Preparation and Production Control in Smart Factory Model

Krzysztof Żywicki, Przemysław Zawadzki(✉), and Adam Hamrol

Chair of Management and Production Engineering, Poznan University of Technology, Piotrowo 3 Street, 60-965 Poznan, Poland
{Krzysztof.Zywicki,Przemyslaw.Zawadzki, Adam.Hamrol}@put.poznan.pl

Abstract. Implementing the smart factory concept places demands not only for enterprises but also for scientific units. In order to be able to effectively develop solutions in compliance with the Industry 4.0 concept, it is necessary to improve qualifications of scientific personnel and students who are supposed to implement those assumptions in practice. The paper describes the structure of smart factory model, developed at Poznan University of Technology, which enables both learning about such solutions and doing research work in that scope. The model includes issues connected with the field of production management – starting from interpretation of client requirements, to automation of product design development, to preparing and controlling the production process.

Keywords: Industry 4.0 · Smart factory · Production control

1 Introduction

The concept of smart factory, featuring highly automated and flexible production, is currently one of the most basic trends in the development of manufacturing systems [1, 2]. Thanks to solutions such as cyber-physical systems, the Internet of things or Big Data, that idea, also known as Industry 4.0, aims at maximizing production capacity in order to address the changing requirements of clients faster and more effectively [3–5]. However, it is worth to note that the concept of smart factory cannot be implemented merely by data processing and rapid exchange of information. In practice, Industry 4.0 requires systemic solutions as regards production scheduling, monitoring material flow, analysis and decision-making [6]. In this context, smart manufacturing will be possible, if the assumed control methods enable dynamic synchronizing the material and information flow under a flexible manufacturing system [7, 8, 17].

All processes implemented under an smart factory system should be coordinated and interdependent. Therefore, efficient production control is undoubtedly based on smart preparation of client orders for fulfilment [6]. In this respect, the process of designing products according to strict requirements of consumers is very important. Considering flexibility as readiness to fulfil individual requirements of clients, engineers must employ an intelligent approach to designing [9]. That is exactly what KBE-based designing (Knowledge Based Engineering) can be like [10]. Solutions of KBE class contain expert

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knowledge about how, when and what needs to be done, and the knowledge is implemented and processed by a computer system, allowing its easier application in new projects. A formal description of rules applied by design engineers helps process standardization and allows automation of repeatable tasks in the design process, while at the same time enabling quick development of variant designs. Advanced CAx (Computer Aided) systems are used for that purpose, allowing enrichment of geometrical CAD (Computer Aided Design) models with a formal description of engineering knowledge. Thanks to that, the stage of designing new variants of a given product is shortened, as the majority of work can be automatically performed by a computer system, and not human personnel [11].

Solutions facilitating evaluation of one's own ideas and comparing different solutions gain importance in design processes. This is undoubtedly made possible by virtual (and/or augmented) reality techniques [12–14]. The techniques allow design engineers to construct and verify a virtual prototype of product, which makes them one of the most basic components of cyber-physical systems.

Shortening the time of product development and sometimes even its faster manufacturing is currently also supported by fast manufacturing techniques which constitute an indispensable component of smart factory. Prototypes or finished products are manufactured directly from digital 3D models. The duration of the process is significantly shorter than when using conventional manufacturing techniques [15]. Modern additive manufacturing techniques are so advanced that they can be successfully used in developing production tools, significantly supporting conventional manufacturing methods [16].

The complexity of issues in preparing and controlling production, combined with the necessity to integrate modern technological solutions, while lacking some clear methods of joining the same, necessitates development of actual models of manufacturing systems for the purposes of scientific research, in compliance with Industry 4.0 concepts [2]. The paper describes a laboratory model which enables to simulate production management processes in accordance with the smart factory concept.

2 Smart Production System Model

A production system model is made up of the following physical components (Fig. 1):

- automated production line,
- assembly stations,
- additive manufacturing technology station,
- warehouse of raw materials and finished products.

An automated production line is made up of four conveyor loops with manufacturing stations located beside. The loops are equipped with switches that enable redirecting a pallet which carries the product to any other conveyor loop. Each pallet is RFID (Radio-frequency identification)-tagged for the purpose of identification. An RFID reader is installed at each point where the loop direction changes, or before each work station. The line is controlled by a control cabinet equipped with power supply components, protection circuits, power adapter, PLC (Programmable Logic Controller) and safety system module. A beacon tower is also installed to display the operational status. Two industrial networks have been applied in the system to control the devices: AS-interface and ProfiNet.

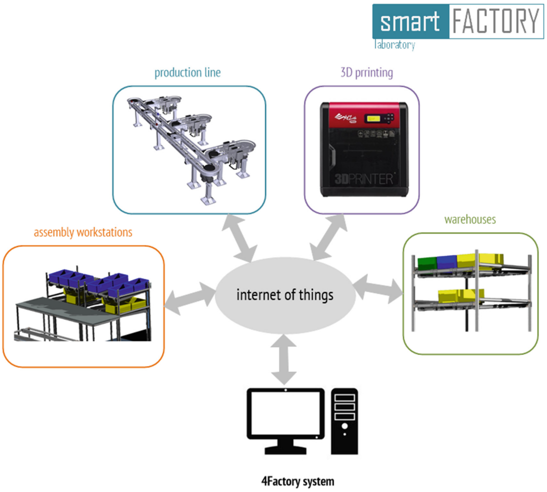

Fig. 1. Structure of the smart factory model

Assembly stations constitute independent organization cells in which subassemblies of finished products are manufactured. Manufacturing stations along the automated production line as well as the assembly stations are equipped with flow-through racks that enable storage of containers with parts and units for assembly. The racks are equipped with RFID readers to identify the transport containers.

The additive manufacturing technology station enables: manufacturing some parts according to individual requirements of clients and providing tools required for implementation of production tasks on the automated line or at the assembly stations.

Warehouses of raw materials and finished products are made of racks with certain areas designated for individual parts and subassemblies used for production. Each location is marked with a unique barcode.

The production system is managed by software called 4Factory. Communication between the system components is maintained through the Internet of things. The 4Factory system is made up of a series of modules featuring functionalities that enable production planning, supervising material flow and production line control. The system modules include:

– resources – information about the production system resources,
– indexes – specification of products and their components (production indexes, procurement indexes),
– orders – information about orders for finished products,
– technology – defining technological processes,

– production planning – tasks related to determining the progress of production orders in the production schedule,
– production control – controlling and analysing the progress of the production flow,
– warehouse – tasks related to turnover of inventory in the warehouses of raw materials and finished products.

Material flow and communication under the production system is controlled on the basis of RFID solutions and the Internet of things concept (Fig. 2).

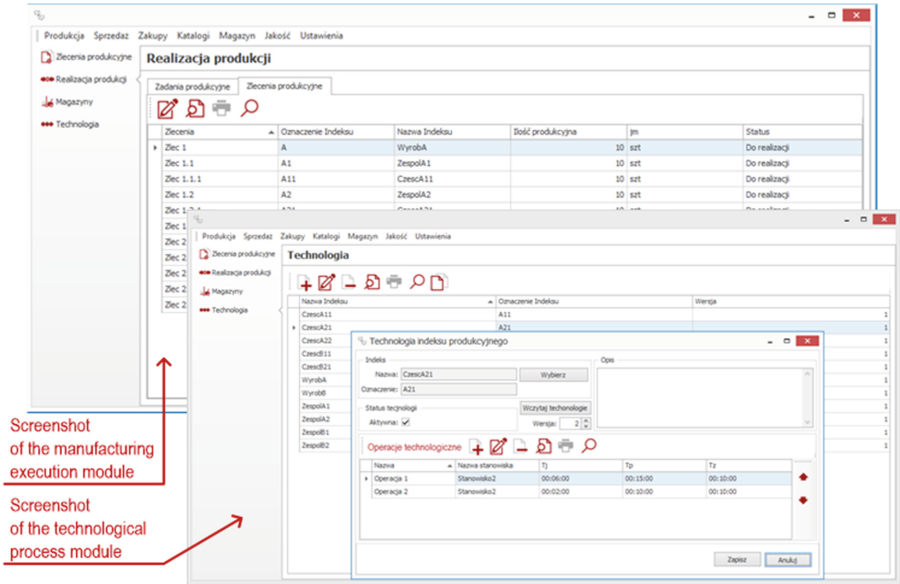

Fig. 2. Examples of screenshots 4Factory system.

3 Order Fulfilment Control System

A production system model enables mirroring the processes connected with fulfilment of client orders in compliance with the smart factory concept.

3.1 Product and Technological Process Designing

To satisfy individual needs of customers at the level of engineering design, technical documentation must be developed for each product variant adopted for manufacturing. A decision was made to combine these issues into a special IT solution (Fig. 3) which eliminates the need for a design engineer to participate in each new order, thanks to development of a KBE-class solution. Configuration of a product (herein represented by a set of bricks which unique connection symbolizes a given variant of the product) is implemented with use of previously developed computer application and intuitive user interface. Unique arrangement of the bricks is saved in form of simple text files which are then automatically processed in CAD software. There the model is checked by internal algorithms and if a component that has never been used before is detected, it is saved in "stl" format readable for a 3D printer. Next, an adequate program which controls the machine is activated and after that the new element is transported to the production line.

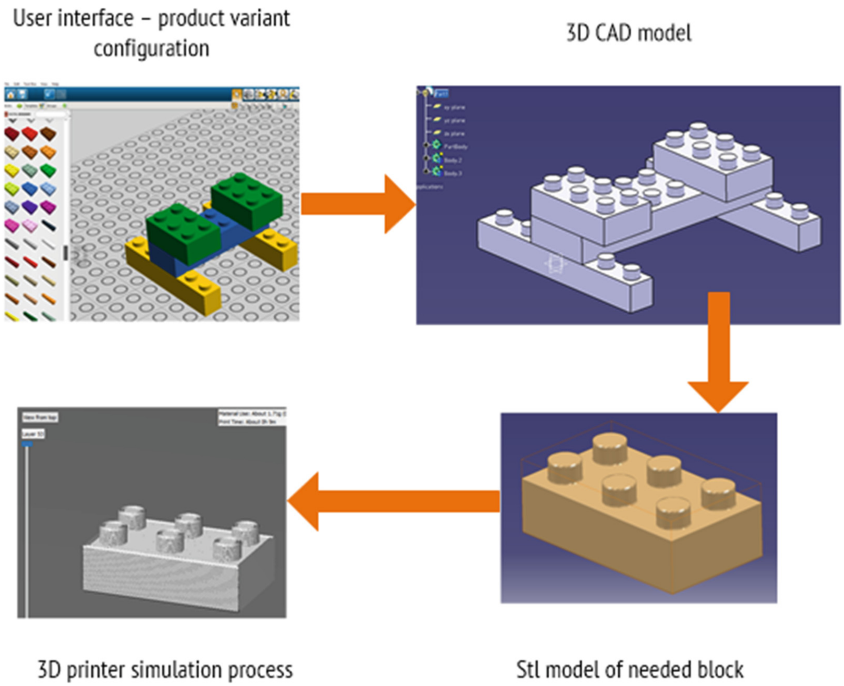

Fig. 3. Steps design variant of the product in the smart factory model

A technological process of manufacturing products and components is generated automatically on the basis of structure and technological capacity of production resources (manufacturing stations). Each manufacturing station on the automated line and each assembly station has its strictly determined technological capacity to implement a specific production task. Due to that the technological process of a product or component can have several variant ways of implementation.

3.2 Production Planning

Production is planned on the basis of information concerning orders and technological processes performed to manufacture given products. The process of production planning includes (Fig. 4):

- the analysis of demand for finished products, based on orders,
- determination of material demand,

– generating production orders on the basis of the determined material demand,
– allocation of production orders – the possibility of selecting a criterion based on which orders are allocated in order to determine the sequence of their fulfilment,
– automatic generation of the production schedule – determining the load of the production system resources resulting from performance of subsequent operations of the technological process on the basis of the assumed criteria and the availability of resources.

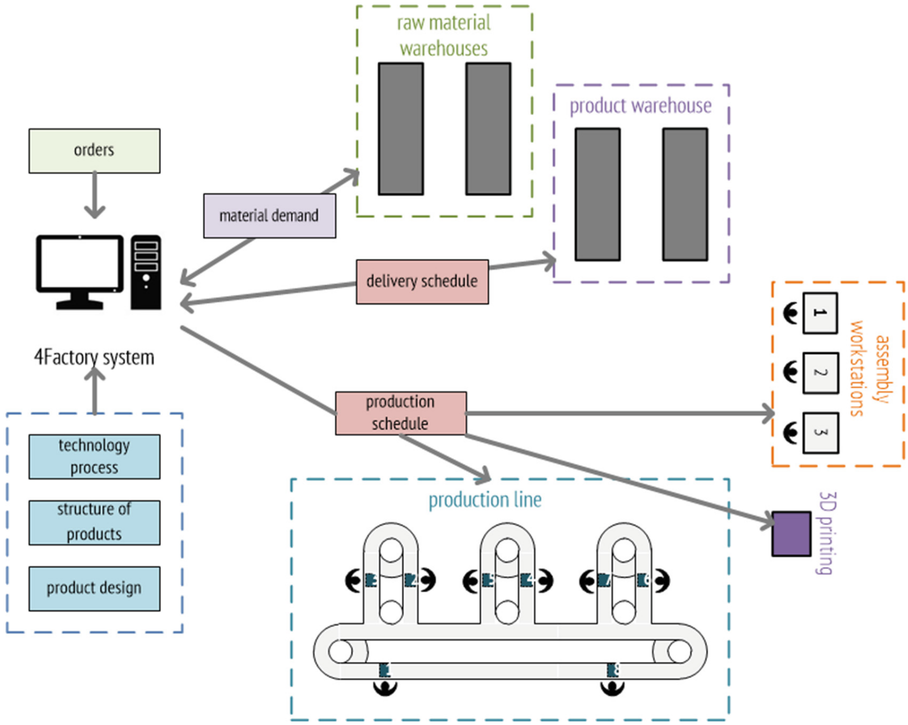

Fig. 4. Production planning of the intelligent factory model

Production planning starts with determination of demand for final products. Based on that a list is drawn up of all the finished products with determined delivery times for which production orders are defined. A production order drawn up for a finished product automatically generates orders for individual parts included in the structure of products. Orders are generated for the following three groups:

– product structure components (parts, subassemblies) which should be manufactured under the company's own production – production orders,
– tools which must be created to implement technological operations,
– materials which must be provided from the warehouse of raw materials – delivery orders.

Production scheduling follows the process of allocating production orders. The purpose of allocating production orders is to determine their sequence pursuant to which the plan of loading the manufacturing stations will be prepared – assigning technological operations to manufacturing stations over time. The process is based on priority rules. Application of the approach enables effective implementation of the scheduling process for manufacturing individual products. Above all, this enables a flexible response to various external (new orders) and internal (change in the availability of resources) factors by selecting various priority rules, while at the same time maintaining short time for implementation of tasks connected with scheduling. The applied priorities apply mostly to date of delivery, defined priority and parameters of production orders.

The defined sequence of production orders is a starting point for drawing up the production schedule. The scheduling process follows the analysis of current load of manufacturing stations (connected with ongoing production) and their system of work. Based on that, a technological operation of duration resulting from the technological process is assigned to a given manufacturing station (load).

3.3 Material Flow Control

Production process control is connected with ongoing implementation of manufacturing processes and it includes the following:

- sending information about production orders included in the production schedule to individual resources of the production system,
- collecting data about the actual implementation of production processes and the status of production resources,
- supervision over the production schedule adopted for implementation, verifying it against the actual production and correcting it, if necessary.

Tasks connected with sending and collecting information in the production system are based on the RFID tags attached to:

- pallets which transport the products along the automated line,
- packages of the internal transport,
- parts and tools created in the rapid prototyping technology,
- packages used for storage of parts and finished products in the warehouse.

A production schedule for automated line is implemented by a PLC that controls operation of the entire line. The data specified in the schedule specify subsequent manufacturing stations for a given transporting pallet, which reflects the technological process of a given product. For individual assembly stations the information from the production schedule is sent to tablets. Additionally, instructions for implementation of production tasks are displayed on them.

Identification of the progress of production processes covers collection of data about implementation of production orders:

- start time and end time of each production task,
- number of workpieces manufactured under the operation,

– number of defective workpieces manufactured under the operation.

Supervision is based on the log of events occurring during implementation of production orders. Based on that a comparative analysis of planned quantities and manufactured quantities is performed, which indicates risks connected with implemented production orders and, consequently, client orders. In the event that some departures from the production schedule are identified, resulting from delays in implementation of the manufacturing process, potential consequences of such events for timeliness in the fulfilment of production orders, and thus client orders, are analysed.

It was assumed that three basic events may occur which may necessitate modifications of the production schedule:

– non-availability of resources – failure at a manufacturing station, lack of personnel,
– lack of material,
– delays in implementing operations of the production process.

As a result of any of the above events, the 4Factory system applies principles and algorithms to introduce corrections in the production scheduling.

4 Conclusions

A factory of the future should be characterized by effective processes which enable satisfying individual requirements of clients. Manufacturing custom products requires analysis of multiple factors as regards production planning and control. Simultaneously, such actions must provide effective utilization of production resources and synchronizing the material flow under the production system. Due to that, an efficient exchange of data connected with, e.g. a structure or technology of manufacturing products, but also those related to coordination of material supplies and cooperation, is an essential requirement for factories to become smart.

The production system model described in the paper contains some basic components of smart factory as far as product design and production control are concerned. The system is managed by the program 4Factory, developed by the authors, which integrates data concerning all the technical utilities. It enables to simulate operation of a manufacturing plant on the basis of solutions that contribute to effective implementation of production processes. The production system is subject to development mostly in the area of further integration and automation of data collection (image recognition) and utilizing augmented reality to supervise production processes.

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