Industry 4.0, digital factory, virtual reality, augmented reality

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NEW TRENDS IN SUPPORTING PRODUCTION WITH INFORMATION TECHNOLOGY

Abstract

Information technologies allow to support production systems functioning, and in particular to solve complex problems in a very short time. Execution of analysis on a large quantity of data by a computer system makes it possible to verify possible solutions and make various decisions connected with production systems functioning. The presented examples of information technologies used in production practice are the main subject matter of this chapter.

1.1. INTRODUCTION

Today, competitive global markets require high quality, quick production and low costs. Such markets requirements create the need for collaboration of all professions, from engineers and managers to shop floor workers. In order to be successful, it is necessary to share knowledge and experience [13, 20, 25] with the use of information technologies and software systems for designing, process planning, manufacturing and assembly.

Another important factor for development and prosperity of production enterprises is quality of workers and especially engineers, who are responsible for designing new innovative products. Investment in education and trainings brings higher increase of productivity than investment in capital assets.

The evolution of production systems is followed by the development of innovative technologies and used machines, devices, methods and tools aiding the work related to preparing technical documentation of products, processes and production resources. The company's progress is achieved by introducing shorter production cycles, developing new products and manufacturing processes, minimizing the work in process, more efficient logistics, and the usage of effective production management, like Lean Production, Just in Time, Total Quality Management, and particularly, Digital Factory Technologies [5, 21, 22, 28]. These methods are focused on continuous improvement of the production process and the organization of workplaces.

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The main types of software used in production enterprises are connected with PLM systems, which control all parts of the manufacturing cycle. There are also many applications supporting various production areas. CAD systems define what will be produced, Manufacturing Process Management (MPM) defines how it will be manufactured, ERP informs when and where it will be produced, whereas MES provides shop floor control together with simultaneously provided manufacturing feedback. The stored information generally aids communication and improves making decisions, but also eliminates human errors from the design and the manufacturing processes. Nowadays, Industry 4.0 has become a very popular concept, whose aim is to integrate various software applications [17, 32, 33].

The socio-economic evolution of mankind takes place in three stages, which are defined by Alvin Toffler [31] as the waves of civilization development. The first wave is the agrarian revolution associated with the acquisition of farming skills and the spread of sedentary lifestyles. The second wave is an industrial revolution initiated by the invention of steam engines, electricity, new means of transport, mass communication, and mass production. The invention of a computer has initiated the third wave, named the postindustrial revolution, which is related to the use of automated machines and equipment, with unlimited access to information and with the movement from mass production to individualized production.

The third wave of socio-economic evolution of mankind is also treated as a continuation of the industrial revolution by creating automated production based on flexible production systems and intelligent factories with cyber-physical production systems in which information is transmitted by the Internet. The industrial changes which follow the third wave are referred to as the third and fourth industrial revolutions (Industry 3.0 and Industry 4.0).

The concept of Industry 4.0 is defined [30, 35] as a common term for the technology and concept of organization of the value stream. As part of the "Smart Factories" modularity, cyber-physical systems monitor physical processes, create a virtual copy of the physical world, and make decentralized decisions. Within the “Internet of Things”, cyber-physical systems communicate and collaborate with each other and with people in real time. Through the "Internet of Services", internal and inter-organizational services are offered and used by participants of the value stream.

The concept is to be seen as an opportunity for the developed countries and in the countries with high labour costs. This is also a chance for reindustrialization and for improving the competitiveness of national economies.

According to the concept of Industry 4.0, the main principles for contemporary production are: cooperation, virtualization, decentralization, quick evaluation of the production system ability in real-time, orientation on services and modularity. These can be achieved only through the use of modern information technologies described below.

Further parts of this chapter present examples of computer aided systems for designing and analysing production systems, and selected new technologies and examples of their use in production practice.

1.2. METHODOLOGY OF PRODUCTION SYSTEMS DESIGN AND ANALYSIS

The process of production improvement includes a number of activities carried out step-by-step. Such an activity may consist of a group of stages, phases, courses or actions. Each activity is characterized by a multitude of solutions. Among all the existing solutions, a set of possible options can be distinguished, from which the non-prospective ones that will not provide satisfactory solutions should be eliminated.

As a result of evaluating the proposed variants, it is possible to select a solution which is optimal according to the chosen criteria. The main evaluation criteria are time, cost and quality. The same applies to all stages of designing production processes and their organization. These aspects should form the basis for project implementation.

Lately, growing attention has been paid to the organizational aspect of implementation new processes. The most important tips include the following [14, 16, 20]:

- one of the managers should be responsible for production strategy and production operations,
- marketing, design, production and finance departments should be tightly bound, especially in the period of new product development,
- the board of directors should be responsible for the research and development of products and production processes,
- initial planning and estimation of company capabilities should be carried out by the core of a technically qualified group having time and resources,
- in an early phase of research and evaluation of projects related to new products and production processes, book-keepers should be engaged in cooperation,
- it is advisable to prepare procedures informing workers of all levels and Trade Unions about company's competitive position, its investment plans and to consult these issues with them,
- a system of labour planning should be worked out to deliver current information, both about skills and experience of company staff, as well as a potential need to start special trainings to update knowledge and qualifications.

The goal of modern enterprises is to create intelligently networked factories that enable more flexible, more efficient and more individually customized production. Experts predict that this will lead to increase in productivity by up to 50%. The increase in productivity should be achieved through the use of new information technologies and the related improvement of the organization and management of the production process [8, 19].

Cyber-physical systems, which integrate the virtual (cyber) world and the real (physical) world into one internet of things, are seen as the major technology of Industry 4.0. The focus of Industry 4.0 lies on the networking of production processes, which allow for value creation processes to be planned and managed in real time. This is achieved through so-called cyber-physical systems (CPS) [3, 11]. CPS stands for the integration of embedded information technologies in objects, materials, devices, and the processes of logistics, coordination and management. The main principles of Industry 4.0 are [17]:

- Inoperability- the ability of CPS, people and all components of Smart Factories to mutually communicate through Internet of Things (IoT) and Internet of Services (IoS) [1].
- Virtualisation – the ability to interconnect physical systems with virtual models and simulation tools.
- Decentralisation - decision making and management are performed autonomously and in parallel in individual subsystems.
- Real-time capability - keeping real-time requirement is a key condition for communication, decision making and management in systems of real world.
- Service orientation - preference of computer philosophy of offering and using standard services which leads to the SOA type architecture (Service Oriented Architectures).
- Modularity and reconfiguration. Industry 4.0 systems should be maximally modular and capable of autonomous reconfiguration on the basis of automatic recognition of situation.

One of the premises for the formation of Industry 4.0 is research in the domains of, among others, Digital Factory, reconfigurable systems, intelligent systems, automation and simulation. Currently, manufacturing companies are using information and communication systems (ICT), which increasingly support their functioning, including process improvement projects.

The implementation of a typical project is a process that includes the activities shown in Figure 1.1. Almost all of the above mentioned activities should be supported by an integrated computer system.

The proposed improvements have a postulating character (management instruction, how it should be done), or a descriptive one (relying on a description of each standard cases of design) [26], and we can test them by means of simulation carried out in a digital factory.

1.3. DIGITAL FACTORY

Current markets and customers require manufacturing systems designers to apply new, advanced approaches and tools in designing future manufacturing systems. The Digital Factory concept seems to be one of the most appropriate approaches to fulfil this task, offering all required functions, among others: a central database, digital models, integrated data management, modelling and simulation functions and visualisation through virtual reality. Virtual reality has become a common tool used in the Digital Factory environment, which creates the environment for innovation related to products, processes and resources [27, 30].

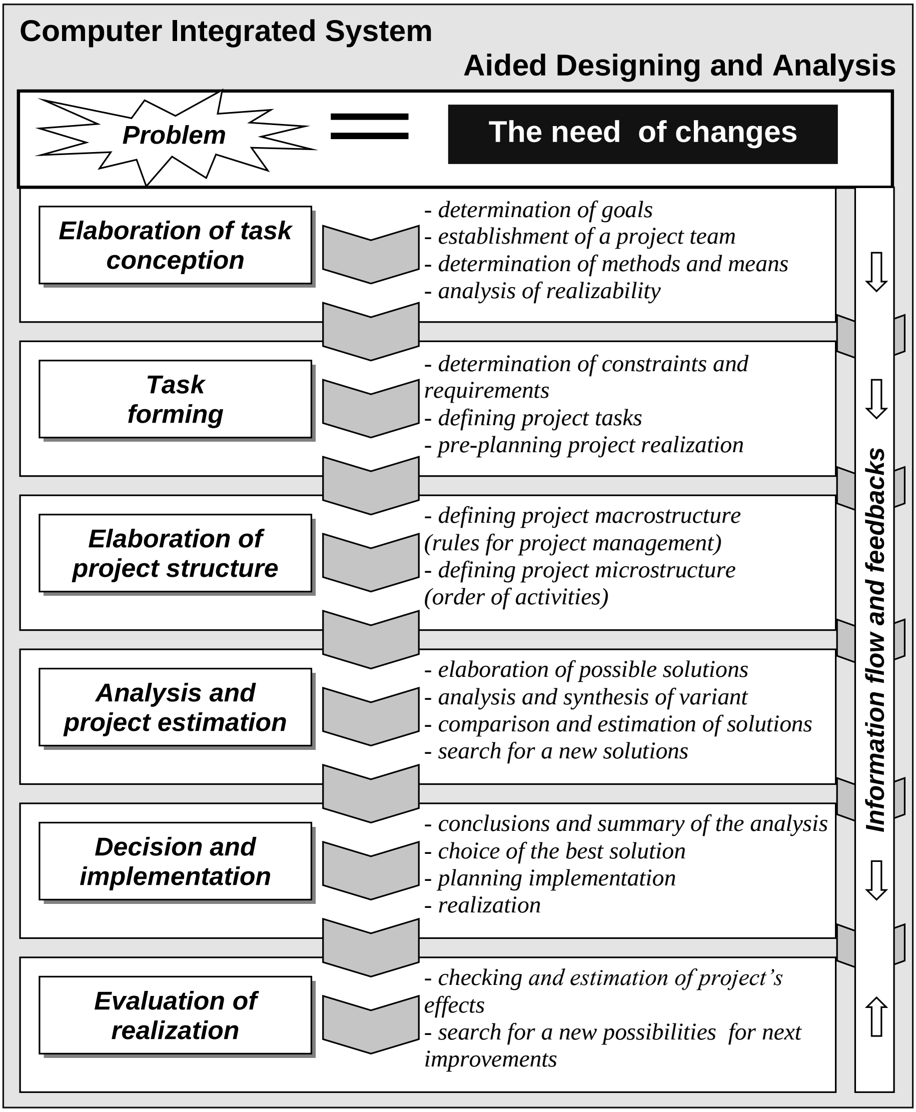

Fig. 1.1. Stages of production system improvements [own elaboration]

Digital Factory is appropriate mainly as support for manufacturing highly sophisticated products, their planning, simulation and optimisation [15, 18]. It is possible to use Virtual Reality technologies to design 3D spatial models and 3D modelling and examination of real objects' properties. On the other hand, Virtual Reality enables to create „real“ environment, in which we can conduct the required analysis. It can be used for different kinds of analysis related to product development, or designing production processes, workplaces and production systems. The use of

Virtual Reality for design and optimisation of production processes and systems is often called Digital Factory application [7].

The Digital Factory can be described as the virtual equivalent of real production. It represents an environment integrated by computer and information technologies in which reality is replaced by virtual computer models. Such virtual solutions enable for production processes' verification before the proposed improvements are implemented. Digital Factory can support planning, organization and optimization activities of complex production, and at the same time creates appropriate conditions for teamwork, ensuring rapid exchange of information between designers, technologists, planners and production organizers.

Digital Factory also represents an integration chain between CAD systems and ERP solutions, which is shown in the following figure.

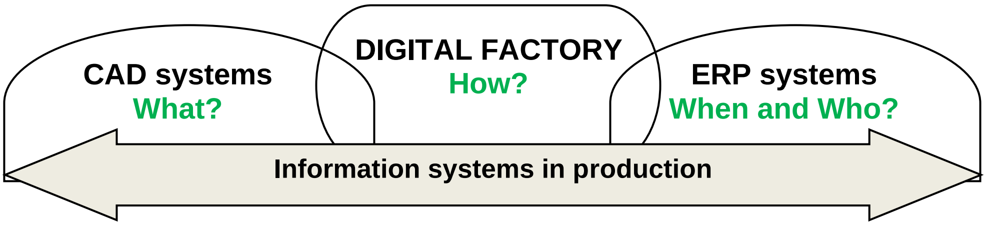

Fig. 1.2. Integration of information systems in production [14]

The most important advantage of Digital Factory is the possibility to realize process planning and product development using common data. It gives a possibility to optimise products and production processes with the use of 3D visualisation and modelling techniques.

The Digital Factory principle is based on the three following elements:

- a digital product with static and dynamic properties,
- a digital production plan,
- a digital visualisation of the product and production processes.

The presented technology brings:

- time and cost reduction,
- a possibility to generate NC programmes for machines,
- visualisation of machines and operational handling processes,
- possibilities to reveal shortages and errors in workplace design and to increase their effectiveness,
- a possibility of material flow simulation, which enables to optimise the run of material, reduce inventories and support activities in internal logistics chain [15],
- an effective ergonomics analysis of work [6],
- more effective analysis of production systems, which enables for optimisation of material, information, value and financial flows in the factory [14].

The Digital Factory system features libraries and virtual objects databases, from primitive up to comprehensive objects representing machines, robots or manufacturing lines. These virtual objects are later used by engineers when designing virtual scenes [12, 24]. Chosen examples of such elements from virtual object libraries are shown in figure 1.3.

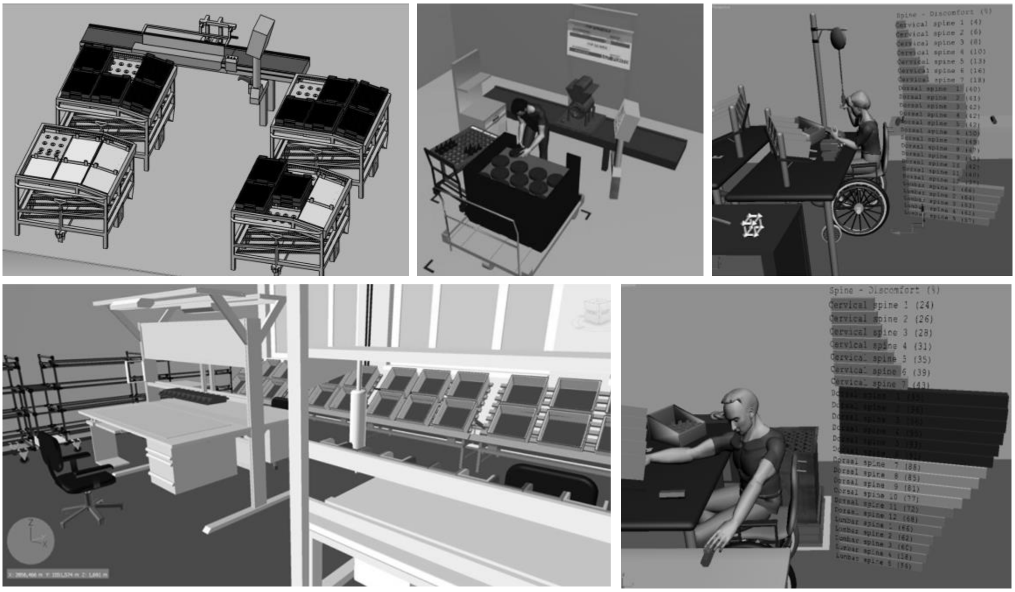

Fig. 1.3. Practical examples of virtual models of production workplaces [own elaboration]

Digital Factory implementation results directly in improving both economic and production indicators. Any small saving realised in the design and planning phases can bring huge cost reductions in the production phase. Advantages of introducing Digital Factory for enterprises include [16]:

- reduction of entrepreneurship risk by introducing new production,
- processes verification before production starts,
- a possibility of a virtual „visit“ to production halls,
- validation of the designed production concept,
- optimisation of production equipment allocation,
- reduction in the required area,
- analysis of the bottlenecks and collisions,
- better utilization of the existing resources,
- off-line programming of machines and equipment, saving time and resources,
- reduction or full elimination of prototypes,
- ergonomics analyses, etc.

Automotive manufacturers more and more often introduce new models, which requires more frequent changes in production processes. Extremely fast changes and product customisation significantly change all branches of the industry. An innovation is successful only if it is quickly launched on the market. Close collaboration between partners is very important not only in product development, but also in production planning and control. The following figure shows the main benefits of Digital Factory.

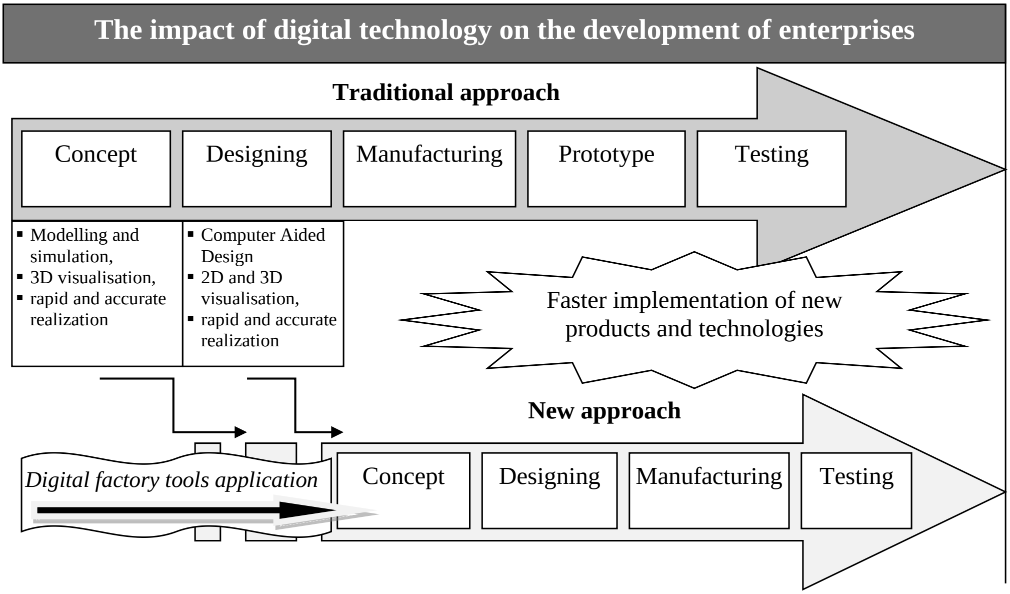

Fig. 1.4. Shortening the time to market [own elaboration]

The highest potential for high quality and low costs of products lies in the product development and production planning phases. The statistics show that product design and production planning influence about 80% of production costs [34].

According to CIMdata report (March 2003), Digital Factory enables to achieve the following financial savings [14]:

- Cost savings by assets reduction by about 10 %,
- Area savings by layout optimisation by about 25 %,
- Cost savings by better utilisation of resources by about 30 %,
- Cost savings by material flows optimisation by about 35 %,
- Reduction in number of machines, tools, workplaces by about 40 %,
- Total cost reduction by about 13 %,
- Production volumes growth by about 15 %,
- Time to market reduction by about 30 %.

1.4. AUGMENTED REALITY TECHNOLOGY

Augmented Reality (AR) is one of the fastest growing part of virtual reality. The basis of augmented reality is the ability to combine elements of the real and virtual worlds into a single view [2, 10]. It is a technology supported by human visual perception. With appropriate combination of real and virtual objects, it is possible to provide a large amount of additional information. The condition is to preserve the link between a user and a real environment.

As opposed to virtual reality, where everything is modeled by computers, augmented reality does not replace the real world, but only adds selected virtual elements or objects into the real environment. The view can be realized through a camera and a monitor or using HMD (Head Mounted Display) – equipment placed on the head [4, 9]. In practice, two basic types of systems for augmented reality are applied:

1. Systems using position sensors and transparent display – position sensor sends information about the position and direction of the user's perspective. Then, the scene generator, basing on this information, prepares to display virtual objects located in the user's field of vision. The virtual objects are projected on a semi-transparent mirror, through which the user sees the real scene.
2. Capturing real camera image for the registration of markers and indication the position of virtual objects – a video camera captures a real scene and sends it to the computer. Than the dedicated software on the computer looks for markers. If markers are found, the software identifies the type of tags, calculates the camera position in relation to markers and assigns a virtual object to the marker image, and then draws on display the resulting image of scenes – the real scene is complemented by virtual objects.

In production systems, an example of augmented reality application is paperless picking systems, thanks to which we can increase storage efficiency and quality. For example in mobile terminals, a worker receives online information via infrared transmission, radio transmission, or offline via a docking station, using a visual LCD display. The system operates on the basis of hardware-independent user dialogues. Mobile user interface is an ideal way to ensure high efficiency in central collection points, such as picking system "Goods to person".

In practice, there are used a few following solutions for picking [23, 25]:

- Pick-by-Light - a visual support implemented by placing traffic signals in shelving racks. The signalling device highlights the item and the quantity which have to be picked. This solution is very costly and inflexible. The Pick-by-Light system is suitable for products with a turnover frequency of five to ten items per day.
- Pick-a-Bucket - a workstation is connected to an automated storage for low-moving items. A worker is picking goods in the storage, and sorting parts takes place very quickly as it is possible to process up to fourteen orders. The displayed number of products is picked from one storage into the upper level conveyor and placed into a slot marked by Pick-by-Light technology. Once the order is

completed, the slot opens and parts slide on the central part of the collection conveyor, which carries them to the place of automatic implementation.

- Pick-to-Tote - is a workstation connected to the computerized storage for low-moving items. Picking is performed directly into crates and cartons. Convenient user guidance and optical monitoring of destinations ensure maximum quality grading.
- Pick-by-Voice - supports a worker by giving him all the information reported by a microport. The Pick-by-Voice system sends voice commands to warehouse workers and also transmits the acoustic feedback. This lets workers have free hands, so that they can perform their job easier. However, it is difficult to use in noisy industrial environments. The Pick-by-Voice system can also be connected with barcode scanners and video input devices.
- Pick-by-Vision – a new technology which provides the necessary information about picking orders directly to the picker´s vision field and at the right time and place. This system may be supported by voice. The systems providing navigation must include a tracking system which can detect not only the position of a worker, but also his direction of view. According to the picking order, it can correctly navigate to the place of storage [29].

The methodology for the picking process "man to goods" with augmented reality was proposed in the publication [9] and consists of several basic steps:

1. Identification of a worker – logging into the system.
2. Identification of the picking order – the searched order to be realized.
3. Generating a list of items for picking – on the basis of the identified order, a list of items to be picked is created.
4. Identification of exact storage location of each item.
5. Determination of the route - from the list of items the route is created in which the worker moves between locations of items with the shortest distance.
6. Execution of the picking process and registration of the picked goods.

Additionally, in the proposed methodology of the picking process for augmented reality applications, the following activities are necessary:

- preparation and processing of input data,
- proposal for navigation system using AR,
- transformation of picking routes into the process map (workflow) in the software for augmented reality.

All necessary steps for using augmented reality in the picking process are presented in the figure 1.5.

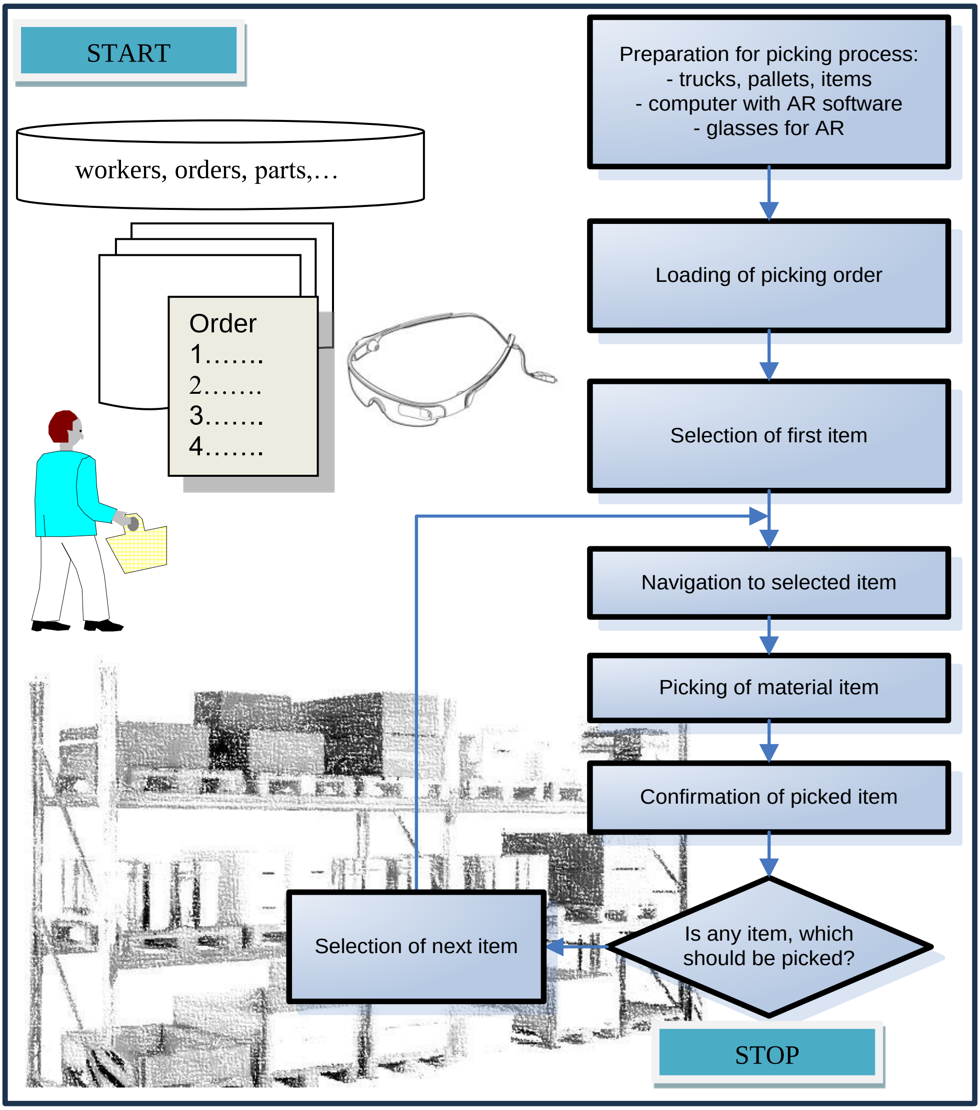

Fig. 1.5. Practical example of using augmented reality in the picking process [own elaboration]

Current research in the field of augmented reality is connected with:
- minimizing equipment of components for augmented reality,
- development of head mounted displays, which should be more ergonomic with transparent glass,
- development of "mini computers", which will be more suitable for augmented reality applications,
- combining the above mentioned components into one unit,
- using navigation systems,
- using a waist wearable computer,

- pick-by-Voice – using voice commands,
- using RFID (Radio Frequency Identification) systems – to check the accuracy of picking a specific item.

1.5. CONCLUSIONS

New information technologies. which are presented in this chapter, integrate the whole production process, from product design to its manufacturing. Generally, such integrated systems are connected with the six following areas:

- product design systems (modelling and simulation of products),
- process planning systems (process and production plans, assembly plans, work standardization, value analysis, cost analysis, etc.),
- production process design and validation systems (NC systems, production process simulation, assembly, inspection, maintenance, etc.),
- production engineering systems (complex production scenarios, layout design, time analysis, ergonomics analysis, designing and analysing manufacturing and assembly systems, load on machines and workers, etc.),
- production planning and control systems (ERP planning systems),
- automation and process control systems (programmes for controlling and monitoring in automated production systems, PLC systems, industrial robots, etc.).

The future outlook shows that digital factory can bring benefits to next generations of products. All types of processes and products will be modified and developed in the future, and these activities should be aided by new information technologies to achieve competitive advantage.

Current research requires huge investment. Industry requires Digital Factory solutions, but unfortunately in many production companies it is still only a concept, which should be popularized.

The common intention of different universities is to develop a concept of a fully integrated system for factories. Such a system should enable us to bring new technologies to both industry and education, and will support the education of future product designers, manufacturing systems designers, technologists and managers.

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