Conclusions

The contemporary customer requirements determine the production systems.

Today, paper form of documentation has not been eliminated. Still, paper substitutes or representations require improving management processes in the factories. Operator 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 is not a goal in itself. The resignation from 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 in the manufacturing workshop. Analysis of documentation emitted inside individual processes (business process, data preparation or production scheduling or control) shows 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 a 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.

References

[1] Matta A., Tolio T., Karaesmen F., Dallery Y., *An integrated approach for the configuration of automated manufacturing systems*, Robotics and Computer Integrated Manufacturing, 17, 19–26, 2001.

[2] Steiner F., Hergenröther I., *Modular product architectures as an enabler of the simultaneous application of a mass customisation strategy and efficient ramp-up management*, International Journal of Product Development, 19 (4), 231–253, 2014.

[3] Da Silveira, G., Borenstein D., Fogliatto F.S., *Mass customization: Literature review and research directions*, International Journal of Production Economics, 72, 1–13, 2001.

[4] Pine B.J., *Mass Customization: The New Frontier in Business Competition*, Harvard Business School Press, Boston, 1993.

[5] Spring M., Dalrymple J.F., *Product customization and manufacturing strategy*, International Journal of Operations and Production Management, 20 (4), 441–467, 2000.

[6] Zhang L., Lee C., Xu Q., *Towards product customization: An integrated order fulfillment system*, Computers in Industry, 61, 213–222, 2010.

[7] Kumar A., *Mass customization: manufacturing issues and taxonomic analyses*, International Journal of Flexible Manufacturing Systems, 19, 625–629, 2007.

[8] Mac Carthy B., Brabazon P.G., Bramham J., *Fundamental modes of operation for mass customization*, Int. J. Production Economics, 85, 289–304, 2003.

[9] Tien J.M., *Manufacturing and services: From mass production to mass customization*, Journal of Systems Science and Systems Engineering, 20 (2), 129–154, 2011.

[10] Ulrikkeholm J.B., Lars Hvam L., *The cost of customising: assessing the performance of a modular product programme*, International Journal of Product Development, 19 (4), 214–230, 2014.

[11] Djassemi M., Sena J.A., *The Paperless Factory: A Review of Issues and Technologies*, IJCSNS International Journal of Computer Science and Network Security, 6/12, 2006.

[12] Yao A.C., arlson J.G., *The impact of real-time data communication on inventory management*, International Journal of Production Economics, 49 (1–3), 213–219, 1999.

[13] Porter J.D., Kim D.S., Paotrakool K., *Performance evaluation of heterogeneous wireless local area networks*, Computers and Industrial Engineering, 48, 251–271, 2005.

[14] Li W.D., Fuh J.Y.H., Wong Y.S., *An internet-enabled integration system for co-design and concurrent engineerings*, Computers in Industry, 55 (1), 87–103, 2003.

[15] Mleczko J., *Manufacturing processes creating with use of dynamic classification in conditions of unit and small-batch production*, Publishing House of University of Bielsko-Biała, 2014.

[16] Duda J., Pobożniak J., *Concurrent Development of Products, Processes and Manufacturing Systems in PLM Environment*, Management and Production Engineering Review, 2 (2), 4–15, 2011.

[17] Zhou Ch., Lin Z., Liu C., *Customer-driven product configuration optimization for assemble-to-order manufacturing enterprises*, International Journal of Advanced Manufacturing Technology, 38, 185–194, 2008.

[18] Zhang Y., Ji Y., Qi G., Dong J., *A Universal Knowledge-Network Model for Customizing the Products*, International Journal of Digital Content Technology and its Applications (JDCTA), 6 (21), 571–577, 2012

[19] Mleczko J., *High-variety products manufacturing based on dynamic classification*, Advances in Manufacturing Science and Technology, 35 (3), 71–86, 2011.

[20] Békés J., *Similarity, variant and generative process planning*, WEB Journal, CA Systems in Production Planning, University of Zilina, Slovakia Cracow University of Technology, Poland, 2002.