Edited by Dariusz Plinta

# Advanced Industrial Engineering

## Industry 4.0

Bielsko-Biała 2016

# ADVANCED INDUSTRIAL ENGINEERING

Industry 4.0

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2. Janusz Mleczko: Komputerowo wspomagane zarządzanie wytwarzaniem (na przykładzie oprogramowania REKORD.ERP). Wydawnictwo Fundacji Centrum Nowych Technologii w Bielsku-Białej. Bielsko-Biała 2008.
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# Contents

# Foreword

Advanced Industrial Engineering (AIE) is a major direction of current and future technological development, and also a strategy of European development and research. AIE arises from the needs of applying new innovative technologies to create better position of production companies in global and knowledge-based society. Solutions for industry need a new perspective, which is presented in the following chapters of this book.

This monograph looks at chosen topics which are connected mainly with Industry 4.0 and new information technologies used in production companies. The next goal of this book was to describe the research realised in some Central European universities.

Industry 4.0 is a concept which is developed very intensively and more and more of its components are being implemented now in industrial practice. The concept concerns different areas of organization's operations, which are aided by IT systems, facilitate the decision making process and improve productivity and quality. Application of the idea of Industry 4.0 can provide opportunities for some companies, whereas for others it can pose a threat.

Initial chapters of this book describe the Industry 4.0 concept, development of the computer technology used in production enterprises and practical conditions connected with application of this concept. Further chapters present integration between different system used in factories – CAD/PDM and ERP systems, the problems connected with data collecting, processing, presentation and knowledge sharing. Three final chapters describe practical examples of the use of different IT solutions, like simulation for optimization of healthcare processes, smart connected mobile robotic systems, and multi agent systems for control and coordination of automated guided vehicles.

We do hope that this publication will increase interest of the advanced industrial engineering and the concept of Industry 4.0.

Dariusz Plinta
Editor

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*Industry 4.0, digital factory, virtual reality, augmented reality*

Dariusz PLINTA*

# 1 NEW INFORMATION TECHNOLOGIES IN PRODUCTION ENTERPRISES

**Abstract**
*Information technologies allow for improving production systems functioning especially thanks to a possibility of solving complex problems in a very short time. Execution of research on large quantity of data by computer integrated system gives us a possibility of verifying possible solutions and making decisions in different problematic situations connected with production systems functioning. The presented examples of new information technologies used in production practise constitute the main object of this paper.*

## 1. INTRODUCTION

Today, competitive global markets require high quality, quick production and low cost. Such markets requirements create the need for collaboration of all professions, from engineers and managers to shop floor workers. The future success requires sharing knowledge and experience [13, 20, 24] with the use of new information technologies. The highly competitive environment requires in production practice new software systems for designing, testing, process planning, manufacturing and assembly.

Another decisive factor for further development and prosperity of any country is quality of its engineers, who are responsible for innovations. Investment into engineers' education brings higher increase of productivity than investment in capital assets. Current discussions concern the topic of products innovations. However, there is no discussion on production and assembly systems innovations, in spite of the fact that the majority of foreign investment in Eastern Europe was focused on production and assembly.

The evolution of production systems mainly follows the development of innovative technology and its direct environment, like machines, devices, methods and tools aiding the work related to preparing technical documentation, including description of product models, processes and production resources. This can be achieved by introducing shorter production cycles, new products and manufacturing processes development, minimization of the supplies level, more efficient logistics, and the usage of effective and innovative ideas of production realization, like Lean Production, JIT (Just in Time), Total Quality Management, and particularly, Digital Factory Technologies [5, 20]. These methods allow for effective production management by constant improvements of work organization and usage of different modern tools by engineers and managers. Thanks to this, integration of tasks and functions takes place in two areas of a company, i.e. in management and production realization.

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The main types of software used in production enterprises are linked in PLM solutions, which control different parts of the manufacturing cycle. CAD systems define what will be produced, Manufacturing Process Management (MPM) defines how it will be manufactured, ERP informs when and where it is created, whereas MES provides shop floor control and simultaneously manufacturing feedback. The stored information generally aids communication and improves making decisions, but also removes human errors from the design and the manufacturing process. Nowadays, Industry 4.0 has become a very popular concept, which in its assumptions integrates various software applications [17, 34].

## 2. INDUSTRY 4.0

The socio-economic evolution of mankind takes place in three stages, which are defined by Alvin Toffler [27] 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 [34] as a common term for the technology and concept of organization of the value stream. As a 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 most advanced country in implementing this concept is Germany. Implementation activities are supported by the government, what is confirmed by publication of recommendations [16] and a special online web platform. We can expect significant progress in these activities in the coming years.

Poland is on the 3rd position in Europe in the number of people employed in production companies behind Germany and Italy (Eurostat, data for 2014). Therefore, we can expect a significant impact of the implementation of the Industry 4.0 concept on the Polish economy, but also on the higher education system, because the new industry will require new competencies.

The concept is to be seen as an opportunity for the developed countries, particularly the USA and Germany, and in the countries with high labour costs. This is also a chance for reindustrialization and for improving the competitiveness of national economies. In this context, it could pose a threat for Central European countries, for which the main competitive advantage is low labour costs. Hence, the concept of Industry 4.0 should be very interesting for production companies.

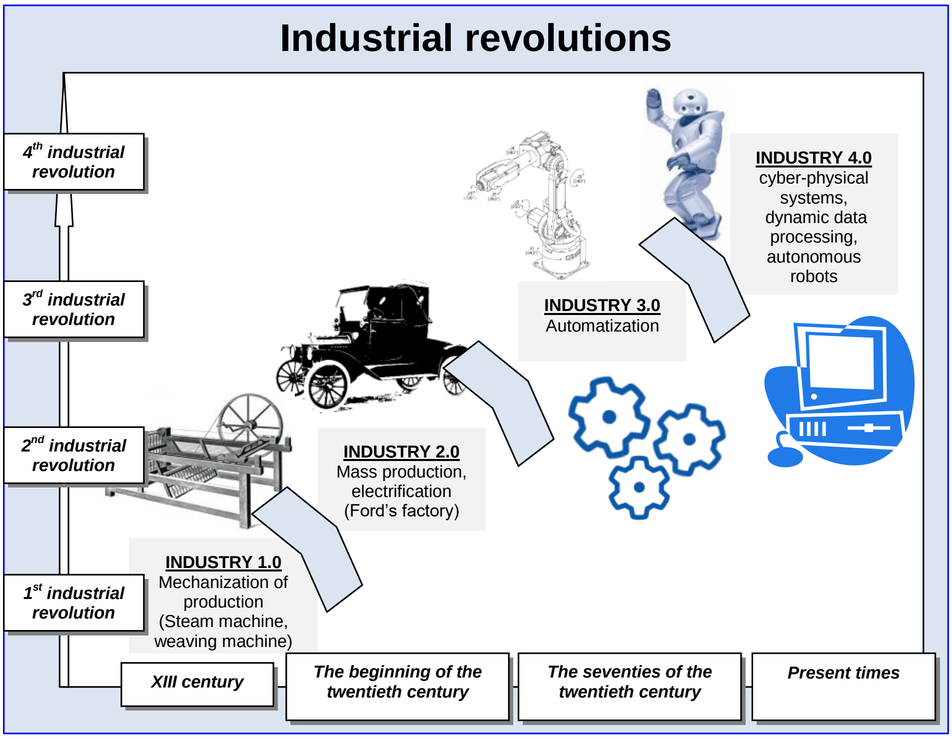


*Fig.1. Industrial revolutions.*

The Industry 4.0 concept was presented in 2011 [16, 34]. In the first publications, the most important technological solutions were listed, which are the basis of this concept. These are:

a) Autonomous Robots,
b) Simulations and Forecasting Techniques [14, 22]
c) Vertical/Horizontal Software Integration [5],
d) Industrial Internet of Things – IoT [1],
e) direct communication between machines – M2M,
f) Internet of Services [1, 33],
g) Big data and analytics [19],
h) Innovative methods of collecting and processing large amounts of data, including the use of potential activities in the cloud (Clouds) [28, 29, 31],
i) Additive Manufacturing [12],
j) Augmented Reality – AR [2],
k) Virtual Reality – VR [26],
l) Cyber-Physical Systems – CPS [3, 10, 17],
m) Digital Twin [34],
n) Artificial Intelligence,
o) Neural Networks [22],
p) Cybersecurity [32],
q) Mass Customization [12].

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. This can be achieved only through the use of modern information technologies, which were described below.

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

## 3. METHODOLOGY OF PRODUCTION SYSTEMS DESIGN AND ANALYSIS

The process of design and analysis of production systems functioning involves a series of subsequent activities realized one by one or simultaneously. Such an activity can consist of a group of stages, one stage, phases, runs, actions, etc. Each activity is characterized by plurality of solutions. From all the existing solutions, it is possible to distinguish a set of possible solutions for realization, from which we should eliminate non-perspective ones that will not give satisfactory solutions.

As a result of evaluating the proposed variants, it is possible to select a solution which is optimal according to the chosen criteria. A proper solution of optimization should take into account the evaluation from the point of view of time, cost and quality criteria as soon as possible, on the stage of concept study and product design. The same relates to next stages – production processes design and their organization. These aspects should form the basis for projects realization.

Lately, a growing attention has been paid to the organizational saspect of implementation processes. The most crucial clues comprise the following items [13, 20]:

- one of the managers should be responsible for production strategy and production operations,
- the departments of marketing, design, production and finance 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.

Designing is generally a sequential process where some activities can be conducted simultaneously. Realization of a typical project is a process which consists of activities presented in figure 2. Almost all the mentioned activities should be aided by a computer integrated system.

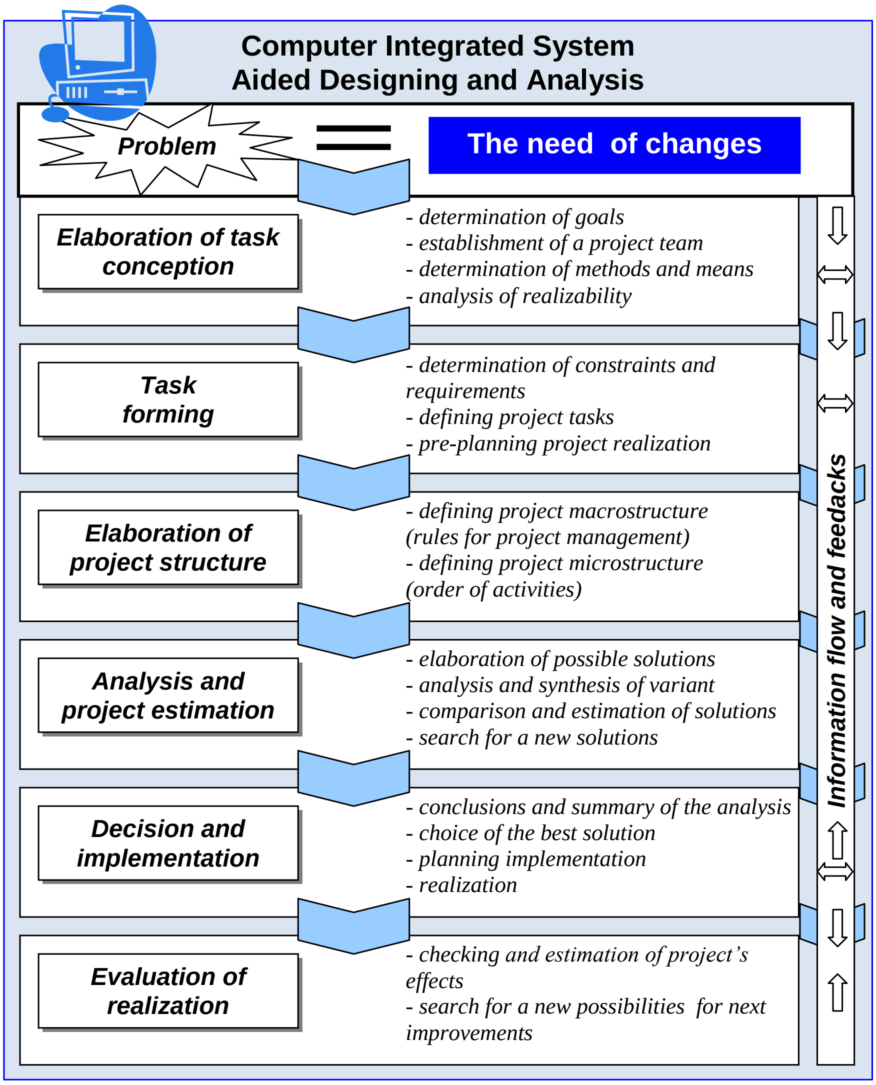


*Fig. 2. Stages of production system improvements*

At different stages some characteristic activities are repeated several times, so it is also an iterative process, which can be realized with the use of a computer software. A production process can be designed for conditions of the existing production system (the most often occurring case), or for a new or restructured production system, which can be created as a virtual system. The proposed improving activities have a postulating character (management instruction, how it should be done), or a descriptive one (how the others do it, relying on a description of each standard cases of design) [24], and we can test them by simulation conducted in a digital factory.

## 4. DIGITAL FACTORY

The Digital Factory concept bases on the Virtual Reality, which is a computer technology supported by hardware and software. It enables to create virtual models of real objects and use them for visualization of products and manufacturing processes [30].

Digital Factory is appropriate mainly as a support for manufacturing of highly sophisticated products, their planning, simulation and optimisation. The main current application area is automotive industry, mechanical engineering industry, aerospace and ship building industry, as well as electronics and consumer goods industries [15, 18].

It is possible to use Virtual Reality technologies to design 3D spatial models and 3D modelling and examination of properties of real objects. On the other hand, Virtual Reality enables to create „real“ spatial environment, in which we can conduct the required activities. The possibilities for Virtual Reality technologies development are tremendous and they are still growing. Virtual Reality can be used for different kinds of analysis connected with product development, designing production processes, workplaces, production systems, etc. The use of Virtual Reality for design and optimisation of production processes and systems is often called Digital Factory application [7].

Digital Factory can be described as a virtual picture of a real production. It represents the environment integrated by computer and information technologies, in which reality is replaced by virtual computer models. Such virtual solutions enable to verify all collisions and critical situations before real implementation of the proposed solutions. Digital Factory can support planning, organization and optimisation of complex production, and simultaneously creates right conditions for team work, providing quick feedback among designers, technologists, production systems designers and planners.

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

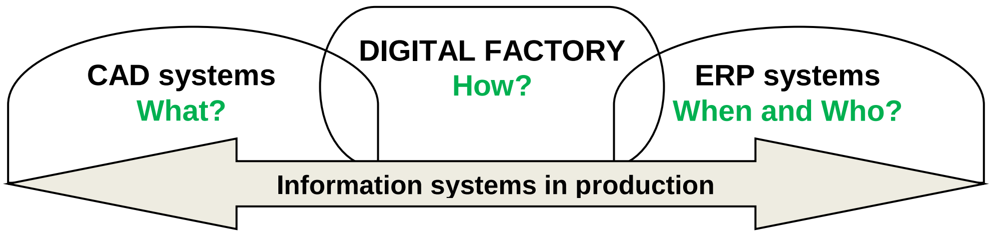


*Fig. 3. Integration of information systems in production [13]*

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, processes and production systems even by the development phase with the use of 3D visualisation and modelling techniques.

The Digital Factory principle is based on three elements:

- a digital product with static and dynamic properties,
- a digital production plan,
- a digital visualisation with the possibility of presenting the future state of the product, production system and enterprise processes effectiveness growth.

The presented technology brings:

- time to market reduction,
- significant cost reduction,
- a possibility to generate real NC-part programmes for chosen production machines,
- visualisation of machines and operational handling processes
- possibilities to reveal shortages in design of machines and changes, remove errors and increase their effectiveness.
- a possibility of material flow simulation, which enables to optimise the movement of material, reduce inventories and support value added activities in internal logistics chain [14],
- an effective ergonomics analysis within international standards, like NIOSH, RULA, etc., which enable for right planning and verification of man-machine interactions on workplaces [6],
- the highest level of analysis of production and robotics systems, which enables for optimisation of material, information, value and financial flows in the factory [9].

Any Digital Factory system has to dispose of user libraries and virtual objects databases, from primitives up to comprehensive objects representing machines, robots or even manufacturing lines. These virtual objects are later used by engineers for designing virtual scenes [11, 24]. Chosen examples of such elements from virtual object libraries are shown in figure 4.

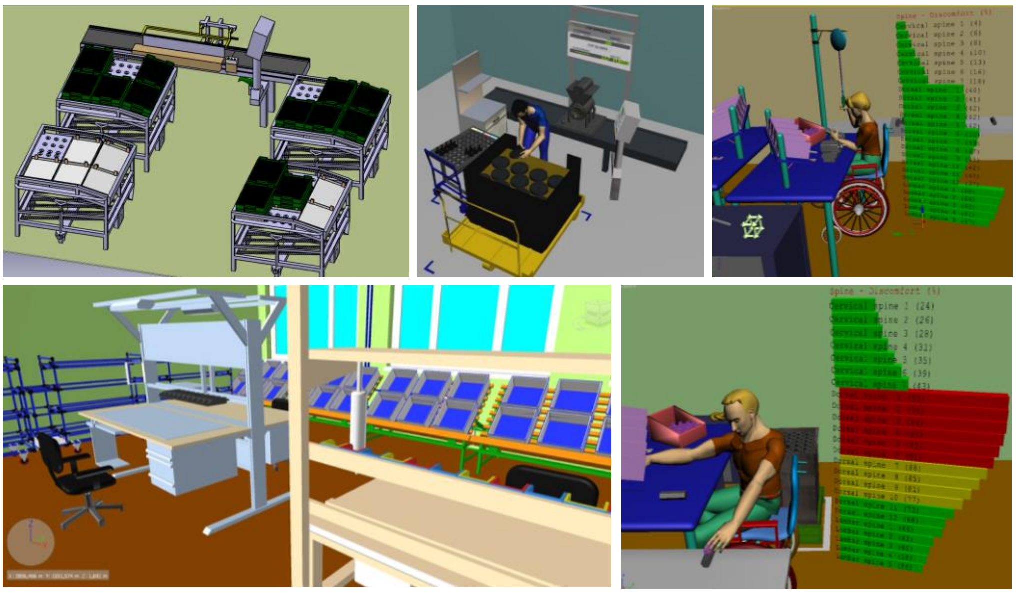

*Fig.4. Example of virtual models of production and handling devices*

Digital Factory implementation results directly in economic as well as production indicators improvement. Any slight saving realised in the design and planning phase can bring huge cost reduction in the production operation phase. Thanks to this, payback period by investment in Digital Factory is very short.

Digital Factory advantages for enterprises include[13]:

- reduction of entrepreneurship risk by the introduction of a new production,
- processes verification before production start,
- 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,
- bottlenecks and collisions analysis
- fast changes,
- better utilization of the existing resources,
- machines and equipment off line programming saving time and resources,
- reduction or full elimination of prototypes,
- ergonomics analyses, etc.

Automotive Manufacturers every 2-3 months introduce a new model, what very often requires changes in production processes. Extremely fast changes and products customisation significantly change all branches of 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. Starting a new product is often accompanied by a lot of chaos and supplementary costs. The following figure shows the main benefits of Digital Factory introduced by Toyota. It mainly emphasizes time factor influence by the new product launch and the possible cost reduction resulting from it.

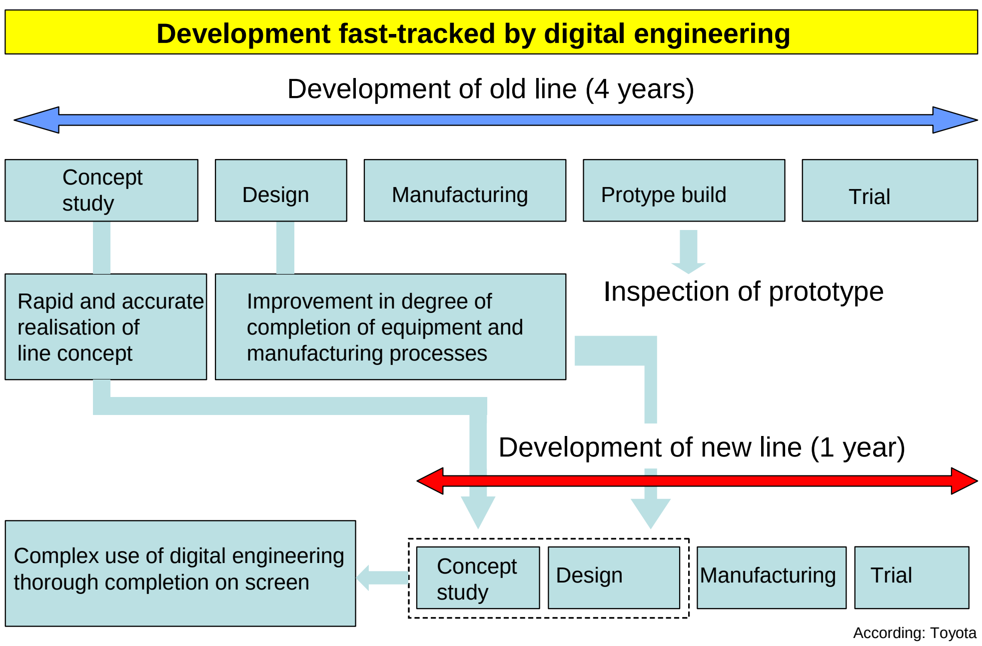


*Fig.5. Shortening the time to market*

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 [2]. Digital Factory enables for product launch time reduction of 25 up to 50 %. The estimated cost savings are supposed to be on the level of 15 to 25 %. According to some studies done in the industry, thanks to using digital manufacturing techniques, twice the amount of design iterations can be processed in 25 percent of the time.

According to CIMdata report (March 2003), Digital Factory enables to achieve the following financial savings [13]:

- 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 %.

## 5. 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]. 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, 21] (fig.6).

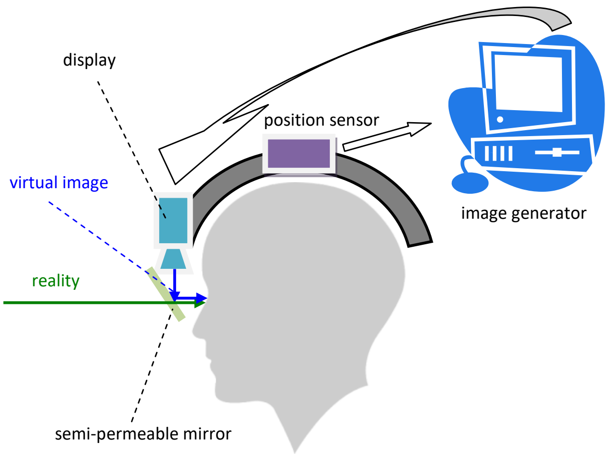


*Fig.6. Basic principles of augmented reality systems*

In practice, two basic types of systems for augmented reality are applied:

1. Systems using position sensors and transparent display (fig. 6) – 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 in mobile terminals, thanks to which we can increase storage efficiency and quality.

In mobile terminals, a worker receives online information via infrared transmission, radio transmission, or offline via a docking station, using a visual LCD display. Mobile user interfaces allow for the exchange of data between terminals. The system operates on the basis of hardware-independent user dialogues. Mobile user interface is an ideal way to ensure high efficiency in a wide range of applications. They are often used to central collection points, such as picking system "Goods to person".

In practice, there are a few following solutions for picking [8, 23, 25]:

- Pick-by-Light - a visual support implemented by placing traffic signals in shelving racks. The signaling 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.

The methodology for the picking process "man to goods" with augmented reality was proposed in the publication [8] 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.

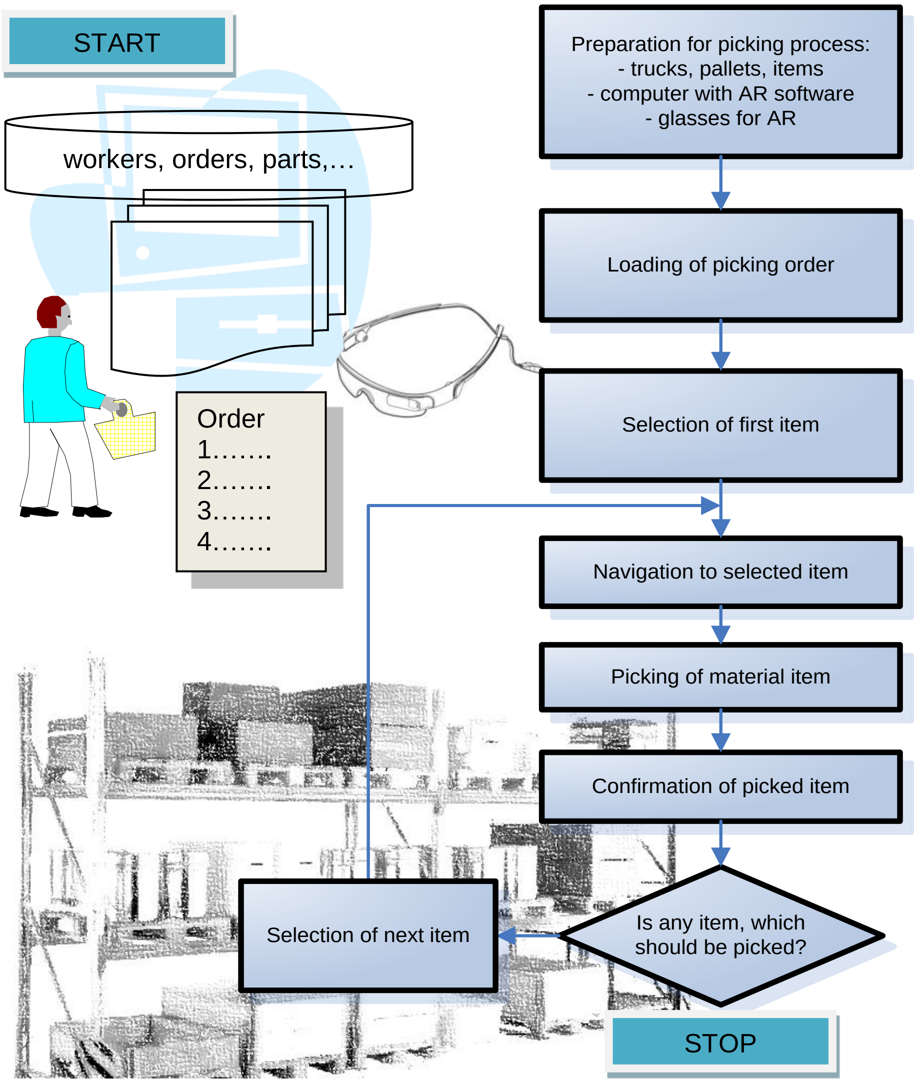


*Fig.7. The methodology of using augmented reality in the process of picking*

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 7.

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 should contain a video card 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.

## 6. CONCLUSIONS

New information technologies. which are presented in this paper, all together 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 a competitive advantage.

Current research requires huge investment. Governments support innovative research and new strategies, like the concept Industry 4.0. Our industry requires Digital Factory solutions, but unfortunately it is still only a concept, which should be popularized.

The common intention of different universities, like, for example University of Bielsko-Biala, University of Zilina and University of Pilzno, is to develop a concept of a fully integrated system for factories. Such a system should enable us to bring new technologies into both industry and education. Such a solution will support the education of future designers, designers of manufacturing systems, technologists and managers.

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*Industry 4.0, Mass customization, Complexity, Demand, Variety*

Miroslav MINDAS, Slavomir BEDNAR *

# 2 MASS CUSTOMIZATION IN THE CONTEXT OF INDUSTRY 4.0: IMPLICATIONS OF VARIETY-INDUCED COMPLEXITY

**Abstract**
*This chapter aims to outline all aspects of special issues of economy and complexity arising in mass customization as a strategy. Firstly, it discusses direct economic aspects of mass customized manufacturing with impact on product and process variety-induced complexity. On the other hand, it is argued that the concept of customization does not necessarily bring higher production cost, rather it brings additional benefits to the producer.*

## 1. CONCEPT INDUSTRY 4.0

Our world is constantly changing. Today there is a sharp increase in the development of new technologies to facilitate, also optimize not only production but also everyday life. Experts in industrial production and futurologists are constantly asking how production will look like in the future. The beginning of the 21st century is connected with the explosive spread of the Internet, smart technologies and their penetration into all areas of human activity. Continuous innovation, optimization and efficiency are the key to gaining a competitive edge in the market. Classic business model is changing, because the current production can not meet the needs of increasingly demanding customers. The customer has increasingly demands and their increasing complexity, in addition want to have everything in the shortest time. Classic business model based on mass production is no longer sufficient. All of the above was the basis for creating the Germany concept of the Industry 4.0.

Concept Industrie 4.0 (original name) was established based on the award of the German government, which in 2006 launched a project "High Tech Strategy", which represents the first national concept and should bring together key experts in order to shift the development of new cutting edge technologies. This project is supported by the resources of all government ministries have allocated millions of Euros per year to support the development of new technologies. The objectives of "High Tech Strategy" were further converted and extended into the structure of the new project "High Tech Strategy 2020 'in 2010, which was subsequently approved in 2012. According to this strategy, Germany in 2020 should be a major and crucial market with cyber-physical systems (CPS). To achieve this goal is to be through investment in research, deepening cooperation between science and industry, including continuous improvement of conditions for further development. In the action plan how to achieve

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objectives determined by the ten key projects, which include the concept of Industry 4.0. The initiator was the Ministry of Education and Research which gathered an expert team. To form this promising concept stands 21 major scientific and research organizations, including leading companies, namely 661 experts from industrial practice (for example Acate, Fraunhofer, Bosch, SAP and Festo), which are closely cooperating on a vision of where should the industry removing [24]. After extensive research, which was presented with the first idea in January 2011, called Industrie 4.0., which was further developed. The very name of Industrie 4.0 refers to the fourth industrial revolution. The final vision was drawn up in the final report of the development team, as a tool for securing the future of German industry published in April 2013 [16]. The concept Industrie 4.0 was officially introduced to the public at the fair Hannover Messe in the same year.

### 1.1 Functional determination of Industry 4.0

With the new German concept will be the industrial producers able to build a flexible production facilities that will be eligible for the production of small lots of products that are configured and based on the customer requirements, thus in various modifications within a very short production and delivery time [5].

Industry 4.0 is built on four basic points which characterize it and distinguish it from the current traditional production (Deloitte, 2014):

- vertical links of the production system,
- horizontal integration through the new generation of global value chain network,
- flow production across the value chain,
- speeding by SMART Technologies

Industry 4.0 is directed to the Smart Process. What it is a big change compared to the current conventional manufacturing (Fig.1). The cornerstone of the concept is to create Smart Factory. These factories will be able to cope with fluctuations in demand. These factories will be more fault-tolerant, while capable of producing with maximum efficiency. Machines, people and resources together can not only communicate, but also to cooperate. Machines proclaim themselves to maintain, moreover, able to define precisely the problem. Product with the help of RFID transponder is able to manage its production flow. The product identifies from which parts consists of and where to be delivered later. The product itself is actively involved in the manufacturing process. The infrastructure of such enterprise is interconnected Smart Logistic, Smart Grid, Smart Buildings and Smart Distribution. In other words, the transformation from the traditional value chain to a completely new value chain [9]. The concept of Industry 4.0 doesn't manufacturing as a single part of the value chain working in isolation, but everything is connected and cooperates effectively. Characteristic will be very close links between suppliers, manufacturers and customers.

Automation and business systems are linked horizontally with vertical manufacturing process and will be able in real time to react flexibly to changes and fluctuating demand. Such production will be the most effective and sustainable optimized [2, 20, 23]. Horizontal integration refers to link the various company departments and information systems used in various stages of production, planning processes, including the provision of materials, energy and information to the factories, and even among individual factories. Vertical integration refers to relate to information systems also hierarchy of the company, that is in all departments, from planning production to distribution. The aim is to link all areas and processes to ensure end-to-end solution [9].

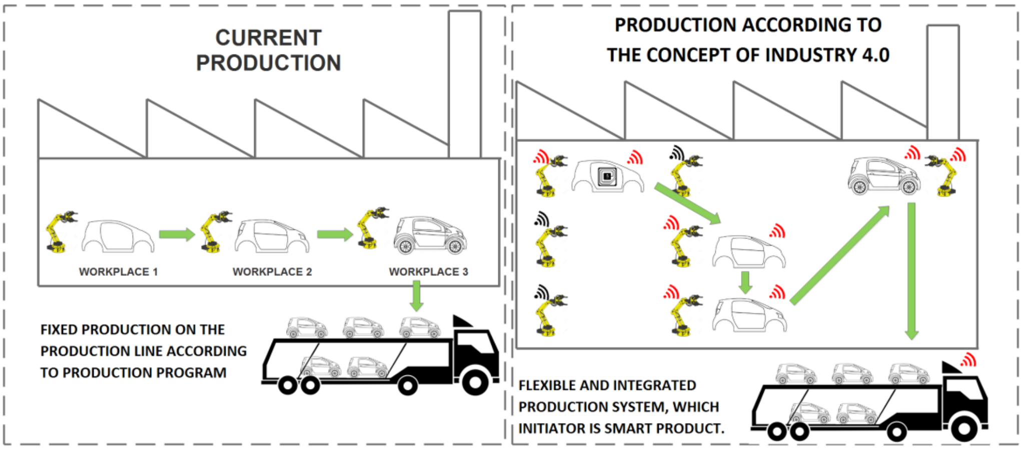


*Fig. 1 Current and future production in the Smart factory*

The key to achieving the above Smart factory is to use CPS. With this technology can both machinery and equipment themselves manage the production process, in order to achieve high efficiency, optimal material usage, tuning and optimizing the production cycle according to customer demand, ensuring low-dose products in various modifications, all in real time. All machines, conveyors, loaders and trucks also the products themselves are autonomous and decentralized. There is a connection between the real world with a virtual [6, 9].

Machines communicate with each other and with people. They can respond to possible disturbances. They can very swiftly adjust production to prevent line stops. This will lead to the minimization of waste, errors, very short production time in the range of hours, up to several days (depending on the complexity of production) and in the final stage to save the operating personnel. Physically demanding routine work procures only the machines and people will focus on the creative and management tasks. Emphasis will be placed on the creation of capable staff that will transform customer requirements into the language of machines.

Internet with the help of CPS interconnects people, machines and software. The virtual world will begin to converge with the real. In the concept Industry 4.0 are for the production of computer-controlled trends included Internet of Things (IoT below), big data, cloud computing, M2M, M2P and T2M communication. All these mentioned technologies allow the CPS to work with maximum efficiency [3]. With the help of IoT products are able to communicate with machines, while controlling production. Information flow, management and control is on digital base through Internet Protocol. Not only production will require a lot of space for a variety of data - historical data, sensor data, production time, etc. These large volumes of data called Big Data that are stored in the Cloud are very important for the analysis, production diagnostics and basis for decision-making, including optimization.

In the real situation, this concept will work for example as follows: The requirements of individual customers will go online using the Internet and the Web configurator directly on the production line. This allows customers to get product for large-scale price. The entire production process is linked from development to service. The customer's request is processed automatically by computer under the supervision of operators. From the warehouse is automatically released material. In the blank is embedded RFID transponder that will drive product range, including references to relevant parts. With the assistance of sensors, cameras, readers, transponders, CPS and the Internet factory is managed autonomously. The finished product together with a computer program will plan the optimum route. Delivery will take place using drones to the customer's doorstep. Thanks to digitization and robotization customer receives their configured product few hours after placing the order [3].

In short concept Industry 4.0 is a new production model that brings together and accelerates the entire value chain. Vertical and horizontal integration of IT as well as automated production will lead to an end-to-end solution. Using IT IoT, Internet of Services (the IoS) and last but not least CPS, cooperate machines, products with people. RFID transponder placed in the product initiates the production process. This will be achieved by flexible production, small-lot production in various modifications according to individual customer requirements in the shortest time. Eliminating the physically demanding work, which is replaced in programmers' sites, controllers and maintenance workers who actively cooperate with the machines, in addition they can learn from each other. This will provide work-life-balance. Principle will be develop other technologies, in particular their incorporation into production such as 3D printing, the use of drones, artificial intelligence, collaborative robots and nanotechnology leading to acceleration and greater efficiency of production processes. Clever solutions such as smart mobility, smart grid or smart factory itself are the cornerstones of the future value chain. With this concept the company is able to carve out a privileged position in the industry of the 21st century.

## 2. BENEFITS AND RISKS OF THE CONCEPT OF INDUSTRY 4.0

With every new concept, research method or the invention it has to consider their advantages, but also disadvantages. It is essential to summarize the advantages, but also disadvantages on account of a possible further development of the concept, so that it can determine the potential risks and minimize it, if not eliminate. For this reason, the following text describes the benefits of the new concept of Industry 4.0 and on the other hand the pitfalls and risks associated with this concept in the current environment.

### 2.1 Benefits arising from the concept of Industry 4.0

Below are described the benefits arising from the implementation of the concept of Industry 4.0. The main benefit is increased productivity, safety, increase efficiency, flexibility and competitiveness (Fig. 2).

This new concept is a source of increased competitiveness. The concept of a manufacturing plant changes, where is waived from focusing only on minimizing costs, which are largely fully automated by IT. These also ensure maximum optimization of processes throughout the chain [24]. Thanks to the flexibility of production is possible to produce small batches of customized products with the advantages of mass production. It can be argued that the company using the concept of Smart Factory achieved a leading position in the market.

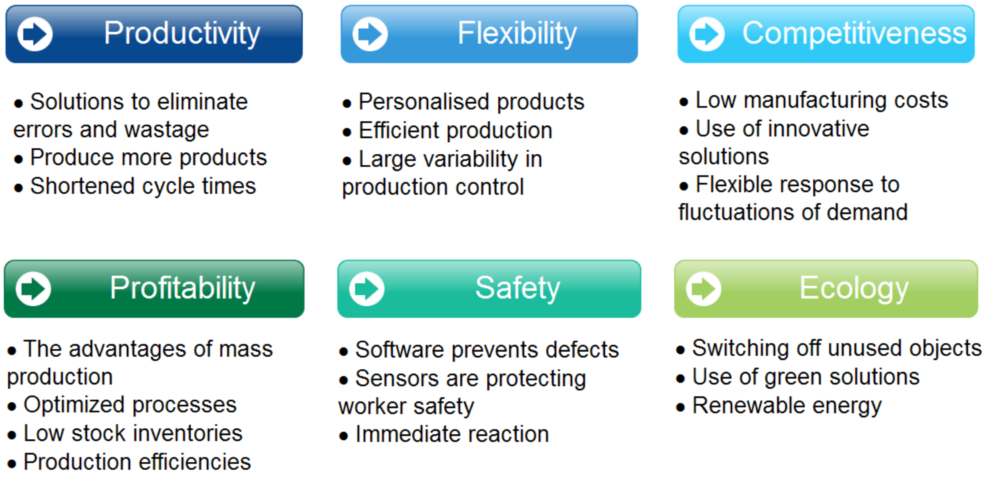


*Fig. 2 Benefits of the Industry 4.0 concept*

The company will be able to have a much higher productivity under this concept. This is due to digitization and robotics of manufacturing, which allows increased variability of production in shorter production time, smart production can eliminate waste, defects and non-compliant parts even before they will be ever produced - these are called predictive methods [15, 24]. Expected is general increase productivity by 5-8%. In the case of the automotive industry the productivity will increase by 30%. Greater efficiency of the production process will facilitate the use of CPS which will enable dynamic settings all sorts of processes. CPS will concurrently control the quality, time, risk, costs and structure of the product [24]. This concept will also result in savings of input materials, and shortening the supply chain. Logistics and production will use Lean principles - elimination of waste, quick reaction to changes, continuous improvement and accelerate delivery times. This concept is characterized by a high degree of horizontal integration in the supply chain that extends beyond corporate boundaries and efficiently connects the complex process participants from suppliers to distributors. All interested parties are actively exchanging information. They are working together for optimum material flow. In this way, manufacturers can offer excellent customer service, efficiently manage inventory throughout the supply chain and they are able to shorten the supporting processes. In short, horizontal integration will bring through associated enterprises increase of value added creation [3].

The new industrial revolution will also bring new business models. For example, in the near future, customers will not have to go to a store or showroom to inspect the product. From the comfort of their home by using virtual product overlooked with the help of virtual reality goggles. By using these glasses for virtual reality customers can look car from the outside and inside.

In addition, they can explore all the options of virtual model. Another example is 3D printing. A customer buys a license for the selected product and based on contract or payment the customer can prints out this product at home on 3D printer [11].

Due to the communication link between the production machinery, products and transport systems production line is able to respond flexibly for possible downtime and changes of the production program, possibly modified route and find alternative machines [9]. This solution should help to elimination of downtime in production. Alternatively faults on machines, thus do not undermine the continuity of production. The desired product is thus delivered in the shortest possible time period in view of the complexity of the production process.

Important element of this concept constitutes a production economy. As the concept of Smart factory is able to produce also small batch production even in the range of one piece in compliance with the advantages of mass production, thus it is possible to eliminate the high production costs, effectively manage the value chain, thanks to its high transparency of data from production, minimizing capital funds committed in inventories due to the principle of Just In Time (JIT). As a result, the company can produce its products with respect to their maximum efficiency [24].

Among the advantages may also include the flexibility and speed of the described embodiments. Due to the high orientation on customer requirements, which you can configure the product according to your requirements and tends to develop the customized product [24]. In cooperation with Smart product it will rapidly shorten the development and creation of technical documentation will be formed automatically using software with added knowledge gained in production. Due to the linkage of production and Smart Product, that is initiating element of production, it is possible to achieve a high variability of in compliance with a very short production time. Optimal decision-making process in this case it means that if it is necessary to make a critical decision, the system chosen the most optimal solution in view of the situation, thanks to multiple data and information [9].By simplifying the value chain, CPS are capable of producing complex equivalent solutions in real time and in the calculation of the number of fundamental factors. Due to the fact that all data is stored in the cloud accessible from anywhere and are continuously backed up for further evaluation [5]. If the cloud is well secured, archived data can thus be taken as a basis for predictive systems, such as Smart Maintenance.

The concept with this approach can provide the working conditions determined by the high safety of the working environment but also production. Since strenuous and mechanical work will be done machinery, thus will not conflict operators with heavy load. All machines, including robots (COBOTS) will cooperate with operators using artificial intelligence and sensors and thus will be eliminated the risk to human health [9].The same approach can also be used on the machine. Using the latest IT technology, machines will conduct their own maintenance, and with a sufficient interval to determine the possible failure thus ensuring the continuity of the production program. Using the latest sensors are eliminated collisions in the working environment, including the nearby machinery and equipment. Flexible production program ensures a steady relationship between work and leisure. The so-called Work-Life-Balance, so the optimum balance between time spent in work and in private [9].The machine is able to adapt working hours and operators are able to make optimum use of working time. Smart Assist systems help optimize and reorganize work assignments with respect to the project deadlines.

In addition to the positive economic aspects it should be recalled and ecological aspects of Industry 4.0. Making best use of energy in a Smart Factory with help of CPS, energy is used optimally, without excessive waste. They use mainly renewable energy, be it by solar panels or wind power and other combinations. The concept also counts with excessive heat production from robots and computers. Thanks to a newly developed cooling system which will manage CPS, these systems will only run at maximum load and when it will be necessary. Also in this regard, scientists have already prepared many scientific studies.

From the concept of Industry 4.0 will benefit small and medium-sized companies. Thanks to the digitalization of manufacturing, these companies will be able to operate in overseas markets, as in the current model, it is very rare [9].The possibility of trading with partners across the world becomes more real for them [21]. Due to the need for new services, such as cloud computing storage for Big Data will these companies open more opportunities for development in the B2B sector. The latest German study brought arguments that the implementation of Industry 4.0 concept in to industry will lead to a rapid increase of GDP. According to a study by Roland Berger Strategy Consultants it could shift from classical to digital production in Germany to bring growth of added value to industry 425 billion € in 2025. For the whole of the EU would therefore mean an increase of GDP by up to even 1,025 billion in industry. All these arguments are, however, subject to the adoption of relevant legislative and economic changes [8]. The Industry 4.0 concept carries advantages also for the final consumer which acquires products of excellent quality, which ones will be customized according to his requirements and they will be delivered in an extremely fast time. All of this is subsumed in a relatively low price, which is achieved due to the high efficiency of production. Products produced in the Smart Factory will be more reliable, and they will supervise themselves on their functional status. The result of this condition will be satisfied customer.

### 2.2 The risks, threats and limitations of the concept of Industry 4.0

This subsection describes the risks posed by the concept of Industry 4.0. The main threats in this regard are particularly cyber security and the costs associated with implementation. Currently, the greatest limitation of this concept relates mainly to knowledge, laws and little familiarization with this concept.

A key factor will be particularly cyber security as has been mentioned above. As the industrial data in themselves subsume key elements such as the manufacturing process and the resulting data, that are an indispensable part of production planning. These data determine detailed information about the products, hence, the need to ensure that information against their misuse already in the production process but also in the cloud. Adequate protection will be provided by appropriate encryption, thought-protection data server via a firewall, automated detection security gaps, in order to protect sensitive information and business secrets [8]. Consistent security against malware and early detection of unwanted intrusions into the system infrastructure are among the most important features of Cyber Security. It is possible to predict that the system infrastructure will be often attacked by unwanted elements. In the Smart factory everything is connected, through the public Internet (IoT) and we can assume that hackers will try to compromise your system and gain non-public data, whether for commercial purposes and in order to damage the company. Most of Big Data will be ensured to the remote server, so the attack will be concentrated on small things such as the sensor from which data is obtained [22]. For this reason it will be necessary carefully to ensure not only servers, but all other objects of Smart Factory. From the concept of Industry 4.0, it appears that manual labour will be completely transformed into a machine production and people will be set aside from production. The opposite is true as most operators and employees will be operating at the computer, either program but providing actual control of production. Production becomes fully digitalized and therefore physical production as we know it today has completely changed, as will be fully traceable online control and recording of the real time. Data will be available immediately and will be stored and evaluated online on the relevant remote production server. The necessity of physical work will be mainly in the maintenance of machine, as the machine will detect the error, deviation, etc., which will must be physically removed. They will now be required operating analysts, who will present the processed data, using them to identify the degree of efficiency of the production process. Despite this fact happened here emerge some concerns. Surveys secure by government agencies have shown an initial decline in employment combined with automation, however, that after a certain period will lead to growth. This issue is already engaged in trade associations, employers as well as government structures. On the opposite phenomenon highlighted by a study by Boston Consulting Group, which showed that due to a higher degree of automation, should raise the overall employment rate. Federal Republic of Germany in their studies expected to increase employment by 6% within ten years [14]. Philosophy and principles of Industry 4.0 is already fully implemented by Siemens in its production plant in Amberk [23]. Full implementation of automation in production had no effect on the number of employees, which remains the same, there has been just a modification of the working structures. At present, we can get in terms of manpower mainly one big limitation. The majority part of jobs has operator character. These are usually the assembly operators who do not know or are less familiar with handling of IT technologies. Therefore it is not ready the current job market for this concept. In order to implement this concept, it is necessary to educate all operators in the IT and already include in the school system a comprehensive teaching of IT in all fields with an emphasis on practical application [23].

For small businesses, this concept will be very costly. Since sophisticated and fully automated production will require the introduction of large amounts of support systems, transponder and sensors. This will entail a high initial investment. In case of insufficient preparedness of enterprises will be transition at Industry 4.0 difficult and protracted. In this respect, it is essential for companies to pay attention to this concept and appropriately plan of action and financial plans. However, due to gains in productivity, reduce production costs, reduce wastage and production optimization, ROI is possible within a few years [23]. Small companies will be forced to seek investment aid from the state or by bank loans. Ideally it will be revolving financing or combination of grants and loans. The essence of Smart Factory is based on the autonomous management of production processes without human intervention, this view is not legally feasible. Many EU countries have enshrined in legislation that machine control is required human [23]. For this reason, it is not possible in many countries to drive cars with autonomous management. Also for this reason, it is necessary for companies to familiarize themselves with the legislation of the country before the introduction of this concept. Also from this perspective, the concept of Smart Factory is difficult to apply because it is necessary to implement a number of systemic but also legislative changes.

Definitely we will need to address liability for damage because the production process will be managed autonomously and will be difficult to find the culprit of the incurred damages. Criminal liability is imposed in some jurisdictions to natural persons only. Problematic is also insurability systems in the concept of Industry 4.0, which will be necessary to modify and draft new rules. Within the concept there is a need for change in legislation dealing with trade secrets. In summary will be necessary to review and modify the number of processes mainly from a legal perspective, or will need to be re-created these standards. From a global perspective this concept has taken a lot of countries that have begun to transform this concept into their own vision of the future of the manufacturing process. It follows that the German competitive advantage in this idea transformed into a competitive advantage in a global perspective. In the current situation it is just a game with time. USA has created the concept of Smart Manufacturing in cooperation with the Industrial Internet, in Italy created a technological cluster Fabrica Intelligent, France has implemented the concept Industrie du Futur and their own concept is also creating South Korea, Japan and China (Fig. 3). The greatest progress in this area is achieved by China, because China is among most developing countries and has the potential to assume leadership in the industry as a whole. . Germany and China are constantly trying to deepen cooperation especially in industrial innovation. Both countries have agreed to cooperate within the concept of Industry 4.0, especially in the sharing of smart technologies. Currently this cooperation is particularly advantageous for Germany, but in the long term will benefit from this cooperation, particularly China, mainly in the field of activity on world markets [23].


*Fig. 3 Overview of initiatives in the world of production digitalization*

One of the huge advantages of the Slovakia's territory is so called “geographical rent” [12]. Due to this fact, Slovak industry has always benefited from production of high-quality products in small lots close to customized production. To achieve this, we need relevant information from not only EU customers. These requests can be sufficiently covered by our SMEs. To do so, we need:

a. 3D 4D printing
b. New materials – (for 3D metal printing), while Slovakia is in the Top-research groups in materials science.
c. Big data processing methods, including complexity management solutions

The aim of the Industry 4.0 is to create industrial background by digitized elements of industrial systems, using information technologies through the small-lot production according to precise specifications, leading to smallest lot sizes up to one-piece-flow production,´; all this for the predefined customer (pull system), and not to produce for the store (push system), where the customer is uncertain.

One the other hand, people say that it will only be about the change of the technology, robotic workstations that will allow production of smaller lot sizes or customized production. But there will also be also a breakthrough of the Industry 4.0. These technologies have been under development for many years, e.g. robotics from 1984, etc., and they are now about to be interconnected.

Due to the complexity of the production systems in general, these “digitization” efforts are not that clear yet. But let us mention and example in internet applications cooperating with customers, mobile phones as products, E-education, E-government. These areas are practically all based on IoT and their transformation towards digitization was more feasible via different software applications.

The trend in production systems is in transformation these years and days. But at the same time, in 2030, 45-60% of workforce will disappear, and the new push into the 4$^{th}$ industrial revolution will necessarily bring radical decrease in the workforce in all aspects of the social life, as well as in the industry.

When we talk about prediction of the future behavior of such production systems, we consider industry as homogeneous all around the world. Although, it is not homogeneous, rather heterogeneous and then each country has its owr absorbtion ability of such technical change, depending on the level of industry.

In order to allow SME in EU produce in small lots, all information flows including specification of the future customized product need to be accesible, without a subcontractor. Such product is produced in acceptable delivery time, in a reasonalble price.

## 3. ASYNCHRONOUS MANUFACTURING

As it is generally known, traditional assembly manufacturing lines are synchronous. This means that both, flows of work and material are predefined depending on the customer orders entering business enterprise system. Production – assembly steps are continually delegated to each workstation. At the same time, all line workstations are synchronized.

With Industry 4.0 it is vice-versa; it is based on asynchronous manufacturing, with variable product components in the production flow using RFID technology to delegate each machine including operator what needs to be done, which variable component or module needs to picked and mounted to produce the customized end product at each step of the production process.

Such use of highly flexible machines capable of adapting to the requirements of customers for the part being made is the core dimension of Industry 4.0. This achieves a highly flexible, lean, and agile production process enabling a variety of different products to be produced in the same production facility [13]. Mass customization as a strategy allows the production of small lots (even as small as one-piece-flow). The reason is that the machines in this system are able to rapidly reconfigure and adapt to customer-supplied specifications and additive manufacturing.

### 3.1 Line balancing for variety

At the very beginning of the model production, products were made one at a time. The product sat on the ground and the group of mechanics and their supporting teams provided all necessary materials and parts. To improve the efficiency of the production process, products have been placed on benches and then moved from one workstation to another along the production line. Since this process was still not fast enough, Henry Ford decided to go for mass production of this car through phenomenal increase in productivity. Although he had built on the basic principle of his earlier pioneers, he continued redefining each operation and process and his first mass production became a reality.

Now, mass production has been in its boom for decades since then, but the concept of customization is now becoming popular, and even more, it has become the paradigm for the latest concept of Industry 4.0. The trend is now still in flow production as before, but the production of each product variant is made on the same assembly line.

With regards to mass customized production, two main approaches to customized assembly can be found in practice:

a) Mass customized assembly lines for multiple product models - a multi-model assembly line. Here, product variants are considerably distinctive, therefore production can be executed in batches (one batch for each distinctive variant) but on the same line.
b) Mixed-model assembly line is a production, where the product model variants are significantly similar, so they can be assembled simultaneously on the same line in batch sizes of one. Every product variant leaving the line has its customized properties but it is the same model).

The applications of these lines are wide: starting in consumer electronics, furniture, clothing, to automotive production.

## 4. PRODUCT AND PROCESS VARIETY

In this part of the chapter, we aim to present a methodology to express/determine the extent of so called product vs. process variety-induced complexity via the number of unique product and process alternatives.. At the same time, we will call the two varieties as complexity with aim to express product and production relative degree of customization. This complexity can be important for both, producers and customer.

As it was previously identified in our works [18, 19] generally, two types of variety-induced complexity can be seen in manufacturing:

- Product variety – as number of unique product options;
- Process variety – as unique assembly/manufacturing process alternative.

The purpose of determining unique product options is to assess relative degree of customization during development phase, since this measure expresses external perception of variety induced complexity. As it was already proved by e.g. [1, 7, 15, 27], the value of variety induced complexity might be reduced to a level that is acceptable for customer. The same counts for the level of process variety.

In order to proceed in accordance with this statement, this paper presents a combinatorial method for determination of all possible product and process options in three situations: a) mass production - single model, b) mass customization – multi model, c) mass customization – mixed-model.

To apply the combinatorial approach to determine all possible product and related process options, firstly it is useful to establish necessary categories of product components. Thus a set unique product options (*PO)* consists of all possible combinations of components through hierarchical product architecture or through assessed production process. Each product can therefore consist of several features $i$, while $i=1,\dots m$, and each feature can have several attributes $j$, while $j=1,\dots n$. An example of such product can be found in automotive, where car as a product has several features, e.g. car body, chassis, electronics, motor, actuating, braking system, etc., while e.g. chassis has further attributes, such as insulation pads, fittings, colour, front and rear bumpers, car glass, etc. Finally, each of the attributes has defined four types of components to form a desired attribute according to customer preferences. As mentioned above, component types are as follow: Compulsory optional components $C^C{}_{ij}$ form a special group of components due to different selection tasks *l* allowed to customers of service activities or products, respectively: a) Individual selectivity rule; in notation, e.g.: $\binom{j}{1}$; while $1 \leq l < j$; b) Maximum selectivity rule; in notation, e.g.: $max\binom{j}{2}$; while $1 \leq l < j$; c) Minimum selectivity rule; in notation, e.g.: $min\binom{j}{2}$; while $1 \leq l < j$. The three selection rules may be applied also for the delimited optional components $C^D{}_{ij}$ except for the lower bound requirement on the selection of *l* components ($0 \leq l$), as this component type, in addition, considers also selection of zero product components as possible option. Applying this algorithm, one may identify possible combinations of product components and enumerate a finite number of element combinations of any customized system, which is characteristic with high number of such configurations. The three component types $C^V{}_{ij}$, $C^C{}_{ij}$ and $C^D{}_{ij}$ and stable pre-defined component $C^S{}_{ij}$ can inter-operate in order to provide variations of the product provided in line with the MC strategy principles.

Subsequently, a set of process alternatives (*PC*) consists of all possible operations within a workstation depending on either technological procedure of the product, or on the production process. Only unique processes are taken into account, e.g. assembly of two alternative products on single workstation with at least one modified operation is considered as two unique processes.

The method presents a unique methodology combining four mostly used component types that the system and industrial engineers have to be aware of when designing new product and technological procedure.

This type of variety can be calculated either for single production line or for the whole manufacturing chain. Then, one may clearly determine the extent of overall variety of the system using values/numbers of product and process alternatives. The values of product and process variety practically represent complexity of either individual assembly/manufacturing station or of the whole manufacturing system.

In our previous works, e.g. [20, 25] a calculation method to obtain number of product options *(PO)* has been presented. Then, one may determine the extent of product variety per single workstation via the proposed method using the following equations:

$$PO_{ST} = \left(\sum_{q=1}^{r} PO_q\right)_{i_j}. \tag{1}$$

where: $PO_{ST}$ – is number of all possible unique product alternatives on single work-station, $PO_q$ – is a specific (unique) product option, $q$=1,…,$r$.

A calculation of so called process variety-induced complexity depends on the number of unique process (manual or mechanical) depending on the product option on the station to be processed. Then, labour or machine has certain degree of process variability on certain work station. This variability can be calculated as follows:

$$PC_{ST} = \left(\sum_{q=1}^{r} PC_q\right)_{i_j}. \tag{2}$$

where: $PC_{ST}$ – is number of all possible unique process alternatives on single work-station, $PC_q$ – is a unique process/assembly alternative, $q$=1,…,$r$.

The advantage of such measure is that it is highly proportional to the number of product design and process elements and to the resulting number of product and process options.

### 4.1 Case calculation of station complexity

Let us now present an example of the three manufacturing models to clearly visualize the relation between the number of product options and related process alternatives on each work station. As for the product variability, one can determine related process variability of the station using Eq. (1) and Eq. (2).

As can be seen in Fig. 4 on the model of Mass production and for Station 1, both the values of $PO_{ST1}$ and $PC_{ST1}$ equal one, since only single model is being produced on the production line.

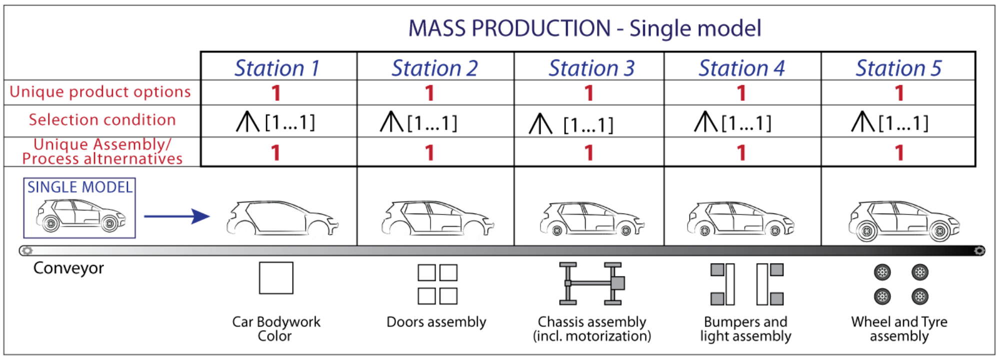


*Fig 4. Product and process variety-induced complexity aspect in Mass production for single model*

Then, every station and assembly worker will perform repeated operation. In the view of product and process variety-induced complexity, mass production reaches the lowest level of complexity due to zero variety:

$$PO_{A-ST_1} = 1,$$

$$PC_{A-ST_1} = 1.$$

Then, all subsequent Stations 2-5 reflect the same minimum value of complexity for all depicted assembly operations.

Mass customized production of multi-model case provides in principle higher variety, as two and more product models can be assembled on the same production line, as can be seen in Fig. 5.

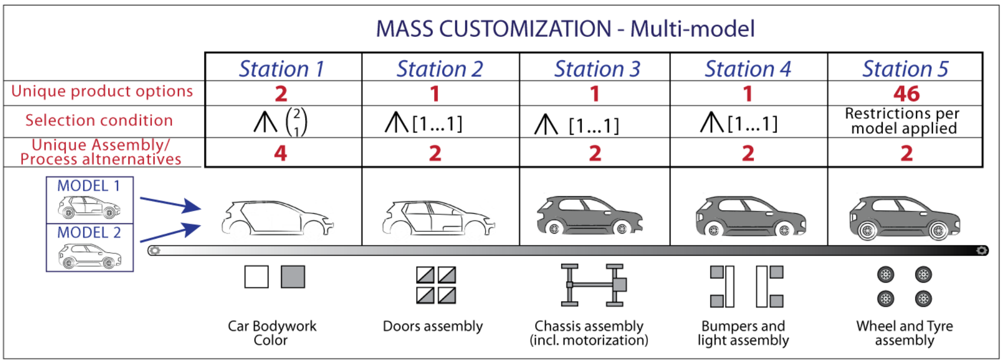


*Fig 5. Product and process variety-induced complexity aspect in Mass Customization for Multi-model*

Taking again the case of Station 1 for car bodywork colour, in this case, every station and assembly worker will not perform repeated operation as in mass production anymore. Here, worker will have a choice of options to perform depending on the number of product options available and on selection criterion (e.g. select only one out of two colours in Station 1). This practically means, that two car models (two product options) and two possible car bodywork colours reflect four possible process alternatives on Station 1 (2 colours times 2 car models), as can be seen in Fig. 5.

In the view of product and process variety-induced complexity on Station 1, the values are as follows:

$$\mathrm{PO}_{\mathrm{B-ST_1}} = 2,$$

$$\mathrm{PC}_{\mathrm{B-ST_1}} = 4.$$

Although the product variety-induced complexity is relatively low (only two car models possible at the station), workers need to be aware of the process alternatives and try to avoid mistakes. Then, all individual Stations 2-5 of the Multi-model consist of inter-related varieties.

Mass customization Mixed-model of production in Fig. 6 is and upgrade of the multi-model in Fig. 5 and produces three car models at the single production line.

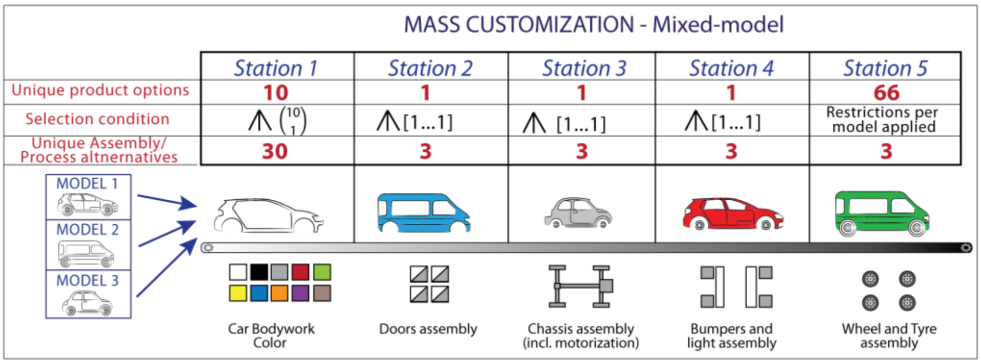


*Fig 6. Product and process variety-induced complexity aspect in Mass Customization for Mixed-model*

As can be seen, selection conditions and restrictions are modified according to higher number of available module accessories, e.g. Station 1 offers this time 10 available car bodywork colours (10 product options) at all three car models produced on the line. If only and exactly one colour out of ten available is allowed per car, product and process variety-induced complexities are as follows:

$$\mathrm{PO}_{\mathrm{C-ST}_1} = 10,$$

$$\mathrm{PC}_{\mathrm{C-ST}_1} = 30.$$

Different views on product and process variety within the three production models allowed us to perform further analysis of possible mutual relations between the product and process.

### 4.2 Station 5 variety-induced complexity

It is generally known that producers are forced to increase the offer of product options for customers (external perception of variety). Secondly, producers are then facing problems with increasing manufacturing complexity, and then higher number of reworks, assembly mistakes, short delivery times, insufficient material buffer, etc. (internal perception of variety). Let us now provide a closer benchmarking of the two types of variety in a MC Mixed model production – Station 5. In this station, mounting of wheels on rims is executed.

Customized selection for car model 1 at Station 5 (Fig. 6):

- variety of three wheel disks; allowed selection: $\binom{3}{1}$,
- variety of five tyres; allowed selection: $\binom{5}{1}$.

Model 1 then offers in total 3x5=15 wheel&tyre options. Next, customized selection for car model 2 at the same station is:

- variety of three aluminium wheel disks; allowed selection: $\binom{3}{1}$,
- variety of five tyres; allowed selection: $\binom{5}{1}$.

The total number of wheel&tyre options for the model 2 is again 3x5=15. Finally, customized selection for car model 3 at the same station is:

- variety of six aluminium wheel disks; allowed selection: $\binom{6}{1}$,
- variety of six tyres; allowed selection: $\binom{6}{1}$.

Model 3 then offers in total 6x6=36 wheel&tyre options. Summary number of unique product options at the station is $\mathrm{PO}_{\mathrm{C-ST}_5}$ =15+15+36=66.

Process variety-induced complexity of the same station 5 is not that “complex”. In this special case of assembly, producer may allow higher levels of variety/complexity while keeping the process-complexity very low. In this case $\mathrm{PC}_{\mathrm{C-ST}_5} = 3$, as each of the cal Models 1-3 have exactly one pitch circle diameter (PCD) and the same number or screws, etc. The following Fig. 7 depicts the shares of the above calculated options on the total number of options per MC Mixed-model production line.

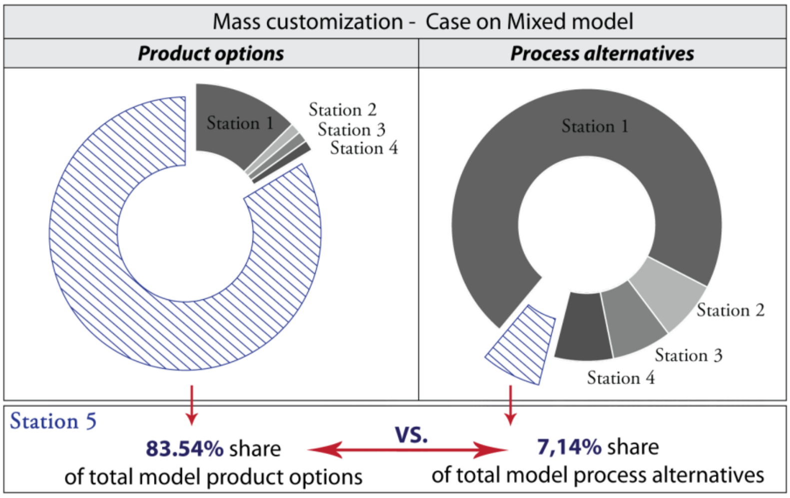


*Fig 7. Shares of Station 5 product and process variety-induced complexity to total model complexities*

Although the share of unique product options at Station 5 is 83,54%, the share of unique process alternatives is only minimal (7,14%). No matter how many product options in the form of wheel&tyre combinations are allowed, still, only one PCD is allowed per model. Such situations are especially in automotive very welcome, as external variety for customers may remain high, while the internal complexity of manufacturing process is low due to modularization.

### 4.3 Case calculation of systems flow complexity

The following section will provide original method to calculate so called flow variety-induced complexity for product and process. This way, mutual relation of flow complexity values will be later analysed and assessed.

According to [10], flow of complexity for individual assembly stations is obtained as a weighed sum of complexities associated with every upstream assembly activity/station. This complexity propagation principle is valid for the process flow complexity $PO_{Flow}$ (Eq. 4). Product flow complexity $PC_{Flow}$ (Eq. 3) adopts a multiplication principle of upstream and downstream stations till the last station of model's flow:

$$PO_{Flow} = \prod_{\substack{i=1 \\ j=1}}^{\substack{m \\ n}} \left(\sum_{q=1}^{r} PO_q\right)_{i_j}, \tag{3}$$

where: $PO_{Flow}$ – is a multiplication of all station product alternatives.
Formula to obtain flow process complexity in the following form:

$$PC_{Flow} = \sum_{\substack{i=1 \\ j=1}}^{\substack{m \\ n}} \left(\sum_{q=1}^{r} PC_q\right)_{i_j}, \tag{4}$$

where: $PC_{Flow}$ – is a cumulative sum of all station process alternatives.

Taking the principles feed-transfer complexity aggregation and applying Equations (3) and (4) we obtain the flow product and process variety-induced complexities based on the number of available product and process alternatives.

$$PO_{Flow-C} = \mathrm{PO}_{\mathrm{C-ST_1}} * \mathrm{PO}_{\mathrm{C-ST_2}} * \mathrm{PO}_{\mathrm{C-ST_3}} * \mathrm{PO}_{\mathrm{C-ST_4}} * \mathrm{PO}_{\mathrm{C-ST_5}} = 10 * 1 * 1 * 1 * 66 = 660\ options,$$

$$PC_{Flow-C} = \mathrm{PC}_{\mathrm{C-ST_1}} + \mathrm{PC}_{\mathrm{C-ST_2}} + \mathrm{PC}_{\mathrm{C-ST_3}} + \mathrm{PC}_{\mathrm{C-ST_4}} + \mathrm{PC}_{\mathrm{C-ST_5}} = 30 + 3 + 3 + 3 + 3 = 42\ options.$$

Summary table of the flow complexity values for three production models can be seen in the following Table 1.

*Tab. 1. Tabular values of flow (cumulated/multiplied) product and process complexity within the three production models*

| Production type | | St. 1 | St. 2 | St. 3 | St. 4 | St. 5 | Flow complexities |
|---|---|---|---|---|---|---|---|
| Mass Production | Flow of product options | 1 | 1 | 1 | 1 | 1 | **1** |
| | Flow of process alternatives | 1 | 2 | 3 | 4 | 5 | **5** |
| Mass Customization Multi-model | Flow of product options | 2 | 2 | 2 | 2 | 92 | **92** |
| | Flow of process alternatives | 4 | 6 | 8 | 10 | 12 | **12** |
| Mass Customization Mixed-model | Flow of product options | 10 | 10 | 10 | 10 | 660 | **660** |
| | Flow of process alternatives | 30 | 33 | 36 | 39 | 42 | **42** |

As can be seen from the Table 1, MP model (Fig. 4) provides in all five assembly stations only one product and process option, as the same processes are repeated on every „mass“ product on the line. Product and even process variability of such MP model is the lowest possible, as only single product configurations is resulting from this system. And vice-versa for Mass customized production models (Fig. 5 and Fig. 6), where the level of variety-induced complexity logically reach high values of complexity, with maximum variety at mixed-model production.

## 5. DISCUSSION AND CONCLUSIONS

Mass customization for multi and mixed-model production poses new challenges. This fact forces producers to attractive variable offers and at the same time, makes them to better use own resources (money and people).

A brief comparison of the three manufacturing models is a proof of lower complexity with MP, and of course of higher complexity of MC Mixed-model manufacturing systems.

According to [4, 25] making decisions about product and process configurations is part of standard product architecture and technological development activities. Producers need to deliver variants to address diverse or change to consumer needs, which are best served by a specific variant. Accordingly, in Section 4, formal approaches to measure product and process variety-induced complexity of individual stations and flow complexity in MCM are proposed and complemented with a case model of manufacturing line.

Based on obtained results it is possible to state that both newly applied complexity measures can be theoretically employed to quantify product and process variety induced complexity and to decide about e.g. the more suitable degree of customization and more suitable technological –assembly procedure of a single product.

Another comparison of the two measures (product and process) showed that there is visible mutual relation between them, what evidently justifies usability of the $PO_{Flow}$ and $PC_{Flow}$ to be used as the variety-induced complexity indices.

The newly developed metrics can be, among others, employed to assist production managers to independently assess competitive technological procedures against each other and to evaluate their customization characteristics numerically through the proposed approach leading to decision for optimal external and internal levels of complexity.

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*integrated information systems,*
*ERP, CAx, IT systems integration*

Grzegorz GUNIA*

# 3 INFORMATION TECHNOLOGY SYSTEMS DEVELOPMENT IN PRODUCTION ENTERPRISES

**Abstract**
*The article briefly discusses the notion of information and information technology (IT) systems in production enterprises. IT systems of different class (CAx, ERP, SCM, CRM etc.) and the scope of their usage in economic practice were presented. The following part deals with information tools development resulting from the growing needs of their users and increasing infrastructure possibilities.*

## 1. INTRODUCTION

Functioning of each organization is based on possessing certain information, which constitutes one of company's main resources. Generally speaking, **information** can be defined as a kind of resource which allows a user to increase knowledge about him/herself and the surrounding world [KiSr, 2005]. A special kind of information is information for management, which makes it possible to realize all management functions, i.e. planning, organizing, leading and controlling. Effective management is possible only with information about the organization and its environment. The criterion which distinguishes information for management is the fact that the received information results in decreased indeterminacy of choice, or evaluation of company's operation. That is why information for management directly and indirectly influences the decision-making process. [KiSr, 2005]

Information in business involves all data streams within an organization and between the organization and its surrounding, i.e. customers, suppliers, governmental agencies, etc. The information issued by an organization, which influences how it is perceived by the environment(e.g. by customers) is not less significant than the information acquired by organizations. Good information is surely one of the most important assets in today's enterprises. [Lewa, 1999]

**A information technology (IT) system** is a separated part of the information system which is computerized from the point of view of the assumed aims, so it is an information system based on computer technology [KiSr, 2005]. In other words, it is a set of mutually related elements, whose function is to process data and realize communication processes using computer technology.

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**A company IT system** is a part of the company information system, within which generating and gathering source data, its processing and analysis, as well as presenting information takes place by means of computer (IT) methods, techniques and technologies [Janu, 2001].

## 2. IT SYSTEMS IN A PRODUCTION ENTERPRISE

### 2.1. IT Systems aiding design and manufacturing processes management - CAx

CAx systems are a group of computer systems directly related to structural design and processes of manufacturing products and their components and to programming and control of the production means which are directly involved in the manufacturing process. Basic systems from this group include:

- CAD - *Computer Aided Design*,
- CAE - *Computer Aided Engineering*,
- CAP - *Computer Aided Planning* or CAPP - *Computer Aided Process Planning*,
- CAAPP - *Computer Aided Assembly Process Planning*,
- CAM - *Computer Aided Manufacturing*,
- CAQ - *Computer Aided Quality Control*.

**CAD** systems are used for creating and editing structural drawings, but also in a wider context, for preparing product concepts, giving it geometric and material form, and for developing and printing a full set of product design documentation [Chle, 2000]. The CAD systems currently in use work on the basis of parametric solid models of products and their components and they make it possible to, among others:

- visualise the designed products and their components,
- control elements' matching and cooperation,
- create virtual product models,
- automatically create structural drawings,
- create multi-media operations and maintenance manual.

**CAE** systems aid engineering works and are also called systems of computer-aided engineering calculations and analyses. They are tools which allow to perform a computer analysis of structure rigidity and strength, as well as to simulate the processes taking place in the designed systems. These programs usually serve as a supplement of the CAD systems in form of problem-oriented applications. They make it possible to perform strength calculations and statistical and dynamic analyses (e.g. stress analysis, temperature or flow distribution).

**CAP** (**CAPP)** systems are tools which aid manufacturing processes design, including preparation of manufacturing documentation together with a geometric model of an object, its intermediate states, tools and equipment, kinds of machines and machining parameters. The systems also facilitate works related to programming of numerically controlled devices (machine tools, robots, coordinate measuring machines, transport systems, etc.) [Chle, 2000]
The manufacturing processes aid provided by these systems includes:

- preparing the manufacturing documentation,
- planning the kinds of machines, tools and devices,
- planning the order of operations and machining parameters,

- standardization of material consumption,
- determining unit time, costs.

The systems' operations is based on variant, generation and hybrid methods of manufacturing processes design [KuMD, 1999], [Więc, 2004]. When it comes to aiding assembly processes design (e.g. determining assembly operations sequence, their grouping, resource allocation – machines, robots, employees), **CAAPP** systems are more and more often applied.

**CAM** systems are techniques and tools which aid the creation and activation of NC programs on the production department level, as well as make it possible to supervise and control manufacturing/assembly devices and processes on the lowest level of production systems. The main functions of CAM include [Chle, 2000]:

- downloading control programs from the database, loading them to devices and activating them,
- transferring and archiving programs in connection with manufacturing orders,
- collecting data from manufacturing workstations and transferring them to manufacturing workshop management system (SFC),
- generating control programs in the direct work mode on the operator console of numerically controlled devices.

The functions usually concern all numerically controlled devices, including machining tools, coordinate measuring machines, robots, or transport systems.

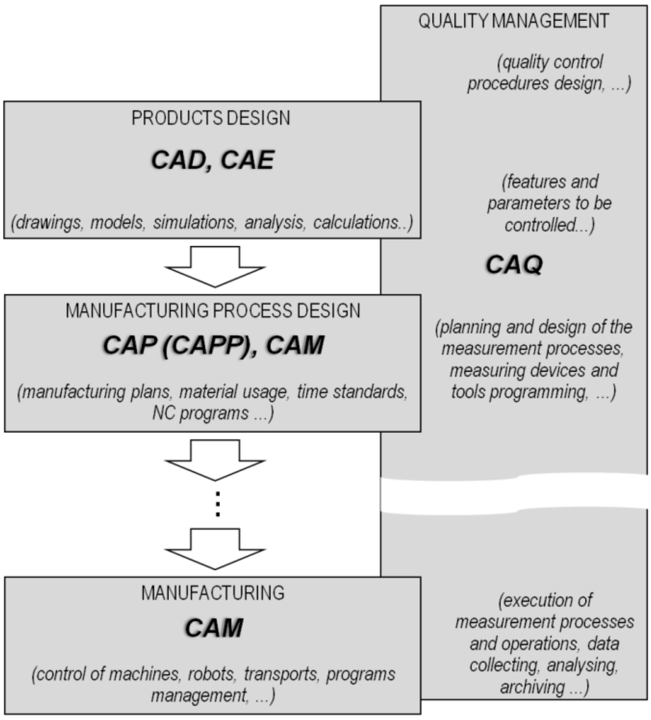


*Fig.1. CAx systems and the production process*

**CAQ systems** are tools of computer-aided design, planning and realization of measurement processes and also of quality control procedures. These systems, which are usually conjugated with the CAD systems (through geometrical model or measurement programs or procedures), are integrated with PPC (see part 2.2.), CAP and CAM systems, mainly in the part related to measurements using automatic devices or measuring systems.

Currently, there are more and more IT systems aiding design and functioning of quality control systems, which can also be classified as CAQ group systems.

The application of the CAx systems on subsequent stages of the production process together with chosen tasks realized by them was presented in fig.1.

## 2.2. IT production planning and control systems - ERP class systems

The development of ERP class systems began in 1960s (fig.2.). The first version was MRP I – *Material Requirements Planning*. This system allows for calculating the accurate quantity of materials and delivery schedule in order to meet the constantly changing demand for particular products. It transforms a production plan for products into a requirements plan for component and materials, providing accurate quantity and date of need for each component.

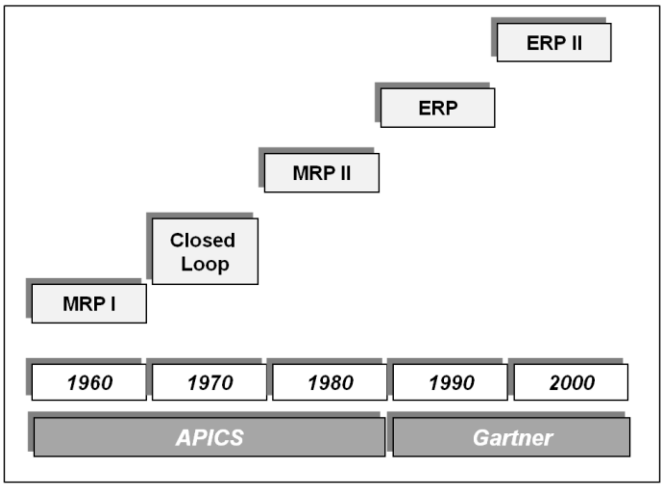


*Fig.2. Evolution of IT management system. (own elaboration on the basis of [Mlec, 1999])*

MRP I was extended by introducing a feedback loop - *Closed Loop*. Thanks to the closed feedback loop it was possible to immediately react to the changing production parameters. This model supported [DiS, 1996], [Klon, 2004]:

- generating manufacturing schedules,
- planning and controlling production capacity utilization,
- control of production orders,
- defining and modifying production routing,
- supplies and purchasing management,
- warehouse management.

In case of this model, apart from the planning aspect (planning of materials, production capacity, production process, purchase orders, production scheduling), the control aspect appeared for the first time (control of the production process, purchase orders realization, flow of materials, finished products to the warehouse). MRP with a closed loop was also extended in comparison to MRP I by requirements planning for other resources (employees, machines, devices, transport means, etc.), necessary to complete the planned tasks [Mlec, 1999].

The next model– *MRP II* (*Manufacturing Resource Planning)* entirely absorbed the *Closed Loop MRP* model, which was enriched by elements related to sales and decision taking support on higher level of production company management than operational production management (marketing planning, strategic planning, financial planning).

MRP II standard was defined and published in 1989 by APICS (*The Association for Operations*, former *American Production and Inventory Control)*. It contains 16 groups of functions which should be fulfilled by a system of this class:

1. Sales and Operation Planning (SOP).
2. Demand Management (DEM).
3. Master Production Scheduling (MSP).
4. Material Requirement Planning (MRP).
5. Bill of Material Subsystem (BOM).
6. Inventory Transaction System (INV).
7. Scheduled Receipts Subsystem (SRS).
8. Shop Floor Control (SFC).
9. Capacity Requirement Planning (CRP).
10. Input/ Output Control (I/OC).
11. Purchasing (PUR).
12. Distributed Resource Planning (DRP).
13. Tooling Planning and Control.
14. Financial Planning Interface.
15. Simulations.
16. Performance Measurement.

Apart from performing resource level control, MRP II also plans the timing of and allocates to resources the subsequent manufacturing processes operations for particular elements of products (production scheduling) and controls utilization of production capacity for particular production sections.

The next step in the development of MRP class models is *Enterprise Resource Planning – ERP*, sometimes called *MRP III - Money Resource*. The term ERP was introduced in 1990 by Gartner Group – an analytical and consultancy corporation. The systems are improved versions of the *MRP II* model and feature properly developed procedures aiding the decision process, procedures using company knowledge bases (know-how), and the ones which realize the idea of artificial intelligence. The systems' task is to fully integrate all areas of enterprise functioning, like: production, marketing, finance, strategic management, etc. What is more, they allow to apply mechanisms for simulating different decisions and analyzing their consequences, including financial results. [YaHZ, 2002], [Gart, 2004]

### 2.3. Supply chain management - SCM

In conditions of growing consumer requirements (cheap products of high quality, adapted to individual needs, timely deliveries), enterprises are forced to concentrate on key competences and their strengths. It is connected with slimming down companies, processes reorganization and the need to outsource some tasks. This leads to situations, when, in many industries, more than 70% of finished product value is created by suppliers, not the final manufacturer [JaTh, 2001]. Also, different forms of finished products customization significantly increase the importance of connections both with supplier, and trade intermediaries and final customers. Consequently, it is necessary to look for a much wider perspective at all activities forming the stream of creating value for customers, and to adopt a new form of cooperation between enterprises, which are oriented on global optimization from the point of view of final recipient [Bedn, 2002].

Thus, the notion of an integrated supply chain can be described as: a *strategic concept involving understanding and managing a sequence of activities from a supplier to the customer, which add value to the delivered products* [Rutk, 1997].

This concept assumes cooperation of all enterprises participating in the chain of transferring goods from the place of acquiring raw material to the final recipient, which is related to coordination of the flow of information and goods, simultaneously adding value for customer by two subsequent links of this chain. This cooperation aims at delivering personal benefits to all cooperating partners, by eliminating the existing barriers and achieving high efficiency of the whole chain thanks to integration and flow coordination. The success of supply chain management depends on integrating and coordinating three kinds of flows: of information, products and cash [Fech, 2002].

Managing an integrated supply chain which functions according to a determined logistic strategy allows for optimal utilization of possibilities and resources of the cooperating enterprises. The cooperation is based on a fast flow of accurate information, planning processes in real time and using advanced simulation and optimization methods.

### 2.4. Customer relationship management- CRM

Classic production management systems (ERP, JIT, OPT) are oriented on internal company management and on improving a logistic chain of materials flow. Due to growing competitive requirements on the market, it has become necessary to improve company relationships with the environment, particularly with its customers. This led to the creation and development of the idea called CRM - *Customer Relationship Management*.

CRM considered as an IT system includes a few integrated applications, which serve a number of areas of company functioning related directly or indirectly to customer service. The application have one common database of customers, products and services, on the basis of which it is possible to create different kinds of analyses and reports. A very important aspect of CRM system understood in this way is its tight integration with other applications concerning production, storing, finance and accounting.

In literature, as well as in production practice, we can notice that the notion of *customer relationship management systems* includes a number of functional areas, including [Krus, 2002], [Adam, 2004], [Kono, 2004], [MaMa, 2004]:

- *marketing* – drawing up plans and schedules of marketing action, managing campaigns, planning revenue from marketing action and analysis of their effectiveness, control of the budget for promotion, preparing and maintaining the catalogue, configurator and product price list,
- *sales* – servicing all distribution channels (traditional ones e.g. network of sales representatives, and modern ones, like call centres, Internet shops), contract management (customer profiles, customer structure, history of sales and service contacts), customer

account management (generating offers, evaluation of talks advancement, trade transactions), customer status monitoring and potential trade contacts monitoring, sales analysis and forecasting, evaluating sales reps, etc.,
- *schedule and correspondence management* – dealing with schedule and database of an individual customer or customer groups, traditional mail and e-mail service, faxing, telephoning,
- *after sale service* – allocating, tracking and reporting tasks, managing the reported service problems, guarantee and post-guarantee service,
- *communications channel service* – call centres, websites, e-commerce, preparing document templates, segregation and archiving of documents, etc.

### 2.5. Modelling and simulation of production systems

In literature, simulation is defined as a technique allowing to conduct experiments on certain kinds of models, which describe how complex systems behave and function in given periods of time [Durl, 2004]. Modelling and simulation methods are used when the solutions cannot be reached by means of analytical methods or direct experiments on a „living organism", or when using these methods is too costly [HrPl, 2000].

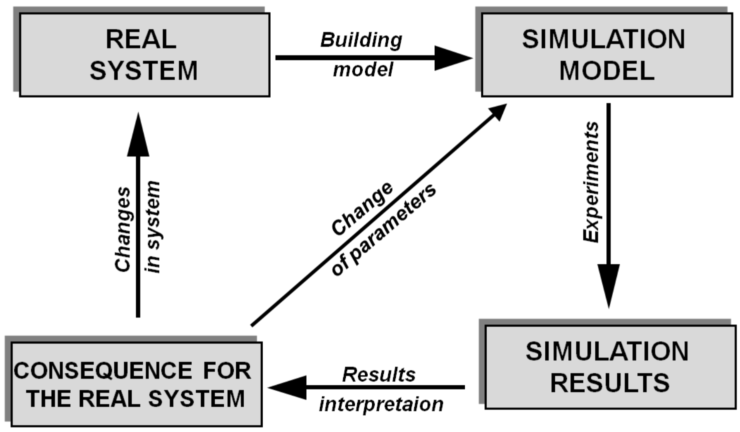


*Fig.3. The course of modelling and simulation realization [GHHKM, 1998]*

Modelling and simulation is a method, during which a computer model of a real system is created, on which a number of experiments are performed. As a result of the conducted simulations, we receive a set of reports, on the basis of which an activity plan is prepared: selection of the best solution by new production system design, or a program of changes to be made in the existing system in order to achieve the assumed objective (fig.3.). There are no other methods or theories which would allow to conduct experiments on a complex system even before projects start to be realized in practice. Moreover, there is no other algorithm which would make it possible within a few minutes to track complex processes lasting often a few weeks or months. Thus, it is a very useful tool aiding decision-making on different levels of enterprises management - [Matu, 2000], [Plin, 2001], [Plin, 2007].

The modelling and simulation method is more and more often applied during designing new production systems and during analyses of the functioning of the existing ones.

The benefits resulting from using simulation include [HrPl, 2000], [Plin, 2007]:
- smooth implementation of new strategies, procedures, decision rules, organizational structures, or changes in information flow, without breaks in enterprise functioning,
- possibility to check production system's functioning in the changed conditions – new machines, transport means, a new IT system – before the new production means are purchased or new solutions implemented,
- determination of system parameters, which the most significantly influence the outcomes of company operation,
- identification of bottlenecks in supply, information flow and the course of production,
- better understanding of system's functioning,
- possibility to control a new situation in the company, in spite of insufficient knowledge and lack of experience,
- possibility of detecting future threats and preparing for them.

It is important to remember that the system for modelling and simulation of new production processes should be integrated with the company IT system. Company databases should by a direct source of data for simulation. In the modelled production system, it is then possible to change e.g. production plan, check different variants of production schedule, or possibilities of realizing different production orders, all easily and fast. [Plin, 2007].

## 3. TENDENCIES IN DEVELOPING IT SYSTEMS FOR PRODUCTION MANAGEMENT

### 3.1. Electronic economy

In the conditions of enormous competition on the market and ongoing battle to win customers, enterprises have to look for new possibilities of promotion and distribution channels for its products, as well as new, effective ways of communication with business partners.

Development of global Internet Network made it possible for companies to become visible in the new reality, often referred to as 'the new economy', with new notions of e-commerce, e-business, e-economy and others [GrSt, 2002], [KoOl, 2005]. In literature an opinion can be found that it was not the IT solutions development which allowed to develop the economy in the new direction, but just the opposite: the developing economy forced the appearance of new IT tools [Bart, 2000].

One fact remains indisputable: the Internet creates a new dimension of company operation [NDHB, 2000], [Szpr, 2000]:
- It changes the balance of forces in favour of the recipient, who can demand much more from suppliers, easily compare their offers and change purchase sources,
- It significantly reduces transaction costs, increases the transfer speed and information accessibility.

E-business can basically be divided into three basic areas, which differ with respect to the assumed goals and target groups [emen, 2009], [KoOl, 2005]:
- B2C ( Business-to-Customer),
- B2B (Business-to-Business),
- B2P ( Business-to-Public).

**Business-to-Customer**

It is a solution realizing transactions between enterprises and consumers. It usually takes the form of electronic trade (e-commerce, e-tailing) conducted by means of internet shops. Basic tasks of B2C systems include [emen, 2009]:
- enabling on-line shopping,
- supporting supply processes,
- ensuring post-sale support,
- improving distribution processes,
- reducing transaction costs.

Electronic trade makes it possible for smaller companies to compete with huge ones, limits geographical barriers and increases the possibility of choosing goods.

**Business-to-Business**

B2B is a model of transactions between companies. As forecast by analysts, it will create the highest turnover and profit (ultimately almost 90% of revenue). American market is currently developing in this direction, and the situation looks similar in European Union countries. The most important element of B2B solution is integration of the supply processes (Supply Chain Management - SCM). Modern technologies properly used in this area allow to achieve the best results – lower the costs, improve logistics. The appropriate utilization of possibilities is a condition of retaining company's competitive advantage [emen, 2009].

Development of B2B heads towards even greater integration of business processes between different subjects. It serves improved effectiveness by, among others, decreasing costs and automation of data processing.

**Business-to-Public**

This area of e-business deals with relations between a company and its macro-environment (mainly social environment).

Crucial tasks of company's B2P system involve [emen, 2009]:
- creating company image (not only on the Internet),
- promoting company brand and its products,
- creating relationships between the company and its environment,
- (last but not least) – attracting new customers.

Company p*ublic relations* policy in a global network can be built in many ways, but the best effects come from connecting the following elements [emen, 2009]:
- properly designed internet website,
- effective advertising of the internet services,
- skilful blending of on-line marketing and traditional marketing,
- using various techniques of Internet marketing.

Apart from the above mentioned models, a number of more detailed ones can be found in literature, like [SiSh, 2002], [Szys, 2003]:
- C2C (*Customer-to-Customer*) – relations between final customers. A basic example are internet auction sites, where the company operating the website works as an intermediary between a seller and a buyer, but parties belong to the C category. Further examples of this type of relations are Internet telephony and Internet forums. Such relations are sometimes called P2P - *Private-to-Private*.

- C2B (*Customer-to-Business*) – a hybrid of B2C and C2C models, where the cooperating customers negotiate common conditions of purchasing a product offered by a trading or production company.
- B2E (*Business-to-Employee*) – a model which allows an enterprise to contact its employees through a wide area network.
- G2C (*Government-to-Citizen*) – a model of relations occurring between public administration units and citizens.
- B2G (*Business-to-Government*) – a model which allows for contact between entrepreneurs and public authorities.

### 3.2. ERP II class systems

ERP II class systems are the next, after ERP systems, stage of development of MRP/ERP class systems (see chapter 2.2.). Their development is based on the fact that enterprises started to transform from organizations oriented on optimizing internal processes and functions, into more flexible organizations basing on their core competencies, which strive to optimally position themselves in the chain of deliveries and the value network. The most important aspect of positioning is not really participation in electronic commerce (B2B, B2C), but rather involvement in the c-commerce processes. C-commerce (*collaborative commerce*) means electronically aided business interactions between company staff, business partners and customers within one trade community. A community can formed by a given industry or its segment, or a delivery chain or its fragment [Gryc, 2001].

Gartner Group defines ERP II as a business strategy and a set of industry-specific applications which generate value for customers and shareholders by providing and optimizing processes both within the company and between the partner companies [GBZF, 2001], [YaHZ, 2002], [Gart, 2004].

Unlike classic ERP systems oriented on aiding internal business processes, ERP II systems are characterized by orientation on external integration and looking for solutions together with business partners. Optimization of resources and processing have been significantly enriched by information related to engaging resources in company efforts aimed at expanding cooperation with other enterprises. Traditional ERP systems made it possible only to manage purchasing and sales in the field of e-commerce. [Gryc, 2001].

During its evolution, ERP II model absorbed SCM functionality, which is management and electronic exchange of information within a delivery chain of business partners. In the ERP II concept, functions of the ERP systems, like production planning, managing logistics and finance, inventory management, were wrapped into electronic exchange of offers, orders, invoices and electronic payments. Table 1. presents a comparison of ERP i ERP II systems.

To sum up, it can be concluded that ERP II class systems support company business processes to a lesser extent, and they will rather focus on reflecting market behaviour and mutual relations of the cooperating enterprises.

*Table.1. Comparison of ERP and ERP II systems [Adam, 2004], [Rzew, 2002], [Wiec, 2002]*

| ERP System | ERP II System |
|---|---|
| Company optimization | Participation in the delivery chain, c-commerce |
| The functional range includes supply, production, sales as well as distribution and financial processes | The functional range includes specific industrial processes (industry-oriented ERP) and complementary applications, i.e. CRM, SCM, etc. |
| Orientation on processes and internal (logistic and financial) integration | Orientation on processes and external integration (business partners, delivery chains) |
| Oriented on solving problems inside a company | Oriented on cooperation and solving common problems with business partners |
| Data generated and used inside the company | Data created, provided and acquired both inside a company and from the external environment |
| Maximal support for user’s needs | Full orientation on satisfying customer needs |
| Aids mechanisms of creating local (internal) values | Aids mechanisms based on sharing benefits between the company and business partners |
| Determines traditional effectiveness measures based on lowering costs and increased efficiency | Determines the effectiveness measures based on added value to the whole process chain |
| Fixed functional range based on central database | Uses data warehouses |
| Closed, monolithic architecture | Architecture is based on the Internet and is open, component-oriented |
| Is designed, implemented and developed holistically (Module architecture) | Is designed, implemented and developed evolutionally (component architecture) |
| Based on customer-server architecture, allows to use the internet | Oriented on electronic markets and based on internet services |

### 3.3. Product lifecycle management

Product Lifecycle Management *(PLM*) is a process concentrating on all the issues related to a product, from the birth of the concept, through the designing and manufacturing stages, to post-sale service and disposal. It integrates data, resources, systems and processes related to product formation, and allows to manage all information about a product.

PLM may be considered in two aspects.

1. As a concept, which can holistically support work on a chosen stage of product lifecycle, through:
   - standardization of procedures,
   - gathering, integrating and sharing data and knowledge about a product,

- automation and support of a number of functions and tasks,
- electronic exchange of data and documents,
- automation of documentation flow and process realization management,
- integration of subjects engaged on different stages of product lifecycle (traders, customers, designers, production organizers, etc.).

2. As a tool (an IT system, and actually a set of integrated applications), whose task is to integrate industry-oriented application (aiding realization of particular stages of product lifecycle) into a smoothly functioning whole. The tools involve the following systems:
   - CAx (see chapter 2.1.),
   - Product Data Management - PDM,
   - Document Data Management - DDM,
   - Model ling and simulation of production systems,
   - Systems aiding cost calculation,
   - Project management systems,
   - etc.

### 3.4. A digital factory

New IT technologies used in companies allow for complex process modelling to be realized in factories on the way to their virtualization. They are an integrating element between the CAx systems used so far and ERP class software – fig.4. Integration of these systems brought about new possibilities of using the old, and creating the new methods and tehniques of production systems management. New terms appeared: *Digital Factory* (*DF*) and digital factory management.

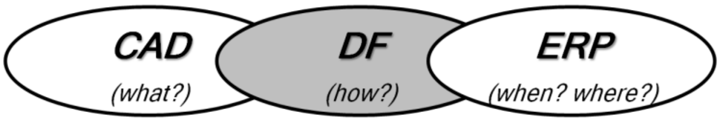


*Fig.4. A position of software related to the notion of a „digital factory" in an enterprise [GMMMH, 2006]*

The notion of a 'digital factory' is connected with a digital image of a real production and presents an environment integrated by computers and information technology, where reality is replaced by virtual computer models. Such virtual solutions make it possible to verify all conflict situations before real implementation and before using the assumed optimal solutions. A digital production consists in applying 3D models and using their in-built information for visualization and simulation of production processes. A digital model of a factory supports production planning, analyzing, simulating and optimizing related to all kinds of products. At the same time, it creates conditions for demining requirements for the working team [GMMMH, 2006]

One of important possibilities offered by a 'digital factory' is a vision of realizing product planning and development, parallelly using common data. The principles of a 'digital factory are based on three elements [GMMMH, 2006]:

- a digital product description with its statistical and dynamic properties,
- digital production planning,

- digital simulation of the production course, with a possibility of using data planned to improve process effectiveness indicators.

Exemplary range of the 'digital factory' technology application includes [GMMMH, 2006]:

- activities aiding new products design:
  - product virtualization – the issue related to supporting and designing new products both during construction and manufacturing processes,
  - according to the reversed technology – preparing the construction and manufacturing processes on the basis of ready, earlier made products (e.g. by means of 3D scanners),
- activities for production systems rationalization with using their virtual models,
- shaping work systems from the point of view of ergonomics, safety, efficiency and quality (fig.5.),
- solving decision problems when it comes to investment, designing workstations, production systems, etc.

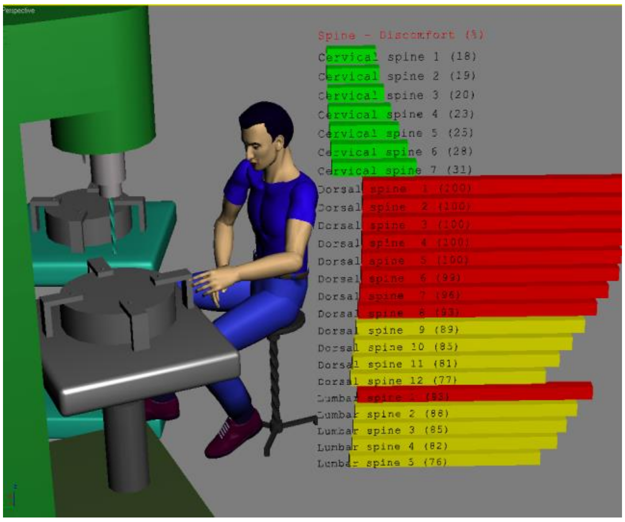


*Fig.5. Ergonomics analysis of workstations [KuKa, 2008]*

Implementation of a 'digital factory' directly influences the economic and ergonomic indicators of production improvement. A little change in the phase of design and planning may bring about a large cost reduction on the stage of production realization. Exemplary benefits of using the 'digital factory' technology are the following [Greg, 2005]:

- reduction of risk related to introducing new production,
- verification of processes before production starts,
- possibility of a virtual 'visit' to production halls,
- checking the concept of the planned production,
- optimization of production resources location,
- improved effectiveness of using production space,
- identification of bottlenecks,
- better use of the existing resources,
- analysis of ergonomics.

### 3.5. ERP and CAD systems integration

One of the biggest contemporary challenges for producers, suppliers and integrators of IT systems used in production enterprises is integration of CAD and ERP systems. CAD (supported by PDM tools) and MRP/ERP class systems belong to the most commonly applied IT systems aiding the widely understood production process.

Both PDM/CAD, as well as the ERP system, gather information about products. For PDM the information is necessary from the point of view of designer, and for ERP - from the point of view of production management process, e.g. product structure.

In the CAD systems, product structures are oriented on the design. They show relations and connections between particular product components, facilitating the understanding the operation principle of the product, or allowing to conduct modelling and engineering calculations.

The ERP systems, on the other hand, use the structure oriented on production process planning. The structure is a basis of the function of balancing materials and cooperation needs and planning the manufacturing process for particular components.

From the point of view of data, it seems the most effective to save data related to materials availability, cost estimation and calculation in the ERP systems, and to create product structures in PDM/CAD and apply mutual bilateral exchange (price, indexes from ERP to PDM/CAD, construction structures from PDM to ERP and there transform them into manufacturing structures).

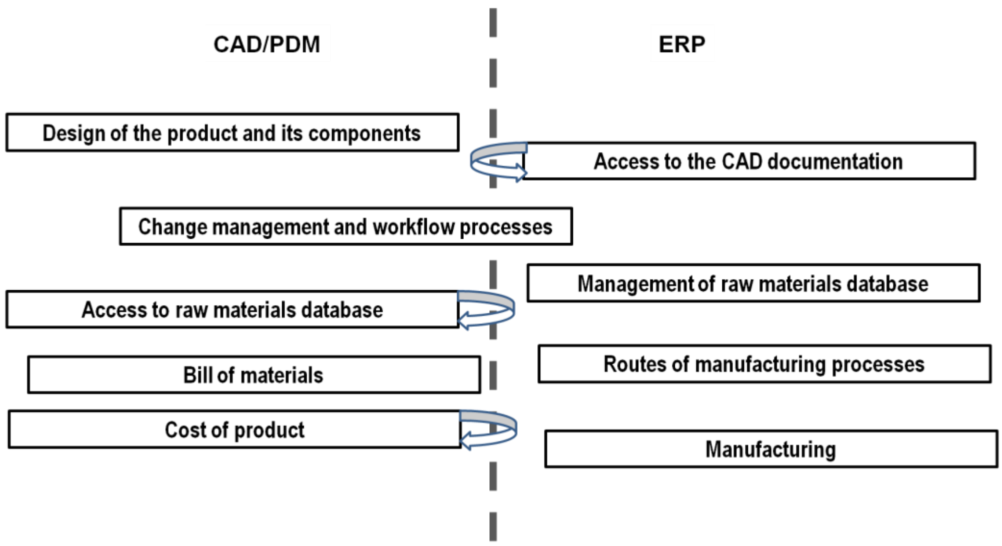


*Fig.6. CAD and ERP functionality [Mlec, 2015]*

Currently, despite the significant analogy between the data from the construction drawing, and product structure ERP, the data is usually rewritten manually from one system to the other. Integration of these areas comes down to an operator translating the constructor's language into the database language of the ERP system. However, the problem lies not in the fact that the constructor uses a drawing, but ERP understands only indexes. Thus, an operator translates from drawing designations, ascribing purchase indexes to product structures and establishing in ERP indexes of the designed elements. Fig.6. presents functional ranges of PDM/CAD and ERP systems together with their mutual dependence.

Automatic integration of data from PDM/CAD and ERP areas may be realized on two levels [Mlec, 2015]:

1st - With the use of temporary files

On the basis of CAD documentation, a file is created with a list of components in a form allowing for recreating product structure. In the ERP system tools are prepared which make it possible to import data from the file (the mechanism establishes the missing indexes of units and parts and builds product structure). The mechanism makes CAD and ERP systems producers independent of itself, but the data is usually transferred in one direction (from CAD to ERP).

2nd - Full integration

It requires cooperation of CAD and ERP systems producers on the stage of design and realization of integration tools. The main elements of the integration system are two tools: a connector and an integrator. A connector is a plug to the CAD system working in the 'online' mode with the ERP system. Its basic functions are the following:

- mapping CAD objects with identifiers of purchasing items of the ERP system (purchasing parts, materials),
- preview of purchasing parts and materials attributes, like designations, price of purchase, unit of measure,
- preparing product structures,
- access to the warehouse stock status and the MRP loop,
- access to the manufacturing cost of product, subassembly and element designed 'online'.

Basic integrator's functions include:

- automatic entering new parts and designed units in the ERP base,
- automatic entering and modifying BOM,
- access to information on drawing documentation and CAD models for products and designer parts.

The basic advantage is bilateral data exchange realized in real time.

## 4. SUMMARY

The development of IT systems functionality is dictated by practical needs and requirements of their users, and it is possible thanks to more and more advanced tools and telecommunications infrastructure. Thus, main directions of the development involve taking advantage of the Internet and advanced telecommunications infrastructure, particularly wireless solutions. This allows for more efficient communication between business partners, more effective integration of external processes and using new marketing and trading tools.

On the other hand, requirements of contemporary market force manufacturers to improve effectiveness of internal processes realization. Currently, manufacturing systems have to be prepared for manufacturing in possibly shortest production cycle, favourably excluding a tiresome process of data preparation and distribution. Integration of systems in the areas of design and manufacturing design is becoming ever deeper. The process of acquiring data for the management process is also undergoing a significant change: it is becoming more and more automated.

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*CAD, PDM, ERP, paperless factory, documentation of manufacturing processes*

Janusz MLECZKO*

# 4 THE PAPERLESS FACTORY AS A RESULT OF INTEGRATION BETWEEN CAD / PDM AND ERP SYSTEMS

**Abstract**

*One of the key elements of the implementation of enterprise management systems is to provide a suitably efficient and comprehensive data acquisition from the design phase of products. What the manufacturing requires from the design phase are a bill of materials, routes of manufacturing processes, and manufacturing documentation. Paperless factory is in many cases difficult goal to achieve. This article describes methods for integrating CAD/PDM and ERP systems and its influences to create a paperless factory. It presents their advantages and disadvantages, while the main objectives and tasks involved in their implementation in engineering organizations are analysed.*

## 1. INTRODUCTION

IT systems have been used for many years to shorten the production time and reduce costs. The recent history of manufacturing IT can be viewed as two overlapping technology waves. The first wave came in the 1990s with the rise of enterprise resource planning (ERP), as companies strove to increase the efficiency of their operations and improve the supply chain management. Today, product lifecycle management (PLM) is leading a new wave–this one focused as much on accelerating innovation and supporting global collaboration as it is on driving process efficiencies to improve business performance. Thus, in most enterprises the application of IT goes in two directions: designing and manufacture preparation systems (CAD/CAM/PDM/PLM) on the one hand, and manufacturing supporting ERP systems on the other [1, 4, 5].

Today, many manufacturers integrate PLM and ERP to improve efficiency and quality. While these organizations may be initially motivated by a desire to eliminate the inefficiency of re-entering data, along with the human error that can accompany it, the benefits go well beyond that. For the vast majority of manufacturers, the question should not be ERP or PLM but how to most effectively implement and integrate these two solutions. Choosing the right ERP and PLM systems for the business is crucial, and manufacturers should not have to compromise on the benefits of either to fully realize the value in both. The value begins when product development and execution processes are no longer implemented as islands, and the functions of PDM and ERP are deployed in a seamless, end-to-end solution.[8, 9, 10, 12].

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Through the well-executed integration of ERP and PLM, companies can develop a smooth flow of major innovations such as new and more highly differentiated products, as well as ongoing business innovations like real cost and quality improvement [3, 4].

## 2. TRENDS TOWARD PAPERLESS FACTORY

Paperless factory is not the main goal of companies. By adopting a true paperless environment, and not just displaying documents, a factory can increase yields, quality and traceability while reducing costs and eliminating many of the risks associated with incorrect or badly controlled documentation [6]. The goal is to respond to the customer's 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 [2], the author presented a review of issues and technologies used currently in the paperless factory. Li [7] described the application of some web-based computer technologies, such as visualization techniques, to establish an integration of product design with concurrent paperless 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 try to do their operations management functions without paper. They used workflow automation to define paths for electronic documents to travel automatically [2].

The 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 unnecessarily. The situation is worse if we look comprehensively at the entire enterprise. Documentation is often 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. Implementation of integrated CAD/PDM can significantly improve production management [14].

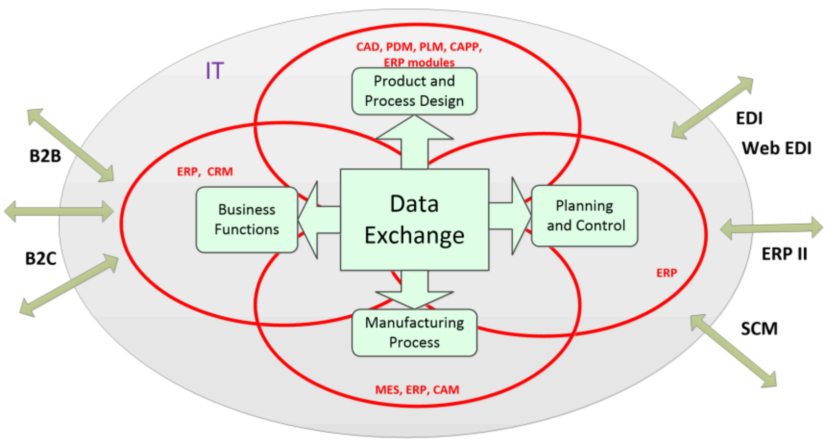


*Fig. 1. Data exchange inside and outside enterprises*

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 [1, 5]. There are also a large stream of data outside contemporary enterprises. This is particularly evident in enterprises in automotive industry, where electronic data exchange in the supply chain management is common.

The key condition for effective concurrent engineering and cross-enterprise engineering is integrated computer environment for design and manufacturing: a common platform for computer-aided systems for product development [6].

## 3. THE RALATIONS BETWEEN THE PROCESS ENGINEER AND THE DESIGN

Unfortunately, at present, in many cases the world of the process engineer and the world of design engineer are two separate worlds (Fig. 2). They typically use separate tools to perform their tasks. Design engineers use CAD / PDM, and process engineers use ERP systems.[Ml1]

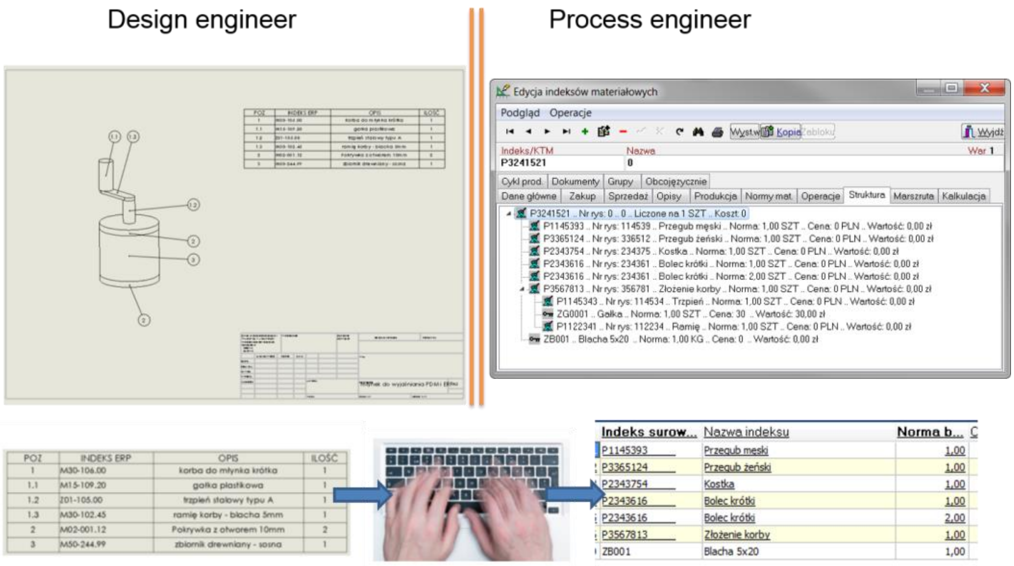


*Fig. 2. Two worlds – the process engineer and the design engineer [10]*

Thus, both directions develop independently from each other, the consequence of which is local automation. As a result there is no uniform information field which could become the basis of a system of technical training, the operative account and manufacturing resource management at below department level, and the design organization as a whole. Therefore, functions are duplicated, the data is repeatedly entered manually, and it is not possible to receive the interconnected data flow. CAD/PDM systems work simultaneously with ERP-systems. Meanwhile in the design department, it is necessary to begin with the introduction of CAD/CAM-systems as program modules of ERP-system, as a whole it will not function without input data about product structure, and also initial and resultants of the data of design/technological preparation of manufacture. Very often this data is defined and entered manually. A special workplace is often created for this purpose in design departments. That leads to a range of errors and reduces the accuracy of work of the account and planning system, increases the recovery time of outlay of realized decisions and has other disadvantages.

The point is that while ERP is not and probably will not become the primary tool of a designer, it does not assume that the CAD/PDM should replace the ERP. However, there are some key functionalities for CAD/PDM and for ERP. The next figure (Fig. 3) shows the typical functional domains of the "two worlds" [10].

It is assumed that the ERP is responsible for creating and managing the database of purchased components, the design of organizational structures and processes of production, manufacturing process management, and calculation of both planned and actual costs of manufacturing the products.

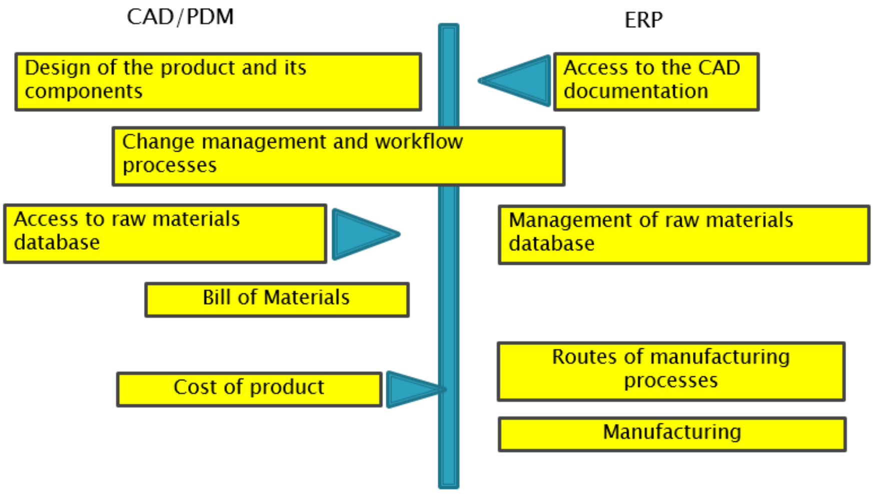


*Fig. 3. CAD/PDM and ERP functionality and its expectations of data [Ml1]*

On the other hand, CAD/PDM is responsible for the design phase of the product and for the bill of materials. The area of change management concerns both spheres: CAD (design changes) and ERP (management changes resulting from the manufacturing processes). Today, the access to data managed by both the ERP and CAD/PDM is required as well. CAD/PDM should have access to the directory of purchased items (including the relevant attributes, e.g. the purchase price), the cost of the estimation phase, and the costs of the implementation phase. The ERP requests access to the current CAD documentation and BOM. [6, 13]

Key problems in the process of integration are: the product ID and the ID of purchased items. ERP is not very tolerant in this area. To be able to work, the raw material, manufacturing part, and assembly element should be clearly identified. The problem is that we have two sources of identifiers. The ID of purchased items is derived from ERP, but for the product or component the source is the design in a CAD system [1]. The problem is that the identifiers lead to over-multiplication, and therefore we should control them in an effective manner. Taking control of identifiers is a good idea for the creation and management. The idea in ERP is to have an appropriate classifier for purchasing items. The identifier consists of two sections: classifying and identifying further members of that group.

The identifier from the source in CAD consists of the following sections: prefix, separator, drawing number and drawing version. It is assumed that the product table (with the product ID) will be created automatically in the ERP by the integrator.

## 4. INTEGRATION OF CAD / PDM AND ERP

Technical aspects of the integration of PDM and ERP systems are important issues. The integration volume can have large range. First step is simple data transmission of structure of a product (order). Next step is technological data transmission before the creation of the routes of manufacturing processes. A more complete integration of systems is necessary for the large design organizations, as they have more difficult interaction of productions. Besides, integration depends on a number of information streams between systems and their orientations – in one or both directions. So, there are also cases of unilateral transfer – for example of the structure of a product from a PDM to an ERP system. In contemporary enterprises there are cases of two-way exchange, in particular for inquiries about change, and the notice on entering them is required. This form of exchange is more difficult, because of synchronization of the data in both systems. It is difficult enough to realize a simultaneous two-way data exchange, therefore it may be limited to unilateral transfer at the first stage.
Currently, basic models of integration are:

- Manual,
- By Files to import,export,
- Api Functions (WeB serwices),
- Full integration.

In the first case, it is difficult to talk about integration. In this method, a user manually maps identifier numbers on drawings to ERP identifiers and assigns links to drawing files.

It is the simplest from the point of view of realization, but data synchronization is more difficult, as is the exchange method through the structured import/export files. In this case, the transfer is carried out according to formats developed and coordinated in advance. A source of the data forms and then transfers them through the export mechanism as files of the coordinated format, which are considered as system-receiver (ERP-system). Thus it is necessary to implement the mechanism of synchronization of the exported data. The data on product structure, results of technical manufacturing training, and the basic directories are in the PDM system. In this connection uniform principles of formation of a product structure taking into account unification requirements are provided, and the data of uniform directories of preparations/materials are used. The given way of transfer provides high enough flexibility and does not demand big knowledge in programming.

Application Programming Interfaces (API) provide closer interaction between systems, however this method has a number of restrictions. First of all, the created interfaces are more strongly bound to certain versions of integrated products. Even minor alterations in the data structure of one of the systems may require alteration of interfaces.

In the case of the application of a method with full integration, the access to one system is carried out directly from another. Thus both systems should be opened and capable to support interaction with each other. Solid Expert and Rekord SI project can serve as an example of such integration. Two-way communication was established between the systems SolidWorks (CAD), Solid enterprise (PDM), and Rekord.ERP. Components of the system are shown in Fig. 4.

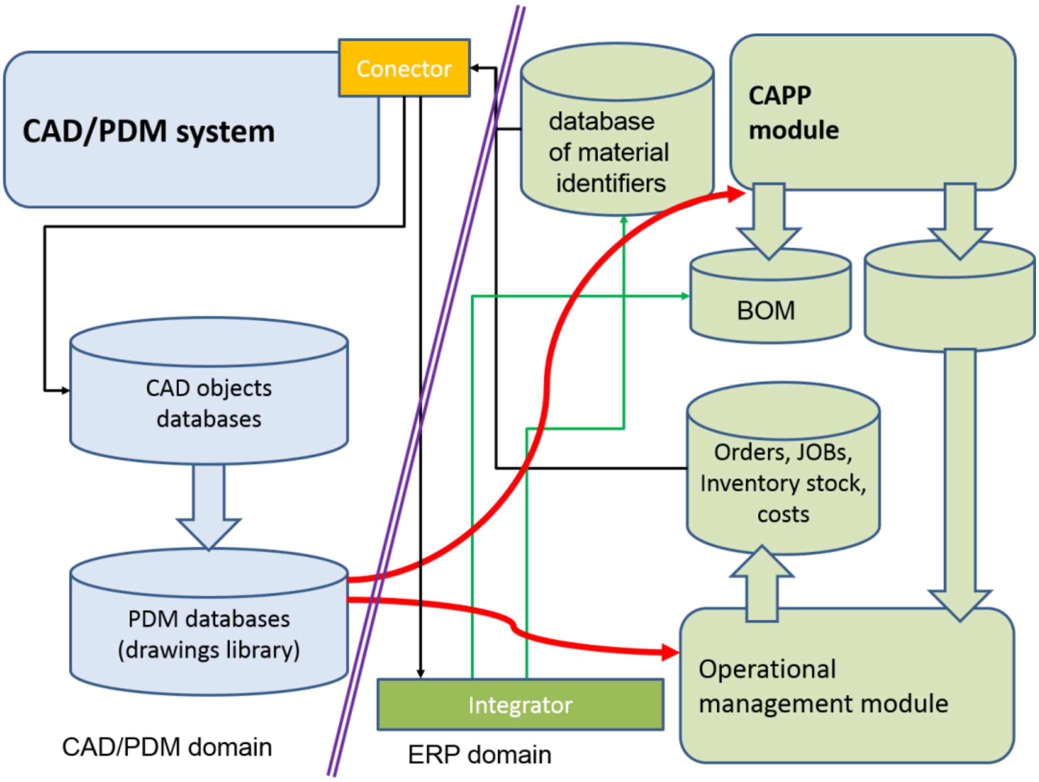


*Fig. 4. Components of a CAD/PDM and ERP integrated system*

The main elements of the system are connector and integrator. The connector is a plug-in operating in CAD system environment (Fig. 5).

Connector functionalities:

- mapping CAD objects with materials identifiers (for purchased parts, materials, elements),
- viewing attributes of materials such as name, price, unit of measure, etc.,
- preparation of the bill of materials (BOM) for the integrator,
- preparation of links to CAD drawings for the integrator,
- access to the data warehouse and MRP,
- on-line access to costs.

Integrator functionalities:

- insert new parts and product into databases,
- insert into databases or update BOM,
- insert into databases or update information about links to CAD drawing.

All functions of integrator are triggered automatically.

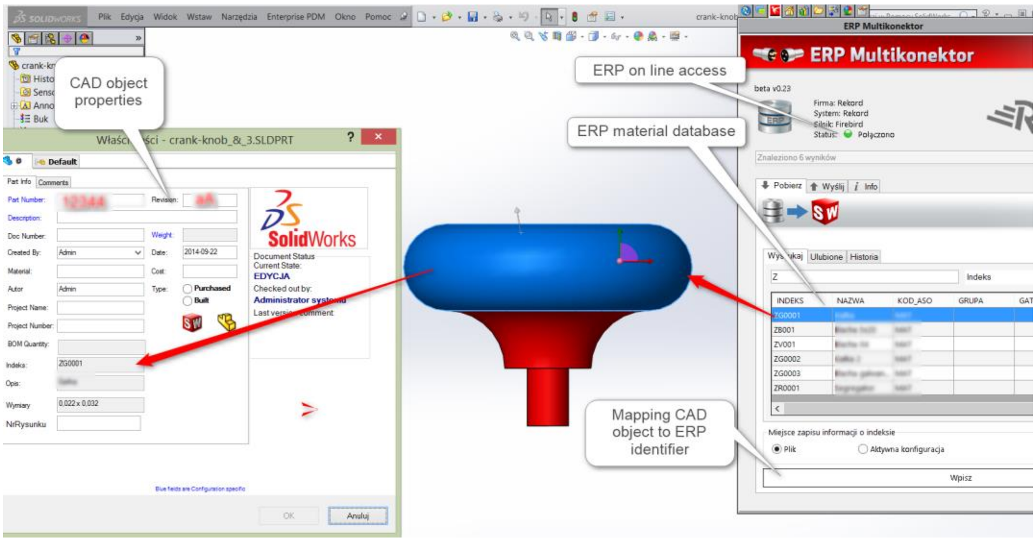


*Fig. 5. Mapping CAD objects with materials identifiers*

The implemented fully integrated model enables efficient aided creation of manufacturing processes. A process engineer can easily view 3D models of products by viewer (eg. eDrawings) in the ERP, immediately after moving the structure of the product (Fig. 6).

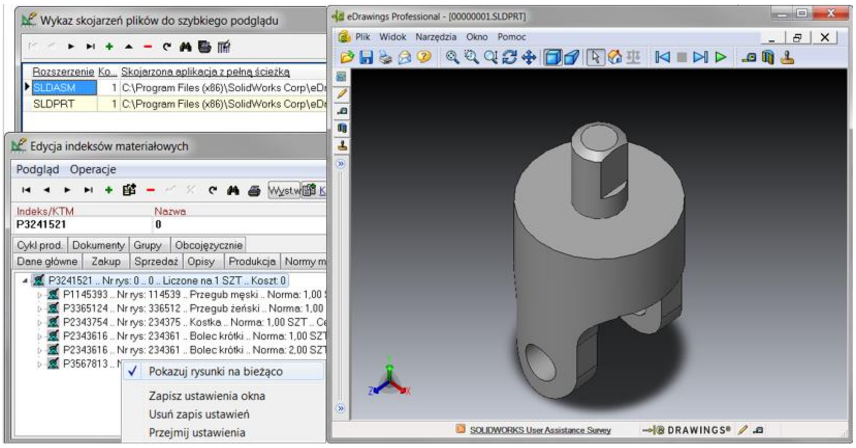


*Fig. 6. Documentation in ERP system*

Another very important feature is the ability to use the documentation in the workshop. A non-editable form of documentation (eg. *.pdf) is the most desirable for workshop. The documentation in pdf format can be created automatically in the PDM, and a link to it can be transmitted to the ERP. It opens the door to a new concept: a workshop without papers. The documentation can be displayed on the operator panel directly or via barcode technology.

## 5. INTEGRATION WITH THE USE OF SERVICES

The most universal method is to use services. This approach allows users to work in a heterogeneous environment of CAD / PDM. Heterogeneous environment appear often in the SME, providing services for different customers with different CAD systems and forwarding executive documentation. An example of integration using the service is the connector between Inventor/Vault and REKORD.ERP. [Fig. 7].The rules are the same the other is only a technical aspect.

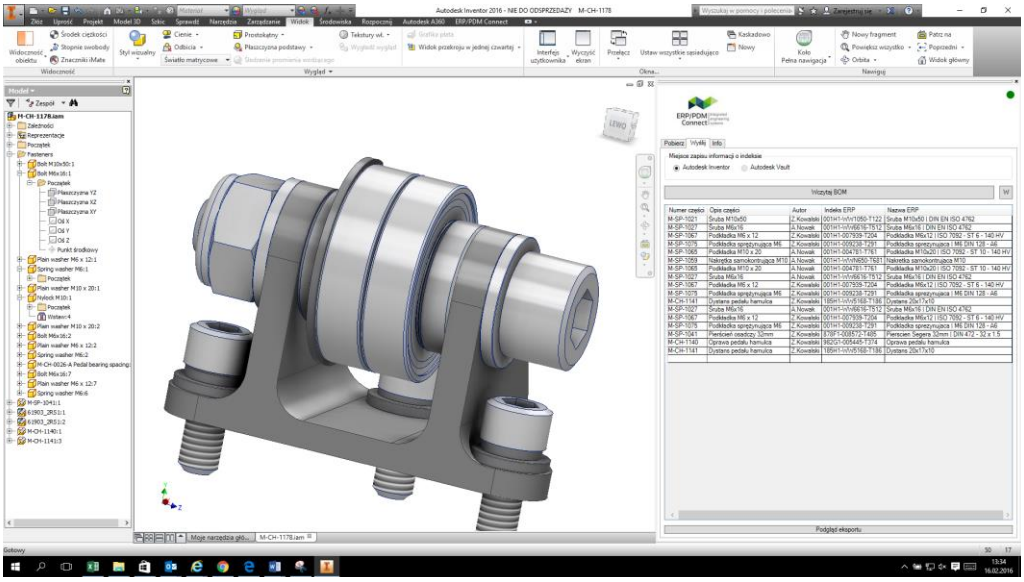

*Fig. 7. Export BOM and documentation links to ERP from Autodesk applications*

Below the sample specification of integration services is given. It consists from 3 basic functions GetMaterialList, GetProductInfo.xml, InsertBOM.xml and one extra responsible for synchronization of drawings indications.

### #1 Function GetMaterialList.xml

| GetMaterialList.xml | | Get list of materials with filter „where” | |
|---|---|---|---|
| Parameters | IN | paramsIn: String; | The parameters transferred in the form of xml data stream. |
| | OUT | Result : String; | The parameters transferred in the form of xml data stream. |

**Input data:**

Sample of xml:

```
<input>
    <Credentials>rekord: 2412</Credentials>
    <WhereSql>WHERE PL.NAZWA LIKE "%00"</WhereSql>
</input>
```

Description of the elements:

- Input/Credentials [String]: {username: password} database user and password. This part can be coded (KryptKey).
- Input/WhereSql [String]: {filter records} condition for filtering data range of table

**Output data:**

Sample of xml:

```
<?xml version="1.0"?>
<Output>
    <Materials>
        <Record INDEKS="9204100" MATERIAL="3E1" JEDNOSTKA="SZT  " GRUPA="OPEL  " ASO="UGO"><NAZWA_PL><![CDATA[Uszczelka wnêki drzwi ty³ L]]></NAZWA_PL><OPIS_SKR><![CDATA[KANBAN:R190MHC:A-29PACKAGE TYPE:13TOOM018]]></OPIS_SKR></Record>
        <Record INDEKS="83719 83E00" JEDNOSTKA="SZT  " GRUPA="SUZUK" ASO="UPS"><NAZWA_PL><![CDATA[Zgarniacz wewnêtrzny przód P]]></NAZWA_PL><OPIS_SKR><![CDATA[]]></OPIS_SKR></Record>
        <Record INDEKS="83739 83E00" JEDNOSTKA="SZT  " GRUPA="SUZUK" ASO="UPS"><NAZWA_PL><![CDATA[Zgarniacz wewnêtrzny ty³ L/P]]></NAZWA_PL><OPIS_SKR><![CDATA[]]></OPIS_SKR></Record>
    </Materials>
</Output>
```

Description of the elements:

- Output/ Materials/ Record
  - INDEKS – varchar(32) – Item of material or component
  - MATERIAL – varchar(21) – Item’s brand
  - JEDNOSTKA – varchar(5) – Unit of measure
  - GRUPA – varchar(5) – Item’s group
  - ASO – char(3) – type
  - / NAZWA_PL – varchar(80) – Item’s name
  - / OPIS_SKR – varchar(150) – description

## #2 Function InsertBOM.xml

| InsertBOM.xml | | Export BOM to ERP | |
|---|---|---|---|
| Parameters | IN | paramsIn: String; | The parameters transferred in the form of xml data stream. |
| | OUT | Result : String; | The parameters transferred in the form of xml data stream. |

**Input data**

Sample of xml:

```
<input>
  <Credentials>rekord: 2412</Credentials>
  <product id_nag="111" status="0" oper="CAD" opis="dodatkowy opis">
    <bom>
       <record ind_wyr="FKTEST" ind_sur="TEST001" norma="1" lp="1"
opis="opis" ilosc_formatek="1" nazwa="indeks testowy" typ="A" masa="5"
autor="konstruktor" pdm_id="123" nr_rysunku="123/16" rewizja="01"
sw_konf="konfiguracja" nazwa_wyr="FKTEST nazwa" path="" level_="1"
path_pdf="" project_id="12" lp_poz="1" mag="01" kon_mat="12"
grupa="05100" szerokosc="250" wysokosc="120.5" dlugosc="350"/>
    </bom>
  </product>
</input>
```

Description of the elements (underline and red sets required fields):

- Input/Credentials [String]: {username: password} database user and password. This part can be coded (KryptKey).
- input/ product/ - description of import session)
    - id_nag – integer – ID of session
    - status – smallint – status
    - **oper** – varchar(20) – user login
    - opis – varchar(256) – description of session
    - input/ product/ bom/ record – material/component data
        - **ind_wyr** – varchar(32) – Master ID
        - **ind_sur** – varchar(32) – Slave ID
        - **norma** – double precision – quantity
        - **lp** – smallint – position
        - opis – varchar(100) – description
        - ilosc_formatek – smallint – additional information
        - **nazwa** – varchar(80) – name of slave element
        - masa – double precision – weight
        - autor – varchar(30) – author
        - pdm_id – integer – ID in PDM module
        - **nr_rysunku** – varchar(16) – drawing ID

- **rewizja** - char(2) - revision
- **nazwa wyr** - varchar(80) - name of master
- path - varchar(250) - path for model
- level_ - integer - level
- path_pdf - varchar(250) - path for pdf
- project_id - integer - project ID
- lp_poz - smallint position
- mag - varchar(3) - additional information
- kon_mat - varchar(3) - additional information
- grupa - varchar(5) - group
- szerokosc - double precision - width
- wysokosc - double precision - height
- dlugosc - double precision - length

**Output data:**

Sample of xml:

```xml
<?xml version="1.0"?>
<Output><Ident>131</Ident></Output>
```

Description of the elements:

- Output/ Ident - integer - id of session

## #3 GetProductInfo.xml

| GetProductInfo.xml | | Download information of materials | |
|---|---|---|---|
| Parameters | IN | paramsIn: String; | The parameters transferred in the form of xml data stream. |
| | OUT | Result : String; | The parameters transferred in the form of xml data stream. |

**Input data**

Sample of xml:

```xml
<input>
  <Credentials>rekord: 2412</Credentials>
  <ProductCode>00-004-9090</ProductCode>
</input>
```

- Input/Credentials [String]: {username: password} database user and password. This part can be coded (KryptKey).
- Input/ ProductCode [String]: {ID of material}

**Output data:**

Sample of xml:


```xml
<?xml version="1.0"?>
<Output>
    <Product>
        <INDEKS>00-004-9090</INDEKS>
        <WARIANT>1</WARIANT>
        <KOD_TECHNO></KOD_TECHNO>
        <KOD_WYDZ>000</KOD_WYDZ>
        <P_BRAKI>0</P_BRAKI>
        <P_M_POM>0</P_M_POM>
        <P_K_ZA_W>0</P_K_ZA_W>
        <SZT_NA_SZT>1</SZT_NA_SZT>
        <PARTIA_MIN>0</PARTIA_MIN>
        <PARTIA_NOR>0</PARTIA_NOR>
        <PARTIA_MAX>0</PARTIA_MAX>
        <CENA_P>0</CENA_P>
        <KOSZT_OG>N</KOSZT_OG>
        <DO_PRZEC>N</DO_PRZEC>
        <JEST_WAR_GL>T</JEST_WAR_GL>
        <CENA_U>0</CENA_U>
    </Product>
</Output>
```


Description of the elements:

- Output/ Product/
    - / INDEKS – varchar(32) – ID of material/component
    - / WARIANT – char(1) – variant of material
    - / KOD_TECHNO – varchar(30) – author
    - / KOD_WYDZ – char(3) – code
    - / P_BRAKI – double precision – additional ERP data
    - / P_M_POM – double precision – additional ERP data
    - / P_K_ZA_W – double precision – additional ERP data
    - / SZT_NA_SZT – double precision – additional ERP data
    - / PARTIA_MIN – double precision – minimum batch
    - / PARTIA_NOR – double precision – average batch
    - / PARTIA_MAX – double precision – maximum batch
    - / CENA_P – double precision – price
    - / KOSZT_OG – char(1) – (T/N) additional cost
    - / DO_PRZEC – char(1) – (T/N) calculation required
    - / JEST_WAR_GL – char(1) – (T/N) main variant

# 6. DISTRIBUTION OF DOCUMENTATION

One of the important problems to solve is the distribution of documentation. It is closely connected with its functions: identification of the product, definition of manufacturing routes and function of a carrier for data collection [Fig. 8.]. It is almost impossible to get rid of paper documentation. You can significantly reduce it. Below is an example of documentation used as the barcode carrier. [11].

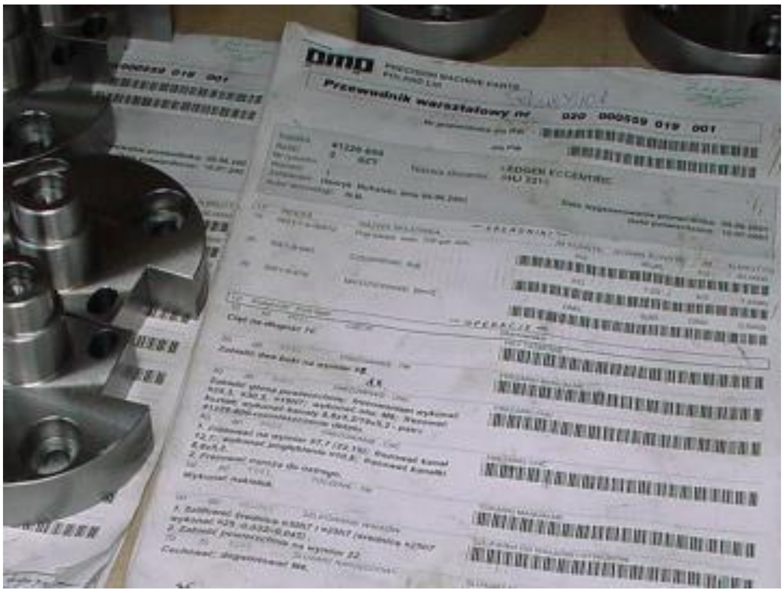

*Fig. 8. Job example*

They are used to monitor and control of progress in the manufacturing process. [Fig. 9]. An alternative solusion is using panels located on positions. [Fig. 10].

*Fig. 9. Workplace with computer station for registration of manufacturing processes' progress*

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.11]. 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 [12]. 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.

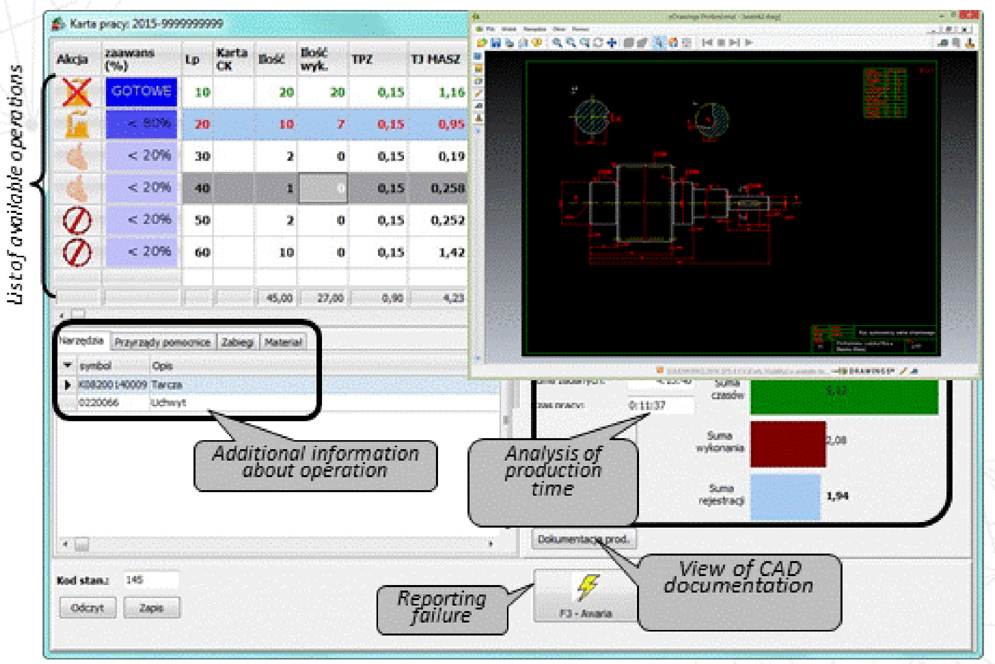


*Fig. 10. Screen of panel at the workplace*

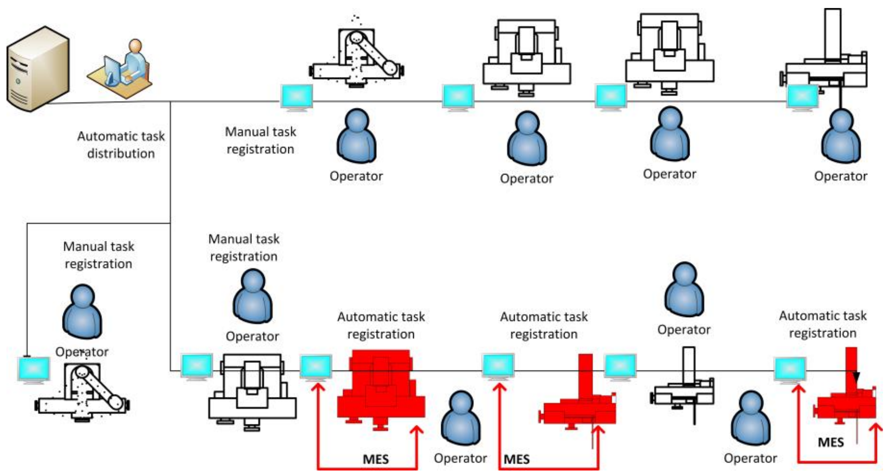


*Fig. 11. Distribution of documentation*

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.

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 cooperatively 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.

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.

## 7. CONCLUSIONS

The paper form of documentation has not been eliminated today. 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.

However, implementing a true paperless factory is a challenge. 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 documents in paper form improves the quality of management. In contemporary production, change management is very important, both in the process of the preparation of documentation and its distribution in the manufacturing workshop.

To summarize, the true paperless factory is a much larger issue than merely digitizing work instructions and presenting them to an operator. Managing the entire digital thread from design data, through revision control, work instructions, bill of materials to final dispatch is the real path to paperless factory. A path that leads to improvements in manufacturing excellence, reduced engineering and management overhead and a more reliably repeatable method of manufacturing. Only a comprehensive approach to the question of documentation, including version and change management and full integration with ERP systems will provide all the benefits available from a paperless manufacturing environment.

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Mária CUDRÁKOVÁ*

# 5 THE COLLECTING, PROCESSING AND KNOWLEDGE SHARING

## 1. THE FIRST STEP OF COLLECTING

The acquisition of knowledge is a process of incremental design knowledge base, verification of their interaction in order to achieve the desired behavior of the system formed.

So far, this process approached ad-hoc methods, but this has not led to the desired result, or to such results that would satisfy the knowledge engineer.

Knowledge Engineer at present a major component of the process and this argument justifies a number of arguments:

- Experts are experts in the field of operation, but may not be good analysts and their knowledge may not be appropriate for a correct analysis of the problem and by creating the application of knowledge.
- Mission of experts is not sensible to have a realistic idea of the functionality of the knowledge system.
- The role of the expert is integrated into the knowledge of their views, perceptions and prejudices that may not be real.
- The development of the entire knowledge system is time-consuming, require expert participation throughout the whole of his work is demanding and very valuable.
- The role of the knowledge engineer is to answer the question to answers that expert would most like to avoid.
- View the requirements of expert knowledge creating an application system often differ from the actual users of the knowledge system.
- The acquisition of knowledge also affects the number of experts involved in the development of a knowledge based system, the difficulty of obtaining knowledge and effort to summarize them is equivalent to the contradiction and difference of individual information to a particular problem. [1]

On the other hand, the effort and tendency to perform and create an application system of expert knowledge through the automated creation process applications and appropriate support resources. The arguments for this approach are several:

- Learn to formalize expert knowledge representation is easier to pass the knowledge to knowledge-based engineers in the creation of a knowledge based system.

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- Expression of knowledge through knowledge engineer experts often feel that they express their knowledge is not exact.
- Creation of a knowledge based system is faster and without the need for process modeling solutions.
- Knowledge and their interpretation is not distorted to lose quality during transmission to the knowledge base.
- Falling prices of technology knowledge system emphasize the high cost of human labor required for the acquisition of knowledge and mere compliance knowledge base.
- Last but not least there is very little knowledge engineers sufficient quality to cover rapidly increasing demands on their profession.

Despite all this argument is in practice very few support the creation of an environment enabling direct application of the knowledge of experts. One of the available we can mention for example. Aquinas, ETS, Student, Teiresias.

## 2. KNOWLEDGE MEMBERS TEAM

The whole knowledge acquisition process is thus based on intensive and close cooperation of the knowledge engineer and expert or group of experts. Expert is the bearer of knowledge that creates the framework necessary to solve the problem and creating a model for solving the problem. [2]

Participants in the development and application of knowledge are:

- **Knowledge Engineer** – his work consists of acquiring knowledge and creating knowledge base for the domain-oriented knowledge-based agents. Participates in the specification of the characteristics of the knowledge generated by the system. A very intense collaboration with experts. Acquire, systematize, structure and try to capture lessons in a language that represents knowledge and data base so that the problems can be solved. The knowledge engineer must have a deep knowledge of the formalization of knowledge gained, the derivation of IC solutions alone solving problems in general. Whereas its role is to work with an expert or group of experts (people), it is necessary to be a good psychologist who can get the necessary knowledge to such an extent that it can be formalized.
- **Software engineer** – his role is different from the fact that the actual creator of empty knowledge system or creating a domain-based knowledge system using an existing empty system. Depending on the extent of different research team (analyst, designer, programmer, tester and i.).
- **Expert** – is the bearer of all sources of relevant problem areas. Through knowledge engineer is involved in the performance, debugging, testing the knowledge base and knowledge system. Its role is especially true at the conceptualization and modeling solutions and at its own debugging and testing a knowledge base.
- **User** – is the one that the knowledge system used in practice. Knowledge of the system is designed so that its use will not need any deeper knowledge of the internal structure or method of work. The user despite its non-participation in the creation of a knowledge based system is an important part because it represents the only feedback when developing applications.

- **Other project team members** – contribute to the various tasks and are part of the team (project manager, systems engineers and support staff).

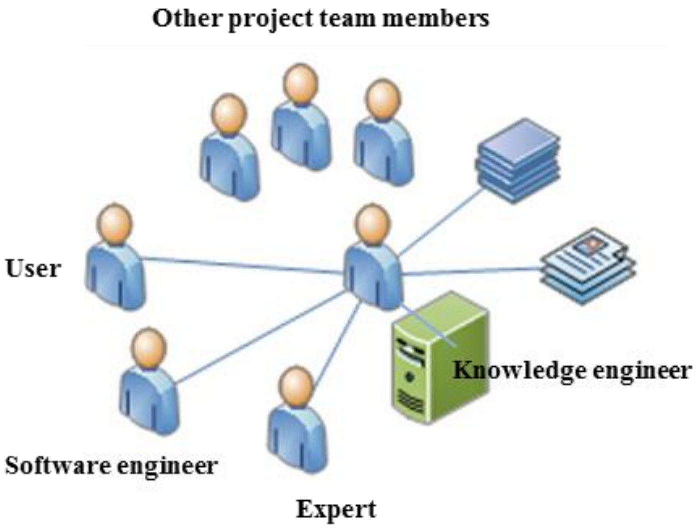


*Fig 1. Members of knowledge acquisition team*

A fact which reflects the need for close cooperation and mutual understanding between knowledge engineers and experts demonstrate subsequent facts:

- In terms of efficiency is a knowledge engineer able to create an average of 3 daily new rules, this fact is in the initial phases of the knowledge of higher and gradually decreases proportionally.
- The price development of one rule is estimated at about $ 700.
- One day expert's work constitutes approx. four days of work a knowledge engineer who analyzes the facts obtained and divided into knowledge base.
- In addition to working in terms of artificial intelligence is an essential part of the creation of interfaces (for data, the surrounding environment, the user). [3]

Knowledge creation and knowledge system not only include acquisition and capture knowledge. The knowledge that we gain, it is necessary to preserve, share and re-use.

Purposeful creation, development, exploitation and valorisation of knowledge is of crucial importance for enterprises and for ensuring their further development as well as in terms of gain and maintain competitive advantage.

The role of knowledge management is to make knowledge within the enterprise to those who need them at the desired location, when they need it and in a form in which it is satisfactory for them to increase the performance of employees and thus the entire enterprise.

Knowledge management is also about creating a corporate culture of technology that will encourage and motivate them to share their knowledge.

## 3. PROCESS OF IMPLEMENTATION

Implementing knowledge system is a long and difficult process, which is influenced by many factors. The actual view on the knowledge management affects the initiation of its building. It differs in the approaches applied. If an organization considers that there is only one best approach to knowledge management, called the universalistic view on knowledge management, which counts on this assumption, it would suffice to apply this one as the best approach to knowledge management. For a small business, however, this approach is expensive and a better way is an appropriate leadership. Contingent view on the knowledge management on the contrary assumes, that none of the existing approaches of knowledge management are the best at all times, and notes that there are several alternatives to the success of knowledge management, depending on the particular company. [4]

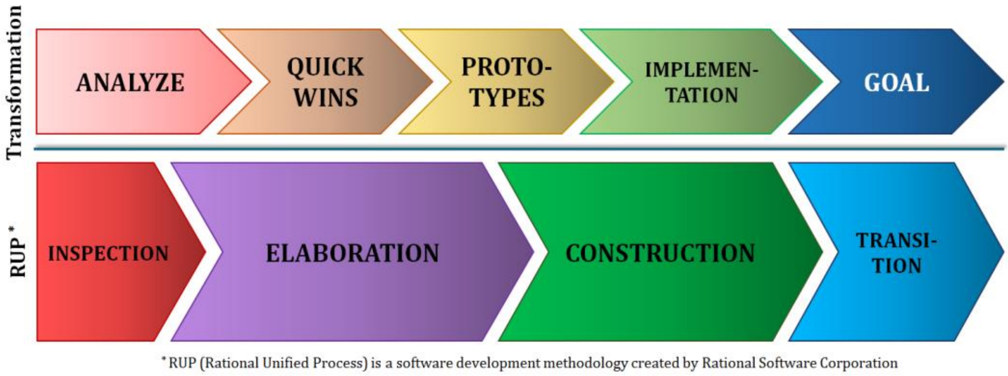


*Fig 2. Process of transforming knowledge society into innovative society [5]*

The company itself affects the suitability of individual knowledge processes. Size and the strategy of the organization influence mainly the choice between a pair of processes supporting the application and knowledge sharing. Companies with more employees will benefit more from the knowledge application on the principle of routines, because they use more standardized procedures than smaller, non-bureaucratic companies, independent of standardization and rules. For a small business, the more appropriate is the management in the application of knowledge. Company size also has an impact on knowledge sharing. Socialization of knowledge is recommended for small business, while for large, this method would be extremely expensive and much more favorable would be the distribution of knowledge. Other conditioning characteristics that affect the knowledge management are characteristics of the solved tasks and used knowledge, the external environment and the already mentioned characteristics of the organization. [6]

There are two basic alternatives of acquisition and creation of knowledge, from which other techniques and instruments are derived. Analysis of alternatives and the subsequent selection must be specified the expected benefits, the company itself and the definition of its business strategy. There are many tools and techniques to acquire knowledge, which differ by time demands, which reflect also into financial requirements, utilization of technical aspects personnel composition of the project team, the nature of the company in terms of knowledge creation and many other factors.

For solving this problem it is necessary to develop a concept of knowledge system creation that is further specified and adapted to specific company and will be a part of a corporate information system.

If we approached the creation of the concept of formation of knowledge based system through the above mentioned process of knowledge system implementation according to Tiwan (Fig 3), part of the first of four basic stages would be an analysis of company's own infrastructure, setting goals and their alignment with the business strategy of the company.

Following phase, which affects the design and development of a knowledge based system is understood as the most challenging part of the project in terms of sources. It consists of five project units, from knowledge system architecture design, mapping company's existing knowledge, establishment of the team, which will form the system, to the development of the system.

After carrying out given tasks, implementation and testing of the system, its tuning and tweaking to more specific requirements takes place. Also, as with every project, even if it is an intangible asset, it must be ended by evaluation of efficiency of developed solution and benefits that it should bring. [7]

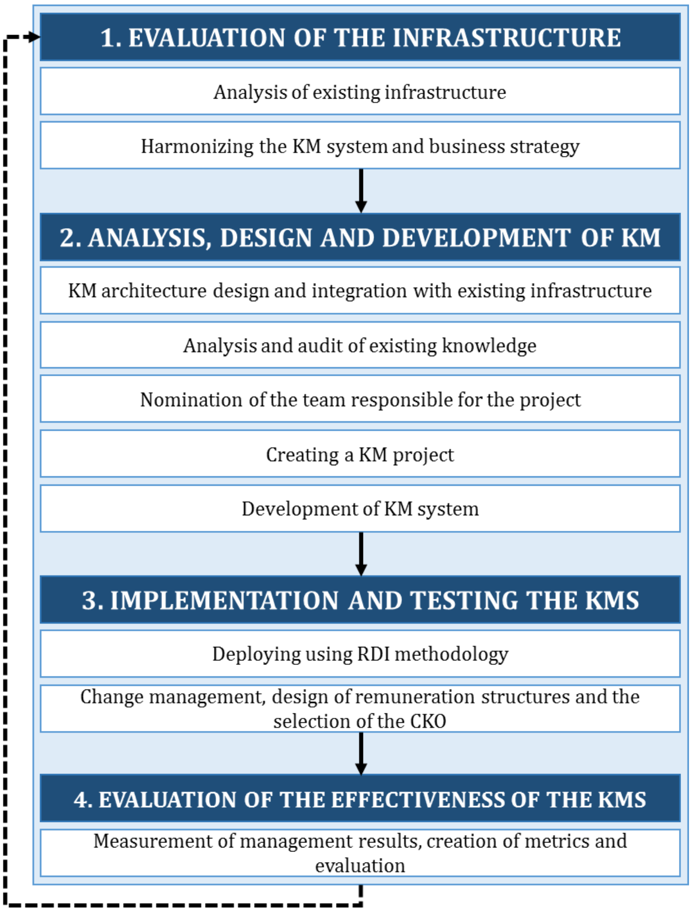


*Fig 3. Procedure for implementing knowledge management by A. Tiwan*

This is a very difficult and lengthy process, where its application and benefit quantification take several years. It represents a process of continuous development and improvement design for the creation of knowledge and the access to it.

The proposal of my solutions is only one part of the creation of a knowledge base, which is an essential part of the knowledge system. The solution is based on the theoretical foundations, acquired during studies that include my subjective perceptions and observation and proposes the concept of the collection, processing and utilization of knowledge for a company that provides services. Company is further specified as R&D organization engaged in applied research and development.

After completing my studies of the field in question and based on the analysis of the current state of research problems, I dare to say that there is no well-defined, created and published detailed concept for the collection, processing and utilization of knowledge, there are no clearly specified detailed steps, which would include the above-mentioned shortcomings of the analyzes and proposals to eliminate them, applied in practice for a company providing services with a focus on applied research and development.

That is why I decided to work on the design of a concept for the collection, processing and utilization of knowledge in practice. Application of the problem solution will be applied to the company providing services and it should provide a comprehensive view on the individual steps of development of this proposal. The solution will ensure the fulfillment of functions of the knowledge base for the selected company, proposals to address the shortcomings mentioned in the analytical section in order to improve processes and foster innovation in the company. [8]

## 4. THE USE OF KNOWLEDGE

Knowledge is an intangible asset of any innovative company that wants its market position definitively confirmed. Building a knowledge management is possible in any society, regardless of the business community. Currently, the trend of creation of knowledge management in large software companies and multinational corporations, but this trend is not curiosity, and this complements other businesses.

The use of knowledge management has significance mainly for companies:

- With multiple branches located in different parts of the country, or the world.
- Focused on a number of fields (with multiple divisions).
- Producing intangible assets (advertising agencies, software companies, non-profit organizations, schools, foundations).
- With space for creating apprenticeships, communities, with workers willing to share knowledge.
- Operating on the principle of project activity.
- With open corporate culture and adequate technical equipment needed to build sufficient network for the knowledge base.

The implementation of knowledge management and its impact on the work in terms of efficiency and productivity positively affects mainly the following areas:

- Improvement of communication between workers or workplaces.
- Direct communication with customers.
- Improvement of teamwork between employees, workplaces and departments.

- Increase of awareness of the company (whether inside or outside).
- More efficient work of employees (in terms of documentation, design, information search, communication, etc.).
- More efficient use of resources (internal).
- Building of knowledge-based society and knowledge workers.
- Improvement of company processes (e.g. administration, project management, human resources, etc.).
- Improved relations between workers.
- Use of modern trends in education, collaboration, educational system interactivity.
- Cost savings related to these activities. [6]

Generally, the main motive of focusing on knowledge management for most companies is cost reduction (44 %) and reaction to increasing competitiveness in the knowledge management field (42 %). These two factors suggest that companies respond to the importance of working with knowledge, whether from the perspective of their own savings and greater efficiency, or because of the risk of lagging behind the competition. Other motives for working with knowledge management are higher expectation of teamwork in the organization (30 %), increase of actual value of the company (31 %), cost reduction (26 %) and easier search for new business opportunities, but this is hardly expressible and measurable.

Based on surveys conducted in 1997 it has found that the benefits of the quality of knowledge management projects are reflected in all areas of the business.

But the implementation of knowledge management does not represent a universal solution for incurred company problems. If the company decided to deal with a particular situation using knowledge management, it is appropriate within the primary considerations to specify bottlenecks in the company and subsequently expectations on the knowledge management. In other words, to propose appropriate solutions to problems through knowledge management and not with it alone.

## 5. THE KNOWLEDGE MEASURING

In companies hard metrics are preferred because of their clarity and better comparability, but their use is more difficult. On this basis, a number of methods were created in pursuit of metrics and indicator design that would better reflect the specifics of knowledge management in companies, for example Scandia Navigator, Intangible Assets Monitor, IC index, Balanced Scorecard, Benchmarking, Return of Investment, Knowledge Management Assessment Tool, or Cost Benefit Analysis. Of course, these methods differ in the purpose of their use, orientation on the hard or soft metrics, or their complexity.

Benchmarking remains the most used method of performance evaluation (56 %). In the soft metrics, the most used is the cost calculation ROI, internal rate of return IRR, and also the economic value added (26 %).

Balanced Scorecard (BSC) mentioned in the previous section also belongs to the selected methods. This method was created in response to the need of companies to remain competitive in the long term and also to complement management model focused on the development of future growth opportunities, and not just financial indicators. The chosen method was modified by the author Amrita Tiwana, to meet the needs of knowledge management, where four fields are being specified with complementary questions:

- Financial aspect (Are our investments into knowledge management profitable and do financial benefits sufficiently cover the cost?).
- Human capital aspect (Is the work of our employees more efficient and are they better cooperating in knowledge sharing?).
- Customer-investment aspect (Did we improve customer relationships by implementing knowledge management, did we gain new customers?).
- Organizational-investment aspect (Do we have due to knowledge management more efficient work with knowledge and better ability to innovate than our competitors?). [9]

## 6. BENEFITS OF KNOWLEDGE

Knowledge management has an impact on the organization mainly in four basic levels. The first is the impact on people in the organization, which can lead to teaching staff, whether among themselves or from external sources, helping employees become more flexible and thereby increase their satisfaction with the work they are carrying out. With the work being carried out are closely related processes in an organization (usually marketing, production, accounting, public relations, and others). Processes are being improved in terms of efficiency, performance and innovation. The innovativeness is associated with the impact on the organization's products, as they can lead to stimulating the creation of new and innovative products with significant added value, or products that are in their nature based on knowledge, for example software companies and their products. All these impacts on individual basic levels form directly and indirectly overall performance of the organization. [1]

Through innovation, businesses develop new ideas and create new products. Management can effectively support the innovation process in terms of cooperation between workers who take part in it. This form of support is efficient because it saves time and money while ensuring continuity of business development. In the innovation process, which is supported by knowledge management, knowledge is automatically created, stored and shared. Knowledge management is not concentrated in one process of the company, but is distributed to all cooperating processes. At the same time, employees are interactively involved in the creation of knowledge. This causes significant reduction of the financial cost on creating the knowledge base. Employee participation on innovation is often very strong motivation. Transformation of enterprises into innovative societies requires also focus on the development of the organization in the processes and procedures, human resources management and technology.

The work that we want to do the right way must be executed effectively. Whether we look at it in terms of the work itself, in terms of the behavior of the team to understanding the work effectiveness or in terms of its relationship to the surrounding environment. [8]

Effective work with knowledge is now considered a key capability for creating relatively sustainable competitive advantage. Expression of the benefits of working with knowledge in specific values and indicators brings us valuable information and feedback on the effectiveness of the knowledge management.

In determining the benefits of knowledge management, it is necessary to take into account the fact that many of them are of a qualitative nature and therefore their financial statement cannot be directly expressed. Many experts and practitioners however specified the benefits of knowledge management and allocated them according to various criteria, e.g. in relation to business processes (increase of company performance, profit increase, revenue maximization, cost reduction, new work methods implementation, new market opportunities creation, etc.), according to the nature of the benefits (qualitative and quantitative) and according to the business processes (process results, such as communication and overall higher efficiency, which represents a shorter time period for problem solving, shorter period to design, faster results and delivery on market and organizational results, where finance, marketing and general fall under). In the perception of the benefits of knowledge management for the company as a whole, five general areas were allocated: growth and innovation, flexibility, customer perspective, internal quality and support of stakeholders.

Our chosen division is based on the relationship of knowledge management to companies in five categories, based on the method of BSC (Balanced Scorecard) and they are: business processes, innovation, financial performance, customers and employees. The following table shows specific examples of the benefits [8]:

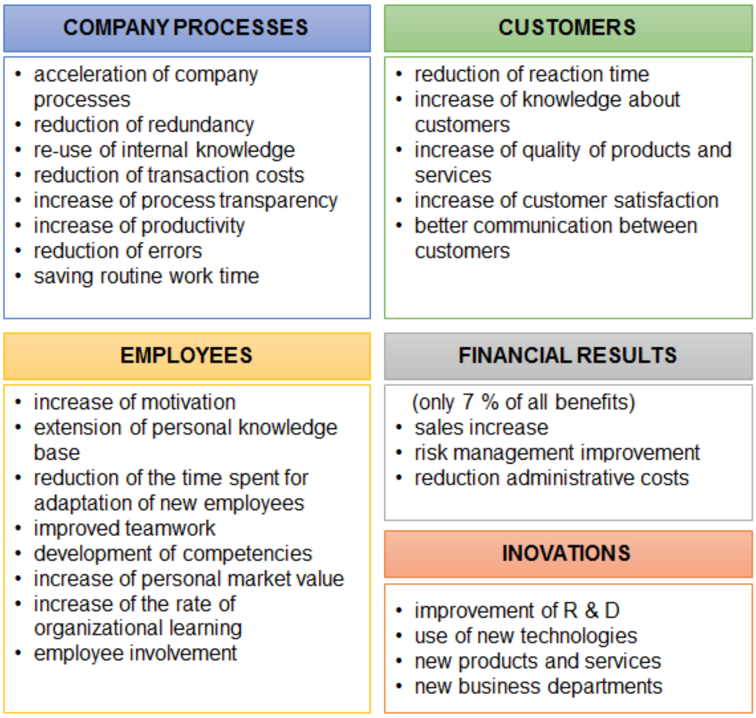


*Fig 4. Benefits of Knowledge management according to BSC*

Improvements of processes and workflows enable the company development of knowledge, its sharing and re-use, particularly in areas such as company strategy making, culture and customs of company, work procedures, staff leadership, return on investment, productivity, laws, risk management, etc.

The result of development of an organization is the introduction of new and effective elements for collaboration and support of innovative processes that automatically collect knowledge. The effective elements include: communities of interest or profession, specialized knowledge networks or matrix organizations. These elements can be effectively integrated into the existing organization. [8]

## 7. THE NEGATIVE VIEW OF KNOWLEDGE

Despite all the benefits, analysis referred to in the previous chapter, knowledge systems are faced with the negative. The key question is will create knowledge management, because this path is a concept of five years or more.

The real problem is the high and exaggerated expectations of the system itself and also the fact that the concept is still forming region, so it is difficult to define whether it is offered by a knowledge system. The fact that someone claims that their information system includes document management features artificial intelligence and knowledge management does not mean that this is the case indeed.

A substantial part of the chaos stems mainly from an undefined terms, thus creating a universal set of concepts, vocabulary standards in the community, which is engaged in a given area. At present the trend to address this issue, many providers in the area "jumps into the moving train" without exactly staging methodologies and technologies of knowledge management, but if these methods are not developed to the extent that they are successfully applied, we can still talk about the lack of understanding areas of concern.

Nevertheless, if it does not change the recognition of knowledge and understanding of their main holders (employees) in the company, but it will dictate the general fact that the market is the one that decides nothing will change. Companies that use knowledge management more efficient, thus producing the higher added-value and strengthen its position in the market are those that will follow the other companies attempting to keep pace.

Moreover, companies forget the gray workers who are carriers of knowledge and have thus be of interest to the capture and sharing of knowledge, rather than these experts retire and left the organization.

The problem also is that knowledge management is not easy to express through specific corporate assets, which in this case, the intangible nature of knowledge. Consequently, it is necessary to continue the development of measures and metrics to quantify the intangibles instead of plain use of anecdotal evidence. Despite the efforts of many, this part still remains an open chapter. After they are sophisticated methods for assessment, recognized and approved by the community is more likely to be accepted by senior management.

If the knowledge management from the perspective of senior management accepted and understood efforts, there are still some potential pitfalls that could hinder knowledge management initiative.

These are for example any of the below:

- Culture in the organization is not set to the climate knowledge is power but not to share the power and techniques then available are not sufficient to create an environment of knowledge sharing.
- Actual value of knowledge management is not implemented, because the organization takes it as part of the strategic vision of the company.
- Knowledge warehouses become cumbersome and difficult to maintain.
- The safety of these storage sites may be compromised and thus know-how.
- Knowledge management system is poorly designed and the user is difficult to work with him.
- Program planning for knowledge management is ill-conceived and problematic
- In the event that employees are not motivated in any way, knowledge sharing will be unsuccessful.

The organization must be careful and pay attention to these pitfalls. A key element in building a successful knowledge management is the proper management of change. Building a culture promoting knowledge sharing should be a function of change management in the organization. People naturally resist change, so change management steps and processes should lead to the elimination of these concerns.

If change management is good and all these pitfalls, the company has successfully avoided, then knowledge management has a bright future especially for building organizational intelligence and growth. Organizational learning (ie. Training and staff development) and knowledge management must go hand in hand and so the company moves in transformation from individual learning to organizational learning.

The problems that we introduced in this chapter are from the perspective J. Liebowitz, who sees knowledge management as a constantly evolving area especially for the sector of industry and even governments. Vision for knowledge management sees in successfully transforming individual knowledge into organizational mainly through the power of artificial intelligence. [10]

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*e-recruitment, data processing, HRM*

Andrej BEDNÁR*

# 6 DATA PROCESSING AND UTILIZATION IN THE TIME OF INDUSTRY REVOLUTION

*Contribution of e-recruitment software and data utilization to HRM*

## 1. ADVANTAGES OF E-RECRUITMENT

Mostly it helps to company to advertise actual vacancy and get all information about candidates which are needed for concrete free vacancy.

It will helps to companies to keep data confidential, and guarantees that suitable data protection regimes are upheld in each country where the recruitment technology is used, and by all entities to which personal data will be provided.

The company must set up and inform candidates that data will only be collected and/or processed for the following purposes (it also show what services e-recruitment is able to provide with). [1]

Global Successor integrates every part of your recruitment process, from job posting, through candidate application, screening and selection, agency and job board management, to HR system integration, management reporting.

The software is able:

- To allow candidates to register for events and to allow Company to contact candidates about and record their attendance at such events.
- To allow candidates to register for job vacancy email and/or SMS alert messages.
- To allow candidates to apply for job vacancies and for Company to process their application.
- To allow company, that candidates can to be identified as a potential applicant for future events and/or vacancies as these occur.
- To allow company to contact candidates to inform them of future events and/or vacancies.
- The software prevents and/or identifies the creation of duplicate database records. [2]

**Collection and processing of data may include:**

- Collection.
- Systematization.

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- Accumulation.
- Storage.
- Processing.
- Distribution (including different types of transferring).
- Blocking.
- Cleansing data (to ensure data is accurate).
- Destruction. [3]

Only data which is required for these purposes will be collected and candidate will not be asked to supply information superfluous to requirements. [3]

Candidates´ data will not be collected, stored or processed without their consent, obtained by you by clicking a YES answer and submitting their data in acceptance of the terms in Data Protection and Privacy Statement. [3]

The provision of candidates´ personal data is voluntary. In this respect, where data is requested during the online application process, and the provision of this data is mandatory, this is because the data requested is the minimum required in order for Company to lawfully and fairly process the application. [3]

**Data Storage**

Company duly performs its obligations to notify the Office for Protection of Personal Data before collecting and processing personal data. [4]

The personal data candidate supply as part of the online registration and/or application process will be held securely on behalf of Company. [4]

**Disclosure of Data**

Candidates´ data may, where appropriate (i.e., if candidates are flexible about the location), be made available to other offices, including outside of the country of application or registration, for the purpose of processing their application or for the purpose of identifying candidates as a potential applicant for future events and/or vacancies, and for the purposes of contacting them to inform them of such opportunities. [5]

Candidates´ data will be disclosed only to company´s employees directly involved in the recruitment and selection process. [5]

**Retention of data**

At such time as company has completed the processing of candidate application, their data may be retained for up to 24 months for the purposes of identifying them as a potential applicant for future vacancies, for contacting them to inform them of such opportunities and for the purpose of preventing the creation of duplicate database records. [6]

After 24 months without any contact, candidate personal data can be erased and only statistical information retained, which cannot be attributed to any individual.

In order to ensure that candidates´ personal data is accurate and up to date, candidate may at any time log into their account and update their personal details or upload a new CV file. [6]

Candidate may revoke their consent for their data to be processed by either:

Withdrawing their application for a particular vacancy by logging in to their account on our careers website. This will have the effect of preventing any further processing of data for that specific application. Data will be stored for a further 24 months before being erased under the standard retention terms and may still be processed for the purpose of identifying you for future events and/or vacancies, for contacting them about such vacancies and preventing duplicate database records. [6]

Withdrawing candidates´ application for all outstanding vacancies and choosing the reason ‘I wish my personal data to be removed'. This will have the effect of preventing any further processing of data for any applications and their personal data will be erased within 30 days of withdrawal. [6]

**Data Subject Rights**

Candidate have the right to access and correct personal data processed by company, the right to ask company for explanations, the right to require company to remedy the detrimental situation and the right to appeal to the Office for Protection of Personal Data with a grievance. [7]

**View of main users inside the company**

E-recruitment enable to sort candidates data, main users can configure what he/she is looking for and find it, also enable to sort data to prepare some (annual or monthly) analysis. Company recorded all candidates´ results from the Assessment Centre. Results are divided into: results from English test, results from analytical and reading skills, results from interview (the notice also could be put in e.g. candidate was rude and he is not suitable candidate for this position, recommendation which he got). These results are in percentages and can be recorded and show the success of all candidates in tests. [8]

E-recruitment also has special notification or signals which show to recruitment specialist that candidates changed information in his application form, or that he/she is requesting for two positions. [9]

E-recruitment enables to send automatic (general) invitation to Assessment center or events to many candidates. [9]

E-recruitment is able to send general refused email where candidates got automatic email where company show the regret the he/she was not successful during the Assessment center. [9]

E-recruitment is able to send automatic email which contains working offer at the company. [9]

Till now, article describes gathering of data, processing, storage and shredding. In the next part the article will describe ways of data usage inside of the company in detail.

## 2. UTILIZATION OF DATAFROM EXTERNAL APPLICATION INTO ENVIRONMENT OF THE SAP APPLICATION

Nowadays, many big international companies use SAP Application in the different areas and departments on several levels of customizations.

This article works with idea of usage of data especially in the several modules of SAP application and also in several areas of the company. As an use case there is presented cooperation between application eRec used within recruitment of employees and it´s possible integration into the SAP environment and other use of collected data in the module HR which are used for a long time in the company. [4]

With respect to the wide range of use of SAP application, this part of the article is focused on presentation of the structure, work organization, development and use of SAP within the company with the main goal of general presentation of the methodology of work and also understandable integration of its each modules. [4]

**Organization of work in sap application**

In company X, is used enterprise application software by German company SAP A.G. The abbreviation means Systems – Applications – Products in data processing.

The main SAP product, ERP (Enterprise Resource Planning) solution R/3, is used widely in this company:

- FI (Financial Accounting).
- CO (Controlling).
- AM (Asset Management).
- PS (Project system).
- WF (Workflow).
- HR (Human Resources).
- MM (Materials Management).
- SD (Sales and Distribution). [10]

For supplier relationship management is used SAP SRM to make the purchasing more effective, easier and automated. Parts of SRM are also module 1 for electronic creation and authorization of purchasing orders, module 2 for e-administration of investment requests, module 3 for full e-administration of improvement proposals and module 4 for e-application of business trips. [11]

For Business Intelligence is used SAP Business Information Warehouse, which allows advanced reporting from many sections of SAP and non-SAP systems to support analyses and managerial decision-making, including modelling, estimating and planning functions. Data warehouse are used for transactional data and data cubes. [12]

As a tool for support of application operation and development in SAP landscape is used SSM – SAP Solution Manager. It is applied on all levels of IT organization for both SAP and non-SAP systems. [11]

SAP can communicate with other systems through many interfaces. Main tool for this is PI – Process Integration (formerly XI - Exchange Infrastructure). It is platform for process integration in mySAP Business Suite components and also in products of other vendors. It uses open integration technology standards as XML or JAVA/J2EE to provide integration of applications from SAP and other vendors inside and outside of company (concern's companies). [13]

**Other possibilities**

- Remote Function Call (RFC) connection through transaction SM59 allows data export.
- Files at MZD.
- Object Linking and Embedding (OLE) from Microsoft allowing import and export of data.
- Electronic Data Interchange (EDI) for electronic exchange of structured data (standard messages) between two applications of different companies.
- DBconnect / dblink.
- Intermediate Document (IDoc) as a format of data of business transactions in SAP. [14]

OSS (Online Service System) is user support system directly from SAP A.G. It is available after registration on service.sap.com and users can then search help and solutions (OSS SAP Notes). [15]

CCoE (Customer Center of Expertise) for Central Europe, Middle East and India (formerly Competence Center) is IT center for 2$^{nd}$ level support and it deals with SAP cases, organizes SAP support among all departments based on the specific modules. It is SAP certified and uses ITIL (Information Technology Infrastructure Library) practices. [15]

System of work in company hierarchy, there is a head of department, with coordinators leading departments that can have multiple regular employees. [16]

From user's point of view, when dealing with IT issues, it begins with contacting Internal Service (IS) and waiting for solution, possibly providing assistance. It can deal with the issue alone or can forward it to Customer Center of Expertise, which can delegate it further to departments that handles corresponding modules. [17]

In processes between employees (E2E - Employee to Employee) processes, one side acts as a customers and one as a supplier. IT department provides SAP support for all departments, internal customers, as well as for external subjects.

- Incidents – when something breaks down, doesn't work as it should be.
- Request for change (RFC, CR) – when we want something to be changed.
- Problem management – long-term cases with knowledge base.
- Projects – according methodology. [14]

**UC4** is it process automation software with six main tasks: run book automation (routine procedures and operations), workload automation (dynamic planning of jobs by time dependencies or other advanced triggers), application processes automation, application release automation, managed file transfer and virtualization management. [4]

**Jobdesign** is group of people in IT that manages UC4, jobs and transport routes in SAP. [4]

OpenText Archive Server is complex archiving system for SAP. It includes processes like document scanning, Optical Character Recognition (OCR), insertion of data into SAP with physical linking, backuping. It archives not only documents (e.g invoices) but also DB tables from SAP. It provides fast access to archived data, intelligent search of them and within them. It uses OpenTextImaging Windows Viewer in client (SAP Frontend) to view the archived data. OpenText is official partner of SAP AG. [4]

Company X has three installations of SAP ERP. Installation 1 for intern costumers inside company and 2 installations for subsidiaries. [4]

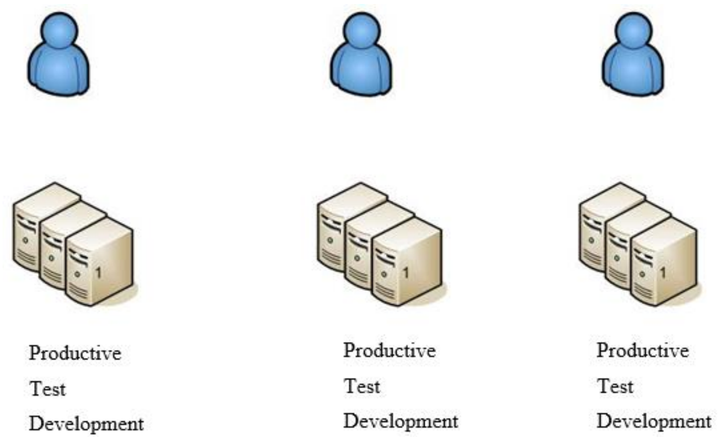


*Fig 1. Concept of system installations and clients [4]*

Installation can have one or more clients-configurations. In the case of multiple companies can run on one installation, so you must state client number on login. Different installation can use different versions of system components. [18]

Every client has three dependent, but separated systems: development, test and productive. The reason behind this is the concept of development and safety of productive data. [18]

Development system (numbered 2) allows setting up and adjustment within SAP standard (customizing), beyond standard (expanding) or rarely even with changing the standard. It allows development of our own functionalities. [4]

Test system serves (numbered 4) as test bed for the changes we made in dev. system. It contains a copy of productive data not older than one month. Testing and debugging is done by developers/coordinators or key users. [4]

Productive system (numbered 1) contains real live data and the company uses it for the actual business, so the changes and functionalities developed and tested must be working on 100 %, or we might be dealing with errors, collisions, data loss. [4]

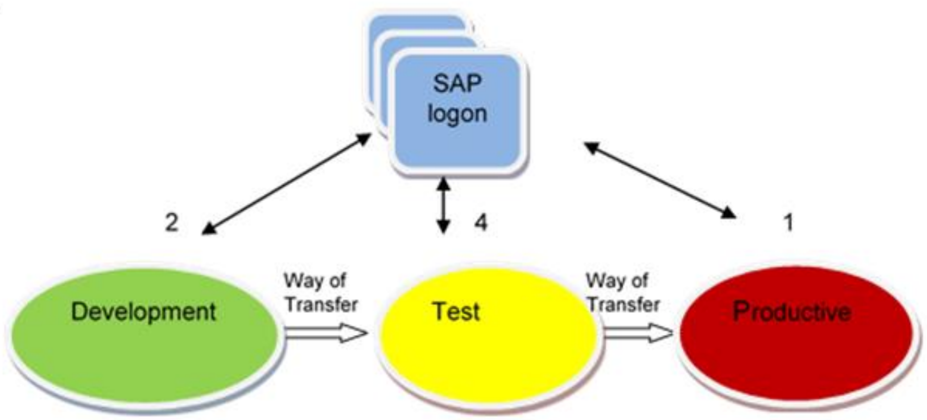


*Fig 2. Principle of environment of systems [4]*

**Organization of development in sap**

Basis structure in SAP is divided in three layers, three systems and two developments.

- Presentation layer – data input and output, communication between user and PC via dialog screen on presentation server.
- Application layer – communication with client through SAP GUI. Programs, which we create, runs on application server.
- Database layer – is used for data storage (database server).

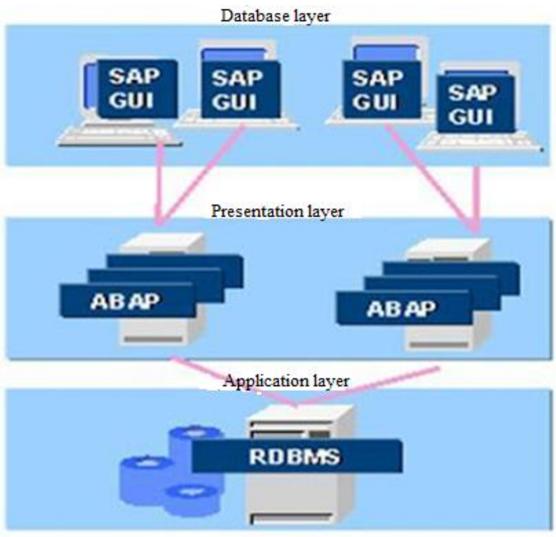


*Fig 3. Development´s layers [10]*

Further under three-tier architecture similar to environment of system:

- Development.
- Test.
- Productive.

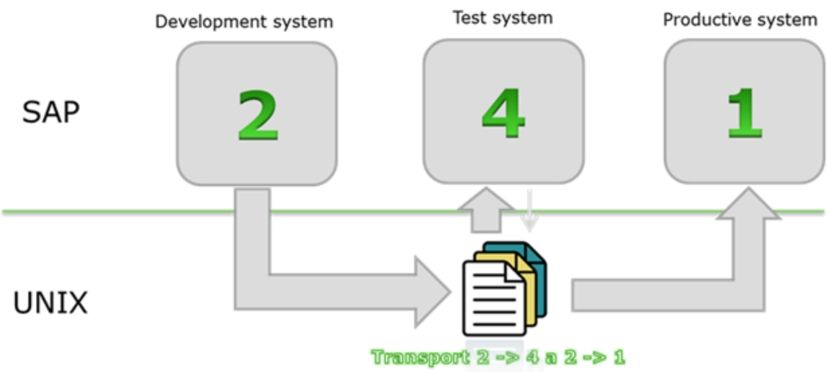


*Fig 4. Three-tier architecture [10]*

Developments are divided in two basis parts.

- Standard / customizing.
- Workbench / Customer development.

Standard CU objects allow setting the SAP to our needs, but with no modification of their code and content. CU are basically tables, table of keys and other client dependent settings. Usually done through SPRO transaction. [10]

WB, modifications (client-independent – applied for everyone). Our own customer's development, labeled Y, as part of the license with SAP. Impacts on the standard are minimal (separated environment through naming convention). It is necessary to supervise and manage the whole Customer development in the organization (through appropriate development steering using naming convention, packages and rules). [10]

Standard objects don't allow modification of their code. There is a possibility of modification of standard (user exit, enhancement points, see other topics) in limited parts of code as determined by SAP – we can consider this before doing Customer development. [10]

Phases of development implementation are following:

- Project preparation.
- Business plan.
- Configuration.
- Testing, final preparation.
- Run SAP and other time plans. [10]

Transport is a mechanism to move the configuration from one SAP system to another. It is simply a group of jobs – changes in tables. Consultant creates transport on development system, job design is then responsible for the next transport (to productive system). [10]

Basic information for working with transports. Developer can create transport only in system designated for configuration. Only development system allows changes. Transport should by separate for all modules. [10]

Transport requests/repairs are automatically exported to test system after being released by the developer. After the release, the number of transport is automatically registered in buffer of the target system (i.e. test or productive system). Release of transports/repairs between development and productive systems are done by jobdesign group. Jobs are development for these transfers, their purpose and rules of use are described in jobdesign methodic handbook. Communication between developers/organizers – related department – jobdesign is done in written form on principle. Execution of releases can be requested exclusively by appointed responsible person. [10]

Principles of testing are below mentioned.

- Development system is tested by developer.
- Test system is tested by developer (test of basic functions) and by requester (integration test). [10]

All steps should be documented in respective request for change or incident submitted.

To this part includes short introduction of ABAP language.

ABAP = Advanced Business Application Programming. It is foundation stone of SAP IS and was created in 1980, supports procedural and object programming of business applications in SAP landscape and allows 3-layer client-server application programming (presentation, application, database). [10]

Types of programs are following:

- Reports – simple executable programs, mostly including criteria selection screen and following view of the selected data from database.

- Applications – can be used for expansion of reports. Application can be modified and expanded with function modules or classes. With application one can modify the data, not only view them. [10]

Types of program presentations are WRITE, ALV, Forms (SAPScript, SmartForms, Adobe PDF).

**Localization of application in the environment of international company**

In the environment of international company there is very important factor which is easy localization of systems which markedly simplify possibility of spread of application and largely contributes to acceptance of systems from the site of users. In the environment of SAP application there are used so-called textual components for this sort of purpose. [4]

These components enable editing of texts in program which are displayed on the selective screen in case of selective texts or in case of output configuration for headlines configuration and text symbols. [4]

Text components are divided on the following items:

- Headlines configuration.
- Selective texts (the name of selective texts represents text. There is a possibility to take over text automatically from the dictionary).
- Text symbols (the text is stated under the number of the text components). [4]

As mentioned above, these selective texts are displayed on selective screen and text symbols on input configuration.

OTR (online text repository) are central storages of texts and translations and are used during the programming from the web environment by the help of BSP (Business Server Pages). During the creation of BSP application there is a possibility to choose between two types of OTR following texts:

- Alias texts (shorter text than 255 symbols).
  Declaration of the code **<%=otr(alias-name)%**>.
- Long texts (longer texts than 255 symbols).
  Declaration of the code<**otr> text………</otr**>. [4]

For translation, the SAP system use function of translation environment which is part of the application.

On the picture, there are several following examples of basic transactions:

- SE63 – transaction for starting of translation environment. It keeps short and long texts here.
- SLLS – transaction for translation statistic.
- TPMO – tool for monitoring of performance statistics of translations.

Objects for translation are configurated into grades. For the replacement of different codes for alphabets of world´s languages was discovered UNICODE. It is a chart of symbols of all existed alphabets which nowadays contains more than 245 thousands of symbols. [10]

Development of UNICODE started in the year 1987 and reached the top in the year 1991 by the establishment of Unicode Consortium. Each symbol has single valued code and name.

Moreover defines for all symbols some basic descriptions like e.g. if it is a letter of alphabet or symbol etc.

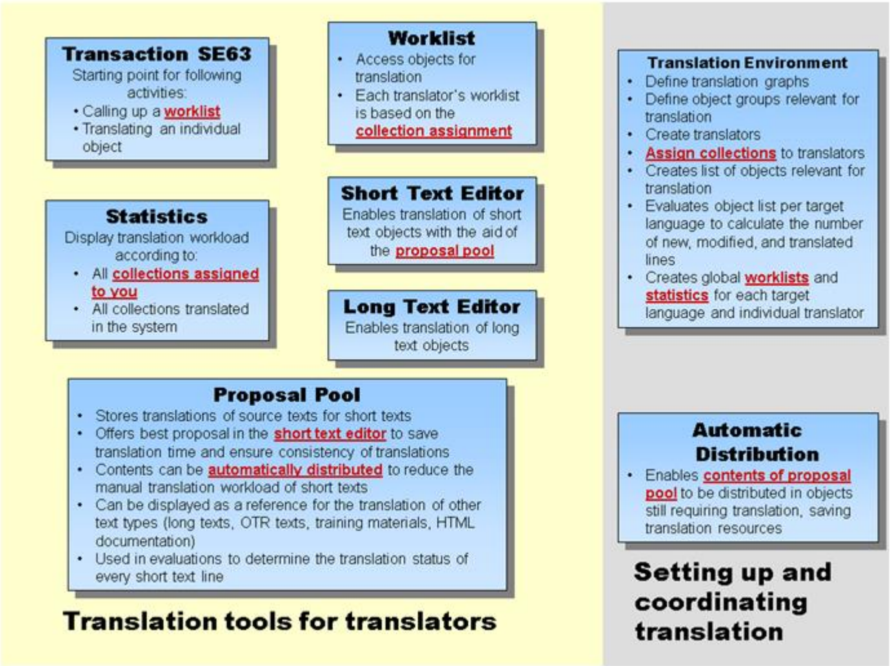


*Fig 5. The scheme of translation environment [10]*

Many ways of coding exists:

- UTF-32 – symbol is defined by 32 byte number.
- UTF-16 – symbol is defined by 16 byte number.
- UTF-8 – symbol is defined by 8 byte number. [10]

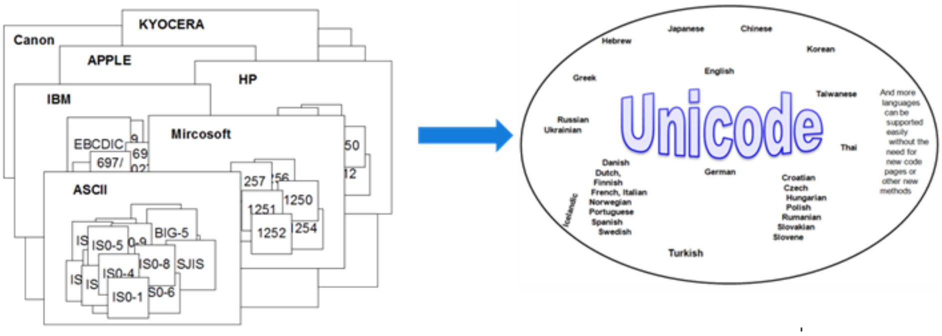


*Fig 6. Replacement of different coding by UNICODE [10]*

During the implementation of UNICODE into SAP there is a need to keep the exact steps of action/plan described in Unicode Conversion Guide. It is required to have upgrade database and particular component for relevant level. The main purpose is to use UNICODE for communication with no SAP systems. [10]

At the end of the chapter there are mentioned advantages and disadvantages of customization in foreign language. The main advantages are:

- Users can work with the system in native language.
- Quick orientation in the data item of programs. [4]

Contrariwise among disadvantages belongs:

- The need of entry in concreate language for fulfilment of customization.
- Often and different organised screens (control components) in different languages.

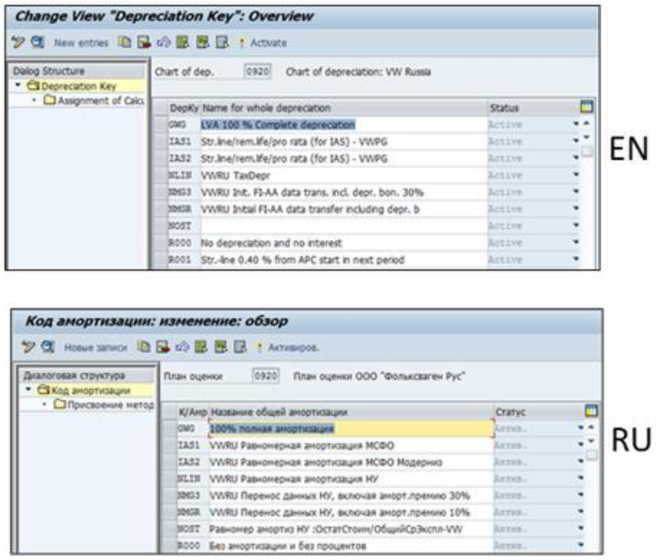


*Fig 7. Example of environment in different language of mutations [4]*

## 3. USE CASE WITH THE INTEGRATION INTO THE ENVIRONMENT OF THE SAP APPLICATION

In this part the article in concentrate on concrete use case which is implemented into real environment of SAP application. On the picture below there is the scheme where is shown which way can be used in order to share modules e-Recruitment a HR.

The candidate who is applying for the job has a several ways of contact with the potential employers. In this case the article is focused on use of application on the internet or personal visit during the interview with recruitment specialists. [4]

In case of usage of internet application the candidate fill online form which is on the environment of the component SAP Netweaver in internet browser. During the personal visit the recruitment specialists activate this web component on the computer and data about candidate will be input into web fields on PHP page. [4]

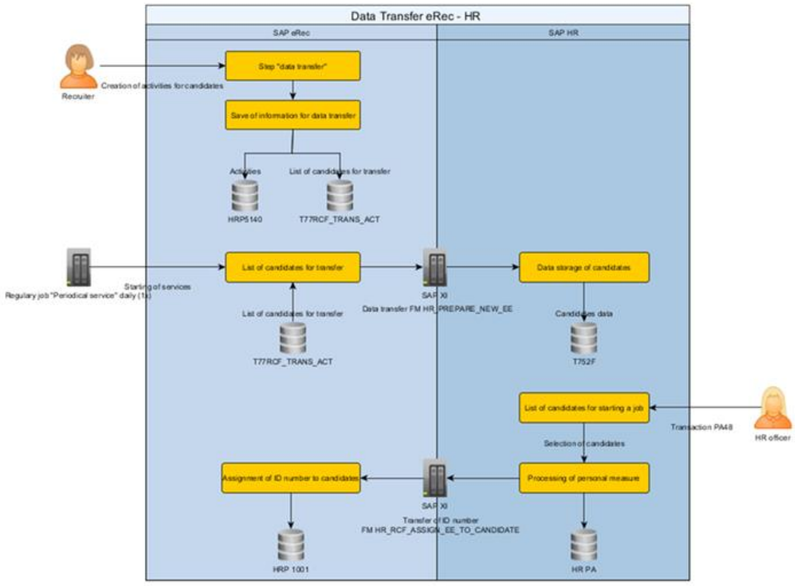

*Fig 8. Data Trasferbetween modules eRec a HR within the SAP environment [4]*

After clicking the button send the function is activated function: data transfer on the serverSAP® Web Application Server (SAP eRec), which provides process of the transaction. [4]

a) In the database SAP **B**usiness **W**arehouse (**BW**)in the chart HRP5140 there is a status of transfer transaction saved. In case of the status that the transaction is notright, information email will be sent to administrators or to developers of the transaction.

b) In the database SAP **B**usiness **W**arehouse (**BW**) data about candidate will be saved there into the chart T77RCF_TRANS_ACT, example on the following picture below. [4]

Once a day the component UC4 exekutorlaunches JOB with steps, which starts procedures (programing in ABAP) for data transfer list of candidates for transfer from the table T77RCF_TRANS_ACT”in the environment SAP XI/PI. This component transports or may modifies data and  save process in the other environment on the server SAP® Web Application Server (SAP HR) into DB T752F. Between serversSAP eRec and SAP HR there existsfirewalls, which protects against attack from outside word in the internal environment of the company. So-Called SAP eRecis external world (internet) and SAP HR is internal protected world of the company. [4]

Data about candidate will be relocated into PC (SAP Netweaver) of worker in Human Resources department, by the help of function for the data transport from the chart T752F the transaction PA48. Loading of these HR data runs and Human Resource Specialists is supplied with multifunctional electronic permit with activated PKI code which contains signed authorized certificates. Or RSA equipment can be used for input of the code. [4]

| Technicaltitle | Description (in Czech) |
|---|---|
| Hire date | Datum nástupu |
| orgunit | Organizační jednotka |
| position | Funkční místo |
| Employee number | Osobní číslo (v případě ručního zadávání) |
| lastname | Příjmení |
| middlename | Jméno (prostřední) |
| firstname | Jméno |
| Academic grade | Titul |
| Form of address | Oslovení |
| gender | Pohlaví |
| Date of birth | Datum narození |
| Correspond language | Jazyk korespondence |
| street | Ulice |
| city | Město |
| zipcode | PSČ |
| country | Země |
| state | Stát (kraj) |

*Fig 9. Example – list of filled fields in the module eRec [4]*

Human Resource specialist is in contact with each department in the company and candidate is offered to managers in these departments. Candidate visit the company and has an interview and in case of getting information about the acceptance of this candidate, the exact department contact Human Resource specialist and he/she input/enter information about the acceptance of this candidate into the system. Then the process of compiling is launched after direction is given from the site of HR Department. Data are saved in the databases with the name HR PA which have fields (picture no. 2-list of filled fields in the modules eRec and more information from the HR specialists). [4]

Once a day the component UC4 exekutorlaunches JOB with steps, which starts procedures (programing in ABAP) for data transfer FM HR_RCF_ASSIGN_EE_TO_CANDIDATE in the environment of SAP XI/PI. From the table HR PA data are loaded which can be or must not be modified, then assigns PERSONAL ID and input data into the table HRP 1001. By this way, the external candidate is accepted in the company as an employee and all information are available on internal Intranet sites of the company and he/she has also admission to these data and data are also available to responsible workers/employees inside of the company. [4]

## 4. BENEFITS E-HRM AND DATA UTILIZATION WITHIN THE COMPANY

e-HRMand data utilization bring following benefits:

- Work saving (reduction of administrative work) – electronic technologies in HRM save about 40% administrative work.
- Costs saving for labour can be measured by the number of work contract in the company for the concrete period.
- Time saving – HR specialists do not waste time with printing of CVs and with it´s storage, leaders do not need spend time on waiting for candidate´s personnel information, they can read it and open it immediately on theirs computers.
- Quality of information – the higher accessibility and accuracy of information.

- Data used across the each departments in the company.
- Simplicity and comfort during the work with information.
- No dependence on personnel department – information can be get without personnel workers.
- Increase of quality in managing processes (line mangers get personnel information about employees, job positions immediately and can work with them).
- Employees can see personnel data which are stored by company, in many cases employees can update their data.
- Employees have opportunity to find out information about free vacation in company or accessible training programmes.

e-HRM increases satisfaction of external and internal clients.

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*simulation, optimization, healthcare processes*

Marko PEDAN*

# 7 OPTIMALIZATION OF HEALTH CARE PROCESSES WITH THE USE OF SIMULATION

## 1. WHAT IS SIMULATION ?

Simulation is the imitation of actual running process in time [1]. By emulating logic and randomness of the process, such as the flow of patients through the various departments of medical facilities and random duration of each type of treatment, simulation is a valuable tool for the evaluation and comparison of the proposed changes to the process [2]. Impacts of process changes, such as increasing the number of doctors are assessed by performance measurement, so for example the amount of time (simulated) that patients waited for examination or treatment [3]. During the course of the simulation, big amount of performance measurements and data are recorded for statistical analysis. In organizations either providing services or producing goods is their efficiency affected by various deficiencies - different kinds of waste, ineffective resources utilization (material, energy, people, equipment and time) [4]. These types of waste are undesirable and must be eliminated [5].

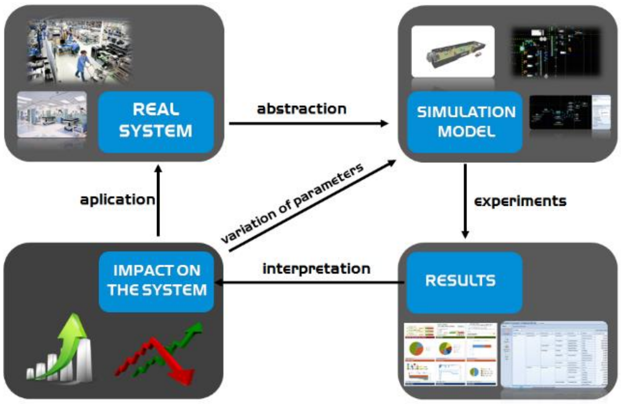


*Fig 1. The principle of simulation [1]*

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### 1.1. The use of simulation in healthcare

Simulation has a broad potential of applications in healthcare, which may be classified into several main directions. General classification of simulation in healthcare is as follows [6]:

- **Clinical simulation** – used mainly for studying, analyzing and replication of some diseases behavior, including biological processes in the human body.
- **Operating simulation** – used mainly for capturing, analyzing and studying the health operations, service provision, planning, healthcare operational processes and patient motion.
- **Management simulation** – used primarily as a tool for management purposes, decision making, policy implementation and strategic planning.
- **Training simulation** – used for training and educational purposes, where virtual environments, virtual and physical objects are widely used and enrich simulation experiments.

Managerial and operational direction of the simulation are closely linked. Together, they form the major components for the management of healthcare processes.

The above classification is just the starting point, that only indicates huge space of simulation application for healthcare domain. In each of these directions can be simulation used for analysis and design, education and training, research and communication purposes.

Brailsford classifies medical simulation models into three groups [7]:

- The models of the human body, often referred to as models of disease, including the biological processes of healthy subjects.
- Models for tactical purposes at the unit level of health care (clinics, departments, hospitals).
- Models for strategic purposes involving the whole system models which often do not model all individual patients.

All these classifications show how large the space and potential applications of simulation in healthcare is. However, the current research and practical medical simulations are rather at an early stage compared with the engineering and production departments. The full potential of simulation of health care has yet to develop.

### 1.2. DES in health care

On the basis of the impact and frequency of application is identified relatively few simulation techniques of relevance. These groups consist mainly of mainstream simulation methods and simulation of algorithms based on artificial intelligence [8]. The same way as many tools and methods, and discrete event simulation (DES) has appeared from the manufacturing sector. DES first language was developed by K. D. Tocher for United Steel Corporation in the late 50s. Since then sequentially programming languages developed over GPSS, Simscript, Simu, SLAM, SIMAN Arena to Simio. At the beginning it is necessary to define a discrete event simulation.


*Fig 2. Simulation methods*

Banks defines simulation as an operation imitating of the real process or system over time. DES is a specific approach to simulation processes and systems in which the system state changes immediately at time points, such as the arrival of a customer or activities completion [9]. This approach is particularly suitable for queuing systems modeling. Of course, also many health care processes can be understood as queuing systems, in which are mainly patients those who are waiting in the queue.

Robinson discribes a key reason for using DES as the need to model processes that are subject of variability, and which are linked, resulting in complexity [10]. Variability may be predictable (e.g. shift changes) or unpredictable (e.g. patient's arrival patterns and times of consultations and treatments). Most of the processes are the subject of a number of sources of variation, which are linked (e.g. patterns of arrivals, triage times, times to first treatment, etc.), the process is complicated. As a result, it is difficult to predict the effectiveness of the process, therefore, simulation should be chosen.

The complexity appears not only from the scope of the process that is under investigation, but also from dynamic interaction and feedback between the various elements of the process. For this reason, the underlying assumption of DES is that the processes are subject of variability and they are interconnected and complex. Queues, which appear in the process and their efficiency (process flow) is difficult, if not impossible, to predict without simulation.

DES is used primarily as a mean of testing whether the proposed procedure is carried out as expected. At the same time they seek means of improving the process. The common benefits of using DES in a manufacturing and health care context, are in the reduction of risk, better understanding of processes, reduction of operating costs, lead time reduction, quick changes of machines, capital costs reduction and better customer service. These benefits, however, can be easily translated to other contexts, such as services and healthcare. DES implementation in health care could not be so easy. The two main issues that are mentioned in relation to management and stakeholders, are the level of their involvement in simulation studies and the problem of managing conflicting interests of different stakeholders [7].

### 1.3. The basics of DES in health care

An important advantage of using discrete event simulation to model medical devices over other modeling techniques, which include linear programming or Markov Chain analysis is the ability to model the complex patient flows and scenarios testing and "what if" changes in the rules and patient flow management [11]. The success or failure of simulation studies in the area of health care often depends on compliance with the standard sequence of steps. Law and Kelton outlined the key steps that are necessary to perform a successful simulation study [12]. These steps include:

- Problem formulation and study plan.
- Data collection and conceptual model design.
- Model validation.
- Design of a computer model.
- Model verification.
- Design of experiments for problem solution.
- Pilot runs using a computer model.
- Statistical data analysis obtained from the pilot runs.
- Interpretation of the results with respect to the system.

Key issue for the success of simulation studies of health care is careful formulation of the problem and the involvement of all stakeholders. When simulating production systems, the model and data errors can lead to unexpected costs and poor performance. In health care, such errors can lead to life loss of patients. It is therefore not acceptable any space for errors in the design and application of medical simulation models. These restrictions provide obstacles and barriers that can be overcome only with the highest attention to detail and accuracy, as well as communication between all stakeholders.

### 1.4 Simulation inputs and outputs

Tab 1 introduce the primary inputs to the model. The simulation terminology, some of them are referred to as controllable variables or decision variables, because their management may change and affect the performance of the process. All other variables are called uncontrollable and are perceived outside the control of management. Various analyzes can often be enforceable just using these variables, which include, for example, sensitivity analysis (e.g.: What if more patient arrive at the same time?).

*Tab 1. Decision variables and simulation inputs*

| No. of : | Time distribution of: |
|---|---|
| • Receptionists<br>• Medical assistants<br>• Physicians and nurses<br>• Treatments per worker<br>• Ambulances per worker | • Registration<br>• Food preparation<br>• Treatment<br>• Next process prescription<br>• Ambulance cleaning |

Fig 3 shows some of the outputs of the performance measurements obtained from the simulation. These data can be collected and analyzed in whole or by employees, type of treatment, and time of day.

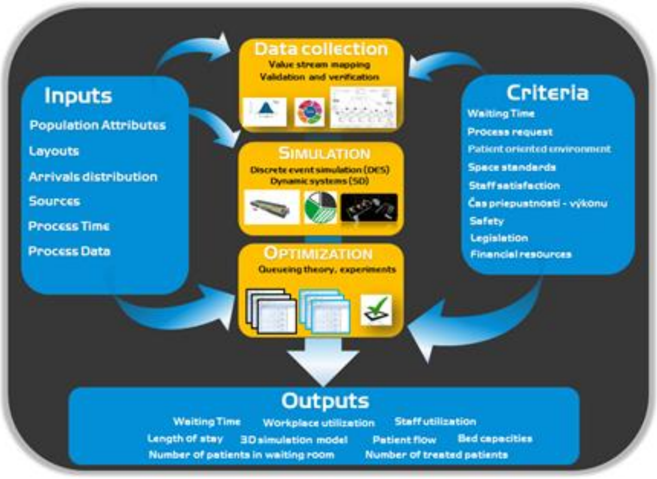



*Fig 3. Inputs, criteria and outputs of simulation*

### 1.4. ED simulation models

Simulation discrete event models can capture the complex patient flow in existing health care facilities, as well as analyze the impact of the new rules, policies and flow of patients. These flows are typical for ED, where patients arrive almost always without scheduled meetings and require treatment over a large and diverse set of diseases and conditions that range from minimal (e.g. a slight sports injuries) to fatal (e.g. heart attacks, gunshot wounds). Although the patient's arrival patterns are highly unpredictable the sequence of treatment can be effectively managed by medical staff.

From the above reason, and given change in direction of the flow of patients, it is possible to minimize patient waiting time and increase the utilization rate of employees. Limited access to primary care led to an extreme rise in the use of emergency departments worldwide. Overcrowding in emergency departments has been recognized by national health groups and regulatory authorities, which include the American Hospital Association (AHA) and the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) as a major public health problem. All this has led to a significant increase in the use of discrete event simulation and modeling of ED in the past decade.

Takakuwa and Shiozaki proposed a procedure for scheduling urgent operations to minimize the waiting time of patients [13]. Sinreich and Marmor developed a general simulation tool for emergency departments that is flexible, intuitive, easy to use and contains the default values for most parameters of the system. They also describe the steps for creating a discrete event simulation tool to determine the best and most suitable configuration for the emergency departments [14].

The key indicator of the health services used by the emergency department is patient waiting time. Garcia analyzed the impact of the fast-track to reduce queue waiting time of low acute patients [15]. Patients are typically triaged according to their acuity, patients with low acuity are waiting excessively long time. Fast Track front is used to treat certain level of patient acuity (in this case, non-acute patients). They found out that fast-track stream that uses small amount of resources could lead to a significant reduction in patient waiting times.

Increased waiting time change the perception of the quality from the patient view [16]. It also requires more space (waiting room) and long waiting times are the cause of many patients leavings.

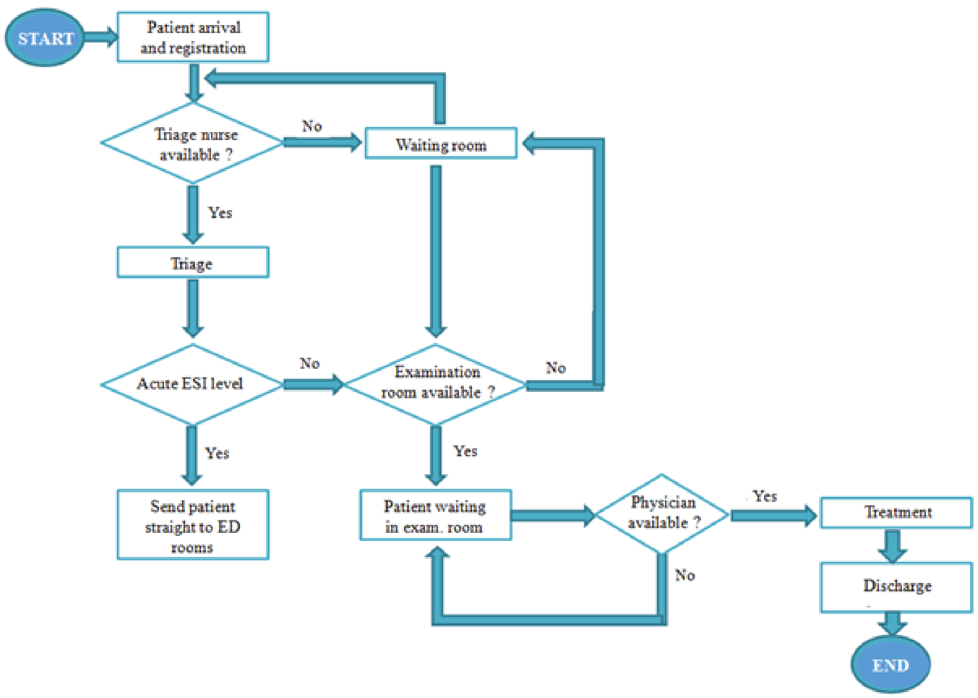



*Fig 4. The basic steps of ED treatment process simulation*

If we want to get model of real system, we have to consider also the restrictions. The model should:

1. Reflect processes of care that contribute significantly to the ED overcrowding to facilitate predictive power of forecasts.
2. To minimize the input data requirements, to facilitate the use of its generality between institutions.
3. Be implemented as quickly as possible to enable real-time predictions.

An interdisciplinary team composed of health care professionals, managers, medical informatics and biostatistics create a model. Development continues iteratively until all team members will not agree with the model. The design and construction of the final ED model is in most cases the same, only with minor adaptations and modifications (Fig 5).

**Patient arrivals (A).** These arrivals vary and depend on the time of day and day of the week. We are trying to replace arrival patterns by the theoretical distributions which suitability we must verify (e.g. a goodness of fit or Chi square). The time between the patient's arrival in the US in emergency departments have usually exponential distribution.

**Left without being seen (B)**. Some patients leave ED without having been seen by physicians. These decisions are influenced by long waiting period. This process is represented by using a regression model of waiting. The number of patients in the waiting room is an independent variable [17]. Whether the patient leaves ED without physician seeing is the dependent variable. Simulation transforms the probability logarithm of leaving ED without treatment for each patient. Then it uses a random Bernoulli experiment to determine whether the patient leaves.

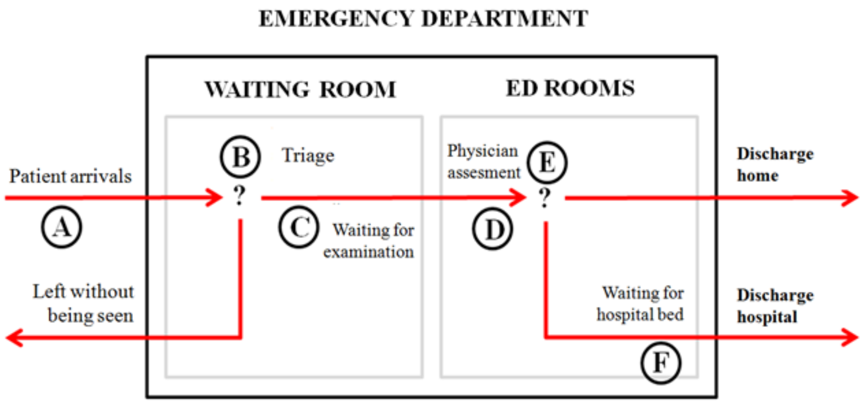



*Fig 5. Patient flow through emergency department*

**Triage - Assign an acuity level (C)**. Patients are usually classified by the level of acuteness. In the model, the triage is represented by chance, respectively by the probability that the patient will belong into a given group of acuteness (ESI 1-5). The simulation model will place the most urgent patients into ED beds immediately, regardless of the availability of beds. This provides a mechanism by which under extreme operating conditions may be the capacity exceeded. Simulation retains all other patients in the waiting room and establishes their order of treatment according to the degree of acuity or by the sequence of arrival.

**Physician assessment and treatment (D)**. It is believed that the most acute patients generally require the provision of time-consuming and broader health care. Normal, Gamma and Weibull distribution commonly describe time data patterns. The simulation uses a single normal distribution within each group representing the acuity of the patient and physician assessment duration of the treatment.

**The decision-making about admission to the hospital (E)**. Most sick and most acute patients are admitted to the hospital more often. After completion of the physician assessment and treatment for each patient, simulation is using Bernoulli random test to determine whether it should be the patient admitted or not. Simulation immediately deprives ED ambulance from treated and completed patients that are ready for acceptance, while maintaining those patients waiting for a available hospital bed.

**Hospital beds (F)**. Getting in patients that are already admitted to the hospital is usually one of the main reasons of ED crowding. It should be taken into account that some hospital processes such as schedules of operating rooms, affect the bed availability. Simulation favors admission of patients to hospital beds by the Boarding time.

Most of predictive simulation models implementations are made using the standard C programming language. Simulation generates random numbers using Mersenne Twister algorithm, which has been statistically verified for simulation.

### 1.5. Simulation in health care and its potential areas and future trends

Simulation in healthcare primarily allows the replication of the facts and examination of possible changes and situations that were not really possible. This can be achieved without high investments in systems development, training, and equipment purchasing [18].

Moreover, simulation in health care may be extended beyond its traditional role of scenarios comparison and workflow visualization. The simulation model can be incorporated as a part of ongoing efforts of performance monitoring and efficiency improving. In this role the simulation model is developed not only for the runs and experiments, but is rooted in the information systems of health care facility [19].

The true benefit of simulation is noticeable only when simulation models are fully integrated into the normal structure of health care provision, i.e. into the existing information system that supports the daily operations of health care provider. The essence of the vision is to consider simulation as a tool for the management of a single set of experiments, which is considered as a significant change. The real vision is to make simulation models that run parallel with other applications as a routine part of everyday working environment.

With this approach, the efficiency of health care becomes today's primary objective, while the future may require even higher requirements. In addition, with rapid changes of health care system variables (technology, finance, policy, service requirements, market, etc.), the effectiveness of health care is becoming moving target that is necessary to revise and re-address. Heed warnings from skeptics from past about the resistance against simulation had disappeared. Today, health care shows more maturity and the need of simulation plays an important role in solving public health problems. In addition, the current economic situation, policy changes and the environment in which healthcare is provided, are ripe for the institutionalization of simulation as a standard tool for management and control support of healthcare service delivery [20].

### 1.6. The potential of simulation in health care

Simulation in health care can be considered as an effective tool, technique or method. Improvements in some aspects of next chapters will lead to the main goal – to increase the efficiency of health care.

#### 1.6.1. The development of information technology

Development of a national electronic health records (EHR) has created a unique opportunity for health care systems around the world to move to electronic medical practice (eHealth), and possibility of the economic benefits.

But the way for benefits from eHealth-U leads through the design of innovative medical processes and redesign of existing processes and practices that deal with the changes resulting from the adoption of new technology. The work [21] estimates the potential savings and the cost of EHR in the US and found that the effective implementation of HER (interoperable with other systems) could ultimately save more than $ 81 billion annually. This savings is achieved by improving the effectiveness of health and safety. However, the authors recognizes that it is unlikely to be realized without related changes in the health care system [21]. This means that the application of simulation in medical redesigning of existing operational processes and IT arrangement has a major potential for scientific research.

### 1.6.2. Decision support

Medical personnel (decision-makers) need reliable operational tools that support them in decision-making at critical moments, costs reduction, patients waiting time reduction, help them predict future patients arrivals and provide visualization to enable them to prepare personnel and other resources for high-quality provision of patietns health care at the right time [22]. These tools should also facilitate with decision making evidence and informative environment. Simulation models, especially those with transparent structure that leads to the core variables that can be easily understood and trusted by people (decision-makers), are a useful tool to support decision making, communication and discussion of ideas, policies and scenario analysis [6].

### 1.6.3. Training and quality

Adequate training of physicians has a direct impact on service quality. This will reduce errors and promote the adoption of best practices. Trainings of medical personnel (doctors, administrators and managers) are costly, time consuming and require a commitment and dedication, which are usually taken for a reasons of time.
Simulation can [6]:

- Successfully enhance and improve the knowledge of doctors.
- Make acquaintance with the new procedures and processes.
- Prevent errors that are caused by lack of training and practical experience.

### 1.6.4. Complexity

The complexity of the medical procedures increases exponentially with various services, for example, laboratories are being moved out of hospitals that had resulted into extreme mobility of patients due to competition on the free market. Modern hospitals are complex systems of distributed subsystems with complex medical processes, human interaction and operating procedures. In these hospitals, citizens can easily plan their health care based on a shorter waiting time, excellent quality and many other factors that lead them in their local, regional or even national boundaries. This makes the process of health care related and more complex and simulation can be a way of : How to resolve the complexity. This means that the complexity of healthcare systems makes the simulation as a potential tool for medical analysts.

### 1.6.5. Process improvement

In most medical simulation projects, for the purpose of efficiency, is the main objective patient waiting time reduction. Waiting for the date of service delivery and just waiting for the health service is an important indicator of efficiency. The waiting time is the cause of many problems that is health care facing today. Increased waiting time affects the patient's quality perception [16], it also requires more space (waiting room) and long waiting periods that are the cause of many leavings.

### 1.6.6. Data collection

The simulation model can only be as good as the input data, so data collection is one of the main challenges in health care. In healthcare simulation developers often do not have enough input data for the simulation models, which then usually bring only approximate results.
Data collection is therefore a major challenge because:

- Historical data may not be available in a useful form.
- Data collection should take place over a longer period of time.
- Communication and interviews with health professionals and the purpose of verification is also a challenging task due to their time availability.
- Input data must be realistic and complete (not approximate), based on the ongoing operations of the system (e.g. From information systems).

Some hospitals may have a more agile and dynamic staffing where simulation that is based on real data can play an important role, and that is the prediction of the number of nurses and staffing on a daily basis, the distribution of nurses between hospital and home care, and many other proposals arising from benefits of simulation model based on accurate and real data. An ideal data collection may require the integration of simulation models with hospital information systems that support daily operations. As other applications (e.g. meeting scheduling, operating rooms reservation, etc.) generating new data, these data are automatically fed into simulation models. Anchoring simulation models into operational hospital information systems prevent facility from many problems that the traditional simulation models have (assuming a lack of support for data or a limited range of data). This will make the simulation model useful for continuous improvement over one aplication. For example, the actual planning that affects the use of resources, will have a dramatic impact on the operating costs, quality of service and effectiveness of health care.

Currently, since as the input data is greatly simplified, the simulation results are often used more for general forecasting and planning than for daily decision-making. The real needs of health systems to lead to lower costs and profits increasements, is the data for decision making support on a daily basis [23]. This is where the desire for efficiency, just simulation prevails over other analytical methods.

### 1.6.7. Health care processes

Organizational complexity and the flow of patients of a modern health care system are enormous and extensive. Modern hospitals have a large number of interacting units composed of specialized and acute units, third part facilities, external laboratories. This comprehensive cooperation and interaction contributes to a comprehensive intra-organizational workflow and even to a comprehensive model. The challenge of simulation model is to capture the complexity of the organizational flow in a systematic and manageable way. Models should comply with certain characteristics such as hierarchical representation [24], more views etc. On one hand, simulation models should be the tool for process representation. On the other hand, they should also be a simple way of communication and understanding between the third parties and the sources of knowledge [25].

**Verification and validation**

The real bogeyman of the simulation is a verification and validation that are the subject of extensive research. Without a thorough verification and validation it would be risky, if not disastrous, to make any decisions or forecasts based on model results. One of the new approaches to facilitate the verification of the model is the emerging approach – collaborative, participatory, interactive modeling [6] or CPI modeling, where models are designed together with the participation of medical staff and hospital management [10]. But validation is a completely different problem. The development of a valid simulation model, designing of valid experiments based on the model and perform detailed analyzes of the experiments has resulted in significant research**.**

### 1.6.8. Conceptual modeling

The simulation model is created and based on the understanding of a fact or the management of a limited space. This is captured in conceptual models that are used as a pattern for the simulation model development and validation of the simulation model from the conceptual model. However, the conceptual approach or model that is the problem domain between the simulation model is largely overlooked. Very little attention has been paid to the research about conceptual medical model. Conceptual modeling as a prerequisite for success in the simulation health care is an area for deeper research.

## 2. CASE STUDY NO. 1

Aim: Measure the utilization of medical staff in the ward

In the inpatient medical ward work at 1 shift medical staff composed of – 1 nurse, 1 medical assistant. Hospital management wanted to map the current state of this department – staff utilization. Simulation run length was 24 hours. Based on the daily schedule and duration of each treatment and activity that staff have to undertake, we have create and design simulation model in the software SIMIO [26].

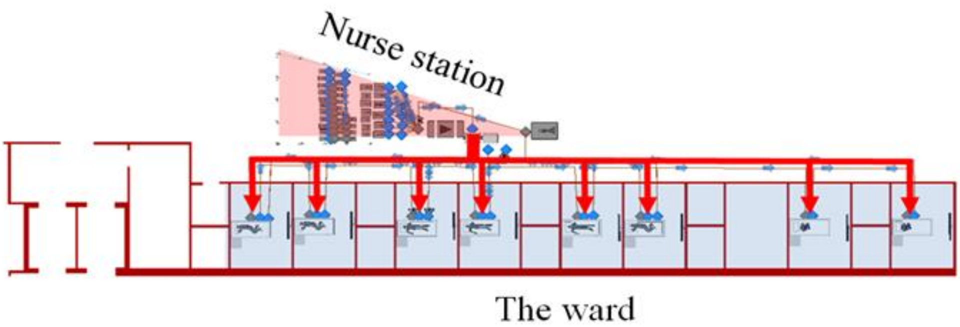



*Fig 6. Layout of the ward*

### 2.1. Variant no. 1

Firstly, we wanted to map the current state of the ward in which we considered the following staffing – 1 nurse, 1 medical assistant (MA), 1 practicioner. After a simulated 24 hours, we received the following results.

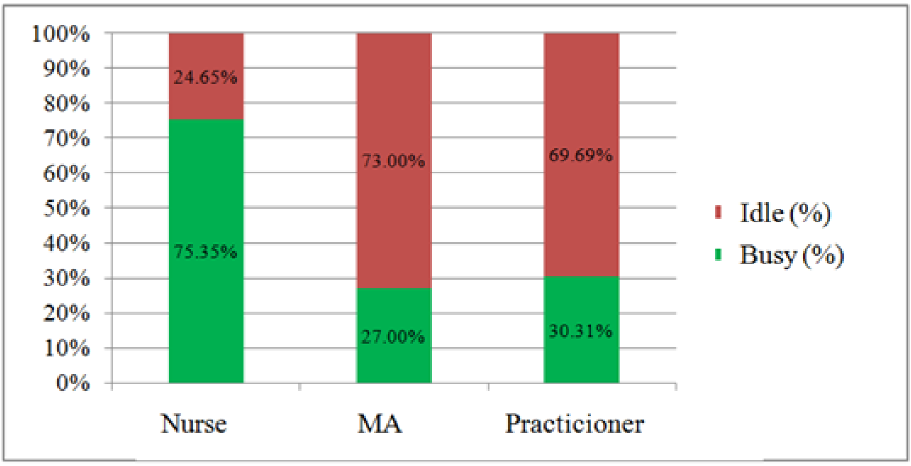



*Fig 7. Staff utilization of variant no.1*

Workload analysis showed that the individual values are within acceptable limits. However, we found that the time duration of individual performances meant that the staff was able to make only 27.27 % of all daily prescribed exercises.

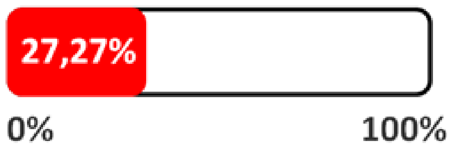



*Fig 8. Percentage of completion*

### 2.2. Variant no. 2

Based on the results of variant no.1 we decided to add 1 nurse. This means that in this case we consider following staffing – 2 nurses, 1 medical assistant (MA), 1 practicioner. The results of simulation runs were as follows:

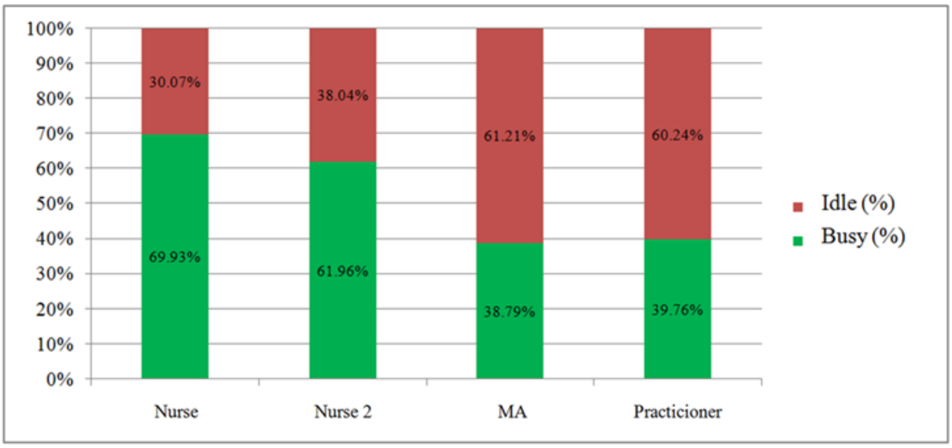



*Fig 9. Staff utilization of variant no.2*

After adding the second nurse, the utiliz ation of the first one decreased. Both nurses are now running at almost the same level. Adding nurse had also a positive impact on the remaining personnel (medical assistant (MA) and practicioner), because their utilization has increased to a better level compared to the no.1 variant. The most important improvement, however, was the value of the percentage of activities completion. This indicator improved to 86.36 %. However, we still have not reached the state in which all scheduled performances per day are done.

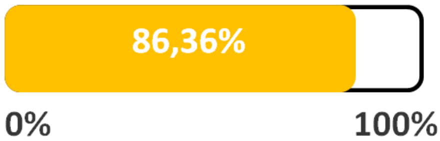



*Fig 10. Percentage of completion*

## 2.3. Variant no.3

In this last variant we've tried to add even a third sister. Thus, staffing was – 3 nurses, 1 medical assistant (MA), 1 practicioner. Simulation results were as follows:

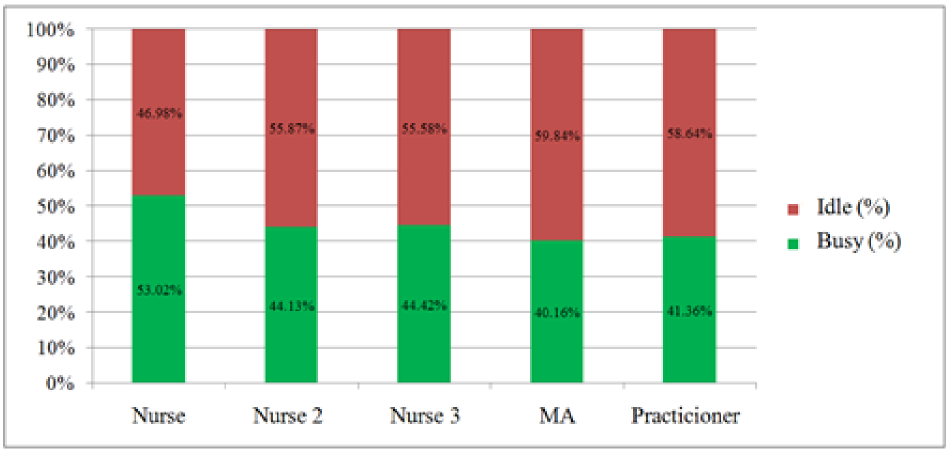



*Fig 11. Staff utilization of variant no. 3*

After the addition of a third sister occurred two positive effects. Utilization of workers was acceptably reduced and almost got on one level (even utilization of the entire staff) (Fig 11). In such a composition the staff has to be able to fulfill all activities in 24 hours, so the percentage of completion finally reached 100 %.

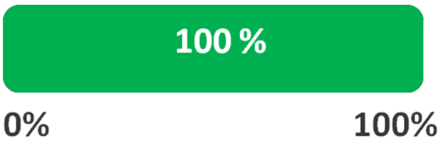



*Fig 12. Percentage of completion*

## 2.4. Summary of results

Using simulation, we were able to map the staff utilization on the ward. But we also found out that, at the expected composition of (1 + 1 + 1) the medical staff is not able to perform all the required procedures that are scheduled daily. But with additional staff we have fixed this issue. Additional staff need not to be seen as a source of additional personnel costs. The simulation results showed that additional staff is not only able to manage all of the required procedures, but with increasement of its number we achieve a balanced utilization of all the staff in the department. The detailed results of each variant can be found in the following table 2 and chart [26].

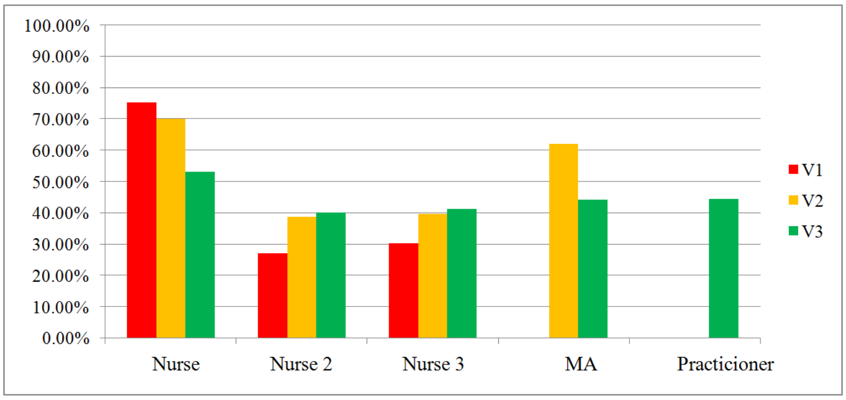



*Fig 13. Staff utilization of each variant*

*Tab 2. Detailed results of each variant*

| Staff | Indicators | Variant 1 | Variant 2 | Variant 3 |
|---|---|---|---|---|
| Nurse1 | Busy (%) | 65,43 | 61,13 | 50,43 |
| | Idle (%) | 24,65 | 30,07 | 46,98 |
| | Transport (%) | 9,92 | 8,80 | 2,59 |
| | Utilization (%) | 75,35 | 69,93 | 53,02 |
| Nurse 2 | Busy (%) | - | 50,85 | 39,91 |
| | Idle (%) | - | 38,04 | 55,87 |
| | Transport (%) | - | 11,11 | 4,22 |
| | Utilization (%) | - | 61,96 | 44,13 |
| Nurse 3 | Busy (%) | - | - | 39,87 |
| | Idle (%) | - | - | 55,58 |
| | Transport (%) | - | - | 4,55 |
| | Utilization (%) | - | - | 44,42 |
| Medical assistant | Busy (%) | 27,00 | 38,79 | 40,16 |
| | Idle (%) / Transport (%) | 73,00 | 61,21 | 59,84 |
| Practitioner | Busy (%) | 30,31 | 39,76 | 41,36 |
| | Idle (%) / Transport (%) | 69,69 | 60,24 | 58,64 |
| Percentage of completion | | 27.27 % | 86.36 % | 100.00 % |

### 2.5. Conclusion

The key issue for the success of simulation studies of health care is careful formulation of the problem and the involvement of all stakeholders. It should be noted that the simulation of production systems can model data errors that lead to unexpected costs and poor performance. In health care, such errors can lead to loss of patients life. It is therefore not acceptable any space for errors in the design and application of medical simulation models. These limitations can be overcome only with the highest attention to detail and accuracy, as well as communication among all stakeholders. [26] In terms of improving health care systems we want to continue in using simulation and we want to focus on following areas: logistics [27], process quality, scheduling and planning, layout solutions, decision making, time reduction, storage and supply.

## 3. CASE STUDY NO.2

Emergency department (ED) is located at the University Hospital in Zilina and provides urgent medical care 24/7. Department has 3 rooms: internal medicine room, surgery room, traumatology room. During one shift, there are 3 doctors, 3 nurses and 2-3 medical assistants on ED. Medical staff is working on two shifts (7: 00 a.m. – 3: 30 p.m., 3:30 p.m. – 7: 00 a.m.) during the weekdays and 24 hour shifts during the weekend.

Department is visited by approximately 19,400 patients per year. Patients are initially classified and triaged by their level of acuity by 1-5 ESI index (Emergency Severity Index).

**The main problems [28]:**

- Overcrowding, caused by non-urgent patients.
- Long waiting times.
- High rate of LOS.

**The ED patient flow**

Doctors use standardized work and algorithms, for patients treatment. The treatment process in ED at University Hospital in Zilina consists of following steps [26]:

1. Arrival.
2. Triage.
3. Assessment (clinician).
4. The initial diagnosis and treatment.
5. Diagnostic Testing – radiology and biochemistry.
6. Evaluation of the results by doctor.
7. Discharge or admission.
8. Access to a hospital bed and admission by doctor.

### 3.1. Analysis of input data

In 2013, the ED was visited by 19,443 patients. Detailed analysis of patient arrival rates during year, months, days and hours are shown in Fig 14 and Fig 15.

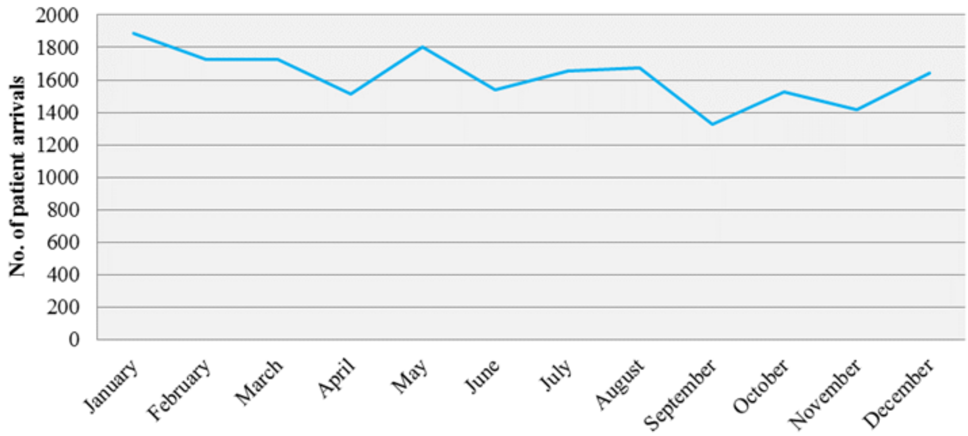



*Fig 14. Number of patient arrivals during months*

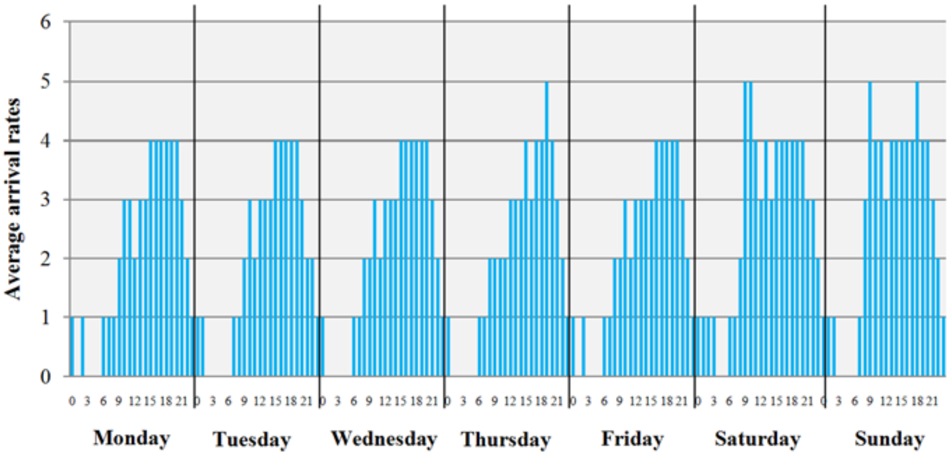



*Fig 15. Average number of patient arrivals during daily hours of the week*

We defined the arrival rates from the average daily arrival rates during the week (Tab 3).

*Tab 3. Patient average arrival rates*

| Hour interval | | Average patient arrivals | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Start | End | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | 2 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| 2 | 3 | 1 | 0 | 0 | 0 | 1 | 1 | 1 |
| 3 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 4 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 7 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
| 7 | 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 9 | 1 | 1 | 2 | 2 | 2 | 2 | 3 |
| 9 | 10 | 2 | 2 | 2 | 2 | 2 | 5 | 5 |
| 10 | 11 | 3 | 3 | 3 | 2 | 3 | 5 | 4 |
| 11 | 12 | 3 | 2 | 2 | 2 | 2 | 4 | 4 |
| 12 | 13 | 2 | 3 | 3 | 3 | 3 | 3 | 3 |
| 13 | 14 | 3 | 3 | 3 | 3 | 3 | 4 | 4 |
| 14 | 15 | 3 | 3 | 3 | 3 | 3 | 3 | 4 |
| 15 | 16 | 4 | 4 | 4 | 4 | 3 | 4 | 4 |
| 16 | 17 | 4 | 4 | 4 | 3 | 4 | 4 | 4 |
| 17 | 18 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 18 | 19 | 4 | 4 | 4 | 4 | 4 | 4 | 5 |
| 19 | 20 | 4 | 4 | 4 | 5 | 4 | 4 | 4 |
| 20 | 21 | 4 | 3 | 4 | 4 | 4 | 4 | 4 |
| 21 | 22 | 3 | 2 | 3 | 3 | 3 | 3 | 3 |
| 22 | 23 | 2 | 2 | 2 | 2 | 2 | 3 | 2 |
| 23 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 1 |

The composition and numbers of patients treated on ED are shown in Tab 4 and Tab 5. Patients arrive in ED irregularly in a given Mix, as shown in Tab 3. Patients are then classified by their acuity level, with the highest priority of acute patients and the lowest priority of the non-urgent [26].

*Tab 4. Patient acuity percentage structure*

| Type of patient | No. of patients in 2013 | Mix | Priority |
|---|---|---|---|
| Non-urgent | 6970 | 36 | 1 |
| Urgent | 9659 | 50 | 2 |
| Acute | 2814 | 14 | 3 |
| Sum | 19443 | 100 | - |

After triage is made, patients are divided according to their diagnosis into trauma, surgical and internal patient. Percentage structure is shown in Tab 5.

*Tab 5. Patient diagnosis percentage structure*

| | No. of patients in 2013 | Percentage |
|---|---|---|
| Trauma | 7113 | 36.6% |
| Surgical | 3827 | 19.7% |
| Internal | 8503 | 43.7% |
| Sum | 19443 | 100.0% |

After the triage, patients continue to one of ED rooms and then to external workplaces – Radiology and biochemistry. The duration of treatment at each workplace is shown in Tab 6.

*Tab 6. Treatment processing time*

| | | Type of patient | | |
|---|---|---|---|---|
| | | Acute | Urgent | Non-Urgent |
| Room | Trauma | Pert (1.02, 1.02, 5.93) | Pert (0.18, 0.18, 1.68) | Uniform (0.01, 0.17) |
| | Surgical | Pert (1.02, 1.02, 8.87) | Pert (0.18, 0.18, 1.70) | Uniform (0.03, 0.18) |
| | Internal | Pert (1.02, 1.02, 7.08) | Pert (0.18, 0.18, 1.71) | Uniform (0.01, 0.17) |
| | Radiology | Triangular (0.21,0.45,0.99) | Triangular (0.07,0.68,2.86) | - |
| | Biochemistry | Triangular (0.02,0.03,0.05) | | - |

## 3.2. Model settings

In this DataTable we set and assigned the Priority, Mix and treatment ProcessingTime of arriving entities (patients) at each workplace.

Patient_Data

| | Patient | Priority | Mix | Trauma (Hours) | Surgical (Hours) | Intern (Hours) | Radiology (Hours) |
|---|---|---|---|---|---|---|---|
| 1 | A | 3 | 14 | Random.Pert(1.02,1.02,5.93) | Random.Pert(1.02,1.02,8.87) | Random.Pert(1.02,1.02,7.08) | Random.Triangular(0.21,0.45,0.99) |
| 2 | N | 1 | 36 | Random.Uniform(0.01,0.17) | Random.Uniform(0.03,0.18) | Random.Uniform(0.01,0.17) | 0.0 |
| 3 | U | 2 | 50 | Random.Pert(0.18,0.18,1.68) | Random.Pert(0.18,0.18,1.70) | Random.Pert(0.18,0.18,1.71) | Random.Triangular(0.07,0.68,2.86) |
| 4 | V | 4 | 0 | Random.Triangular(0.17,0.2,0.23) | Random.Triangular(0.17,0.2,0.23) | Random.Triangular(0.17,0.2,0.23) | 0.0 |

*Fig 16. Processing time settings*

We set patients ArrivalRates by Rate Table (Fig 17), in which we assigned average patient arrival rates for each hour interval of the day (7 days). Triage process and patients result obtaining process we set by Processes that are shown in Fig 17.

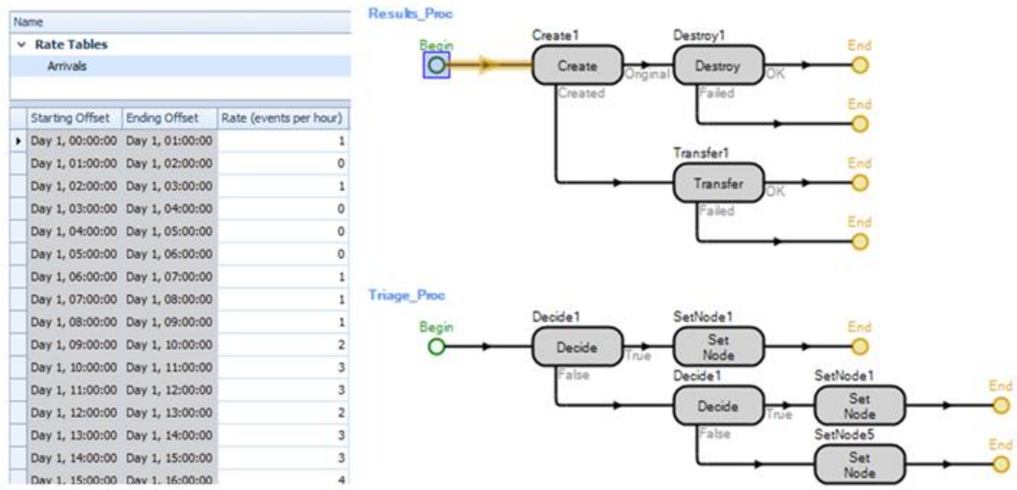
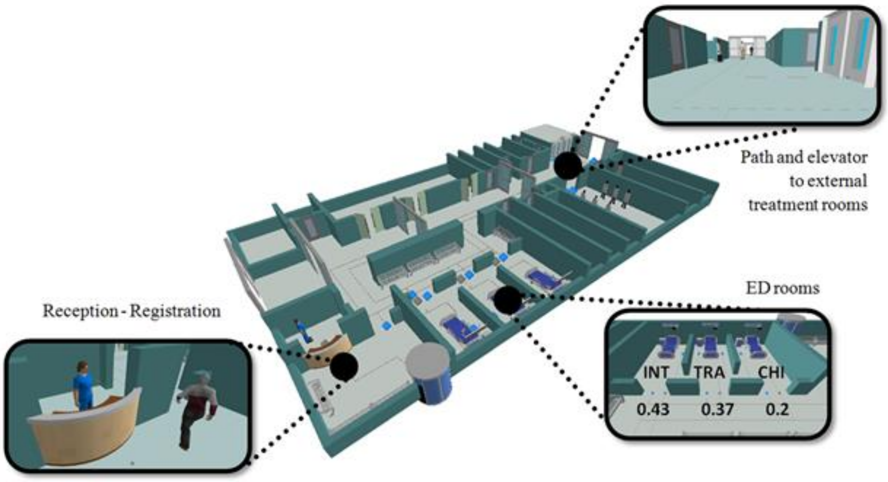



*Fig 17. Model logic processes settings*

### 3.3. Simulation model - Current state

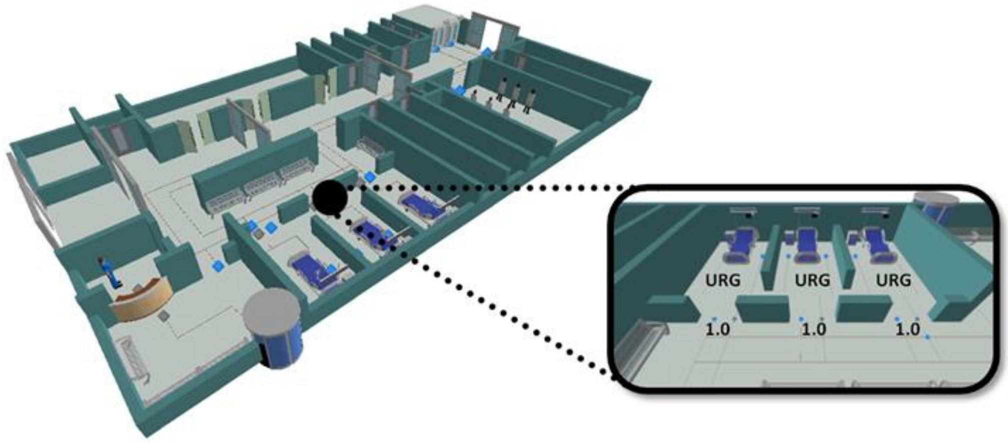



### 3.4. Simulated variants

The length of simulation run we set to 7 days (1 week) and we simulated current state and 3 improvements. The detailed description of each improvement can be found in following chapter.

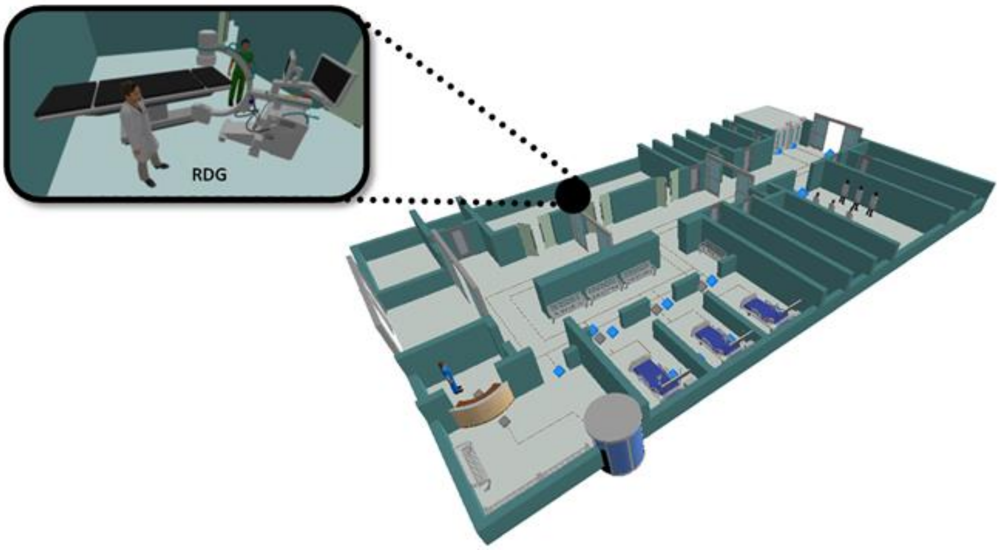
### 3.4.1. Improvement no. 1

Transformation of 3 specialized ED rooms into 3 equivalent urgent rooms. So the patients can be treated at any free room.



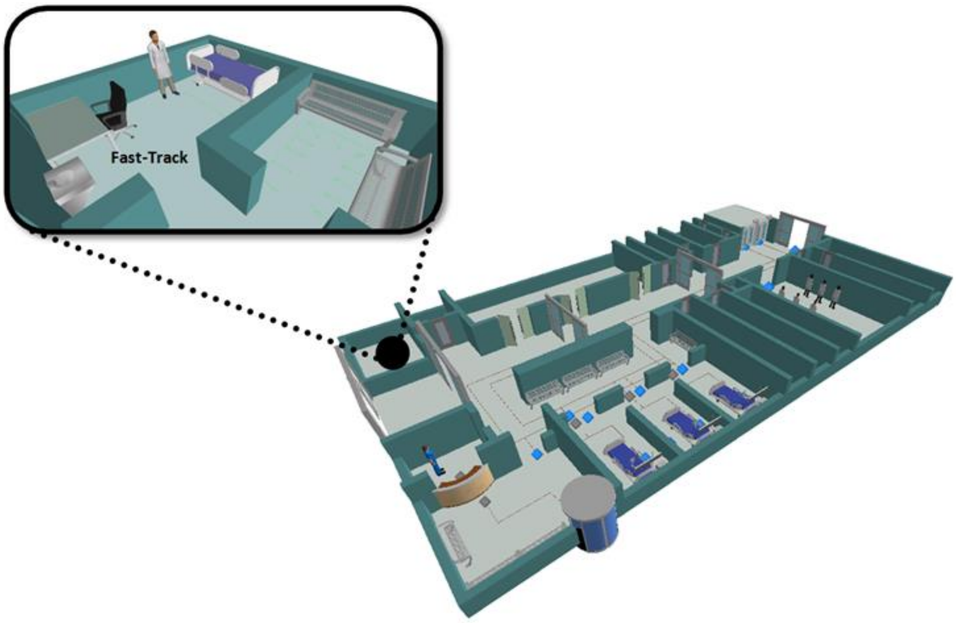

### 3.4.2. Improvement no. 2

Creating Radiology room in ED (C-arm). So the patients do not have to go to external workplace. They can be scanned on ED. (necessary additional personal resources: radiologist and nurse)



### 3.4.3. Improvement no. 3

Implementation of Fast-track. With this improvement, it would be possible to find out (by quick set of tests) if a given patient need to be treated in ED. ED will be then able to recognize non-urgent patients. These patients would be send home or to another hospital department, so ED will not be overcrowded in such rates. ( necessary: triage doctor / nurse).




## 3.5. Comparison of improvements

After the simulation, we got the results that are shown in Tab 7, Tab 8 and in charts. In the results we focused on these indicators:

- LOS (average).
- Utilization of ED rooms (%).

*Tab 7. Average LOS in ED (hours)*

| | Average LOS | | | |
|---|---|---|---|---|
| Patient Type | Current state | Improvement no.1 (URG) | Improvement no.2 (RAD) | Improvement no.3 (FT) |
| Acute | 4.06 | 4.2 | 3.76 | 2.33 |
| Urgent | 28.92 | 14.21 | 9.17 | 2.83 |
| Non-urgent | 1.64 | 0.93 | 1.77 | 2.26 |

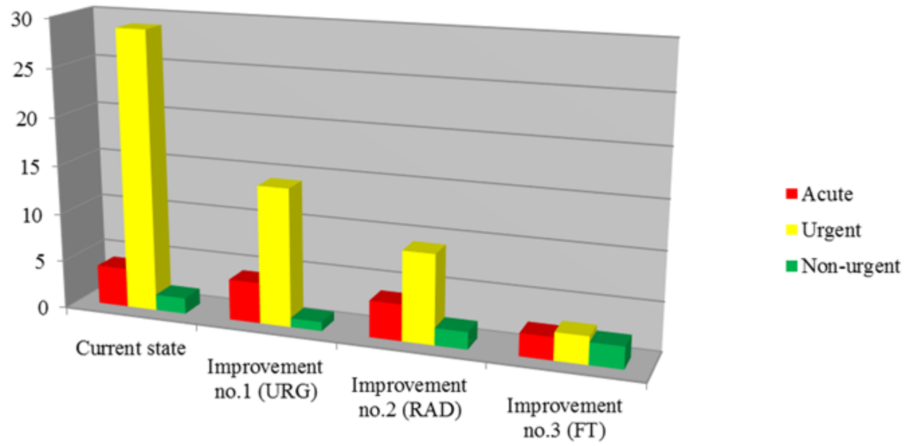



*Fig 18. Average length of stay of each type of patient in ED*

Despite the fact that the improvements were done only on one isolated departments (not in whole facility), we were able to eliminate steps that do not add value for patients. [29]

*Tab 8. Utilization of ED rooms*

| | Utilization | | | |
|---|---|---|---|---|
| ED Room | Current state | Improvement no.1 (URG) | Improvement no.2 (RAD) | Improvement no.3 (FT) |
| Trauma | 46.59% | 48.42% | 42.46% | 24.45% |
| Surgical | 37.19% | 38.26% | 31.23% | 20.98% |
| Intern | 52.96% | 39.78% | 46.44% | 35.34% |

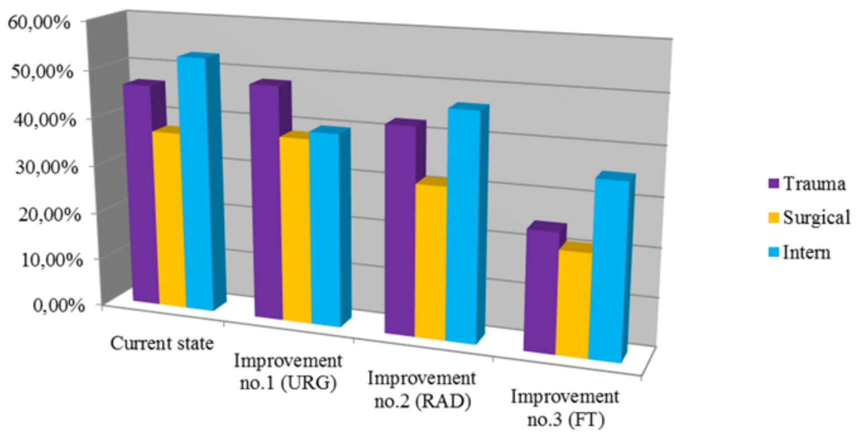



*Fig 19. Utilization of ED rooms in each improvement*

### 3.6. Results

From simulated variants we found out, that overcrowding and LOS in ED are directly caused by number of non-urgent patients and by length of treatment on external workplaces. First indicator, we were focusing on, was average LOS. When we look at the results, we can see that improvement that most reduced the average LOS, was the implementation of Fast Track. This improvement is not only reducing LOS but is also aligning LOS for each type of patient. The creation of Radiology room had also an positive impact on LOS but in lower rate. The second followed indicator was the utilization rate of ED rooms. The utilization rates, in comparison with the current state, were most reduced by Fast Track implementation. It means, that this improvement had double effect: Firstly, we were able to eliminate non-urgent patients from ED. Secondly, we managed to reduce the average LOS on ED. [26]

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*internal logistics, robotic systems*

Tomáš GREGOR*

# 8 SMART CONNECTED MOBILE ROBOTIC SYSTEMS

## 1. INTRODUCTION

The standard internal logistics, which provides for transfer and handling of the material in the production process, is an area burdened with high demands for manual labor. The most commonly used logistic means are handcarts or motorized carts, with high energy consumption and usually also high environmental costs. Conventional internal logistics is usually an origin of injuries. Such a logistics system usually doesn't suffice to ensure the logistic requirements of modern, automated factories, which results in the formation of bottlenecks, occurrence of delays in deliveries and formation of unplanned, unnecessarily high stock. [1]

One solution to this situation is the use of mobile robotic systems and automated logistics equipment for the reliable functioning of the internal logistics in the challenging conditions of factories of the future. Such solutions are referred to as Adaptive Logistics Systems (ALS), see. [2] It is estimated that by 2030 up to a half of European factories will be able to operate its own internal logistics with the use of autonomous mobile robotic systems. [3]

A new principle used in fulfilment of the future requirements of manufacturing and logistics systems is reconfigurability. There's plenty of publications introducing basics of this approach, e.g. [4], [5], [6], [7], [8], [9], [10]

Mobile autonomous platforms (MAP) and mobile robotic systems (MRS) are becoming an inseparable part of advanced logistics concepts. Standard control methods of such advanced logistics systems are being gradually replaced by new systems based on emergent properties. Entities of emergent systems must communicate with each other and based on this communication they have to make better informed decisions. Decision making requires real data from the system and its surroundings, but also experience, knowledge of the previous historical behavior of the system and its ability to learn from previous situations. These properties transform a simple piece of hardware into a smart product. To meet these requirements MRS and MAP both have to possess an autonomous capability for interconnection and communication. The forms and means of communication shall evolve progressively to the most sophisticated solutions. The development of information and communication technologies (ICT) allows the integration of various technologies into complex solutions, which is often referred to as the convergence of technologies. [11], [12]

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## 2. MOBILE AUTOMATED PLATFORMS

Mobile Automated Platforms are being formed alongside the lines of service robots. They're usually designed with support of, and operated by, open-source operating system for robotics called ROS (Robotic Operating system, www.ros.org). Specifically for the area of manufacturing, ROS provides an industrial platform (http://ros.industrial.org), which uses an interface based on HTTP-RPC technologies that allow for easy connection to various types of industrial networks and also provide a simple way to connect to the web.

MAP represents a class of humanoid robots specially developed for assistance in manufacturing operations. In Germany, a robotic system known as rob@work developed by IPA FhG, is becoming the standard in the automotive industry. Rob@work (Fig 1) is a new development platform based on the concept of IPA-Care-O-bot 3, which was originally developed for the area of industrial and household services.

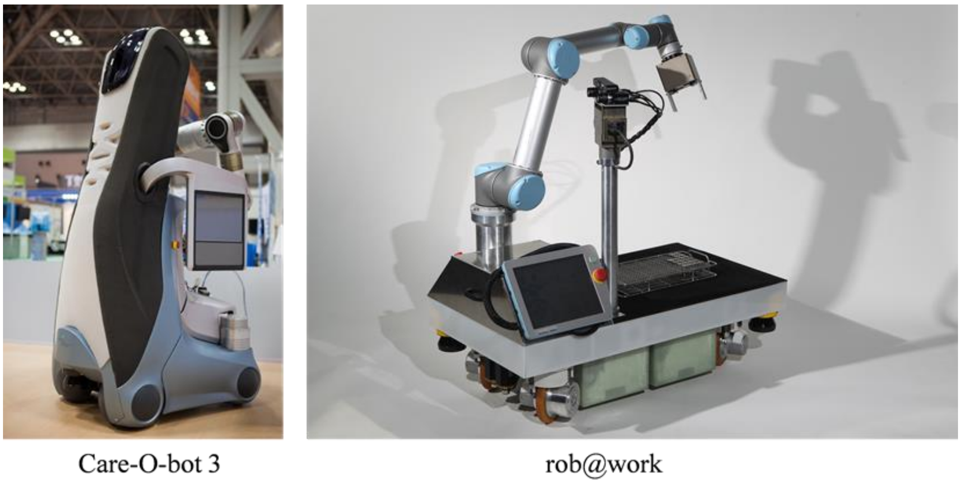


*Fig 1. O-Bot 3 a rob@work developed by IPA FhG [12]*

The development in this field is caused by the rapidly growing needs for robotic assistant solutions by the industry, as well as the fast development of cooperative robots (cobots), which are able to safely cooperate with humans and other devices implemented in manufacturing systems. [14]

It is estimated that within 20 years androids will be quite commonly deployed in industry and households. [15] Mobile manufacturing assistants support workers in the production process, have to communicate with them and therefore require a suitable interface for communication with a man (HMI – Human Machine Interface), such as Bosch APAS automatic work assistant, developed within the project PRACE (http://www.prace-ri.eu/), or the plug-and-produce solutions developed within PAN-Robots project (http://www.pan-robots.eu/).

CEIT technological reflector in the form of a hype curve (Fig 2) shows that MRS and MAP are nowadays getting into a very interesting area of development, as they are becoming a source of productivity growth, as opposed to being mere research topics. [16]

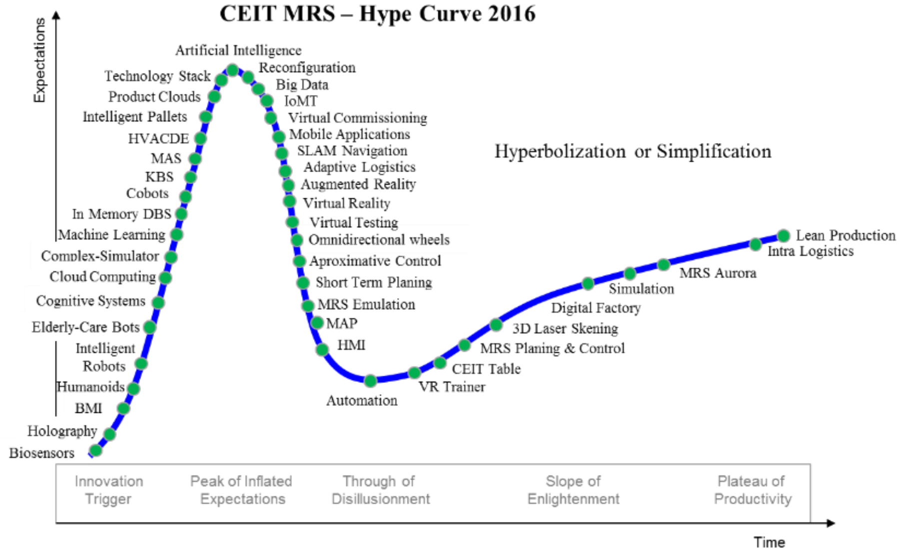


*Fig 2. CEIT Hype Curve – MRS and MAP position [17]*

CEIT Technology Reflector for MRS is shown in the Fig 3.

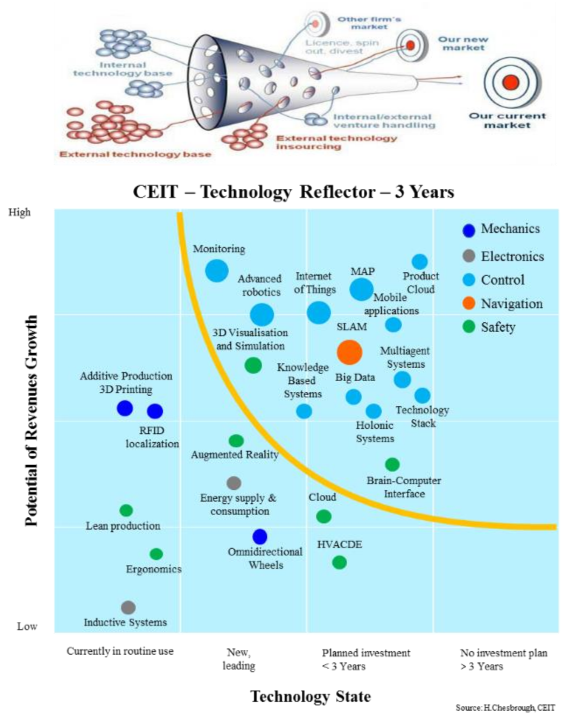


*Fig 3. CEIT Technology Reflector [17]*

## 3. MOBILE ROBOTIC SYSTEMS

Even though MRS solutions achieve rapid return on investment, the current MRSs are still in the early stages of development. Further development will certainly be very fast and it will be influenced mainly by progress of new digital technologies, artificial intelligence and software engineering.

Even today's solutions are based on the use of laser scanners to ensure safety. Systems of visual navigation, using the 3D video camera mounted directly on the MRS device in combination with an appropriate mapping system are fairly widespread in internal logistics.

New mapping systems are experiencing revolutionary development right now. Researchers have swiftly proceeded from complex theories to pragmatic solutions. The market now offers several innovative generations of mapping systems that are able to quickly map an unknown environment of the whole factory.

The newest hit in MRS solutions is the ability to see around the corner, which is especially interesting if the MRS is deployed outdoors. Another area of development is vision and perception located in the MRS. One of the challenges for researchers is the system for monitoring, visualization [18] and control of the entire internal logistics. In this field, the efforts are concentrated mainly on cooperative control systems, which are based on the principles used in holonic [19] and multi-agent systems.

There is a fundamental need for standardization of MRS and MAP solutions in the automotive industry. This involves the aspect of hardware design (modularity, reconfigurability, and so on), as well as software, sensors, navigation, control, interconnection to ERP, etc. The future development of mobile automated platforms [1] is shown in Fig 4.

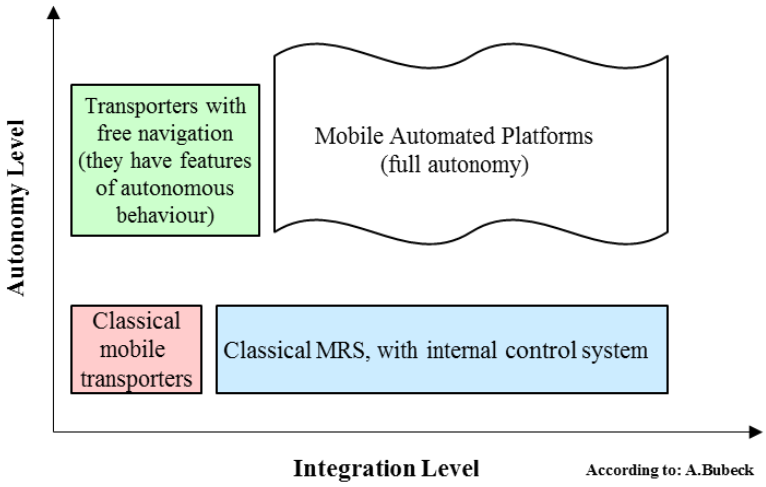


*Fig 4. Future development of MRS [17]*

The first versions of MRS systems were developed for one way movement. The newer solutions also allow bidirectional movement across the entire workplace, depending on the type of navigation. The trend right now is a universal mobile robotic platform, upon which various expansion devices can be installed (modularity). These expansions (such as robotic arms) can then work together to solve problems.

Sometimes we can even see the so called production assistants, which automatically travel to the place in production where they are needed most (e.g. bottleneck). When we are talking about MAP implementation, the requirement for autonomous behavior of the individual MRS devices increases significantly. In larger scale solutions, these systems behave as emergent systems, and the best way to manage them is by using multi-agent control systems based on intelligent agents as described in following. [20], [21], [22], [23], [24]

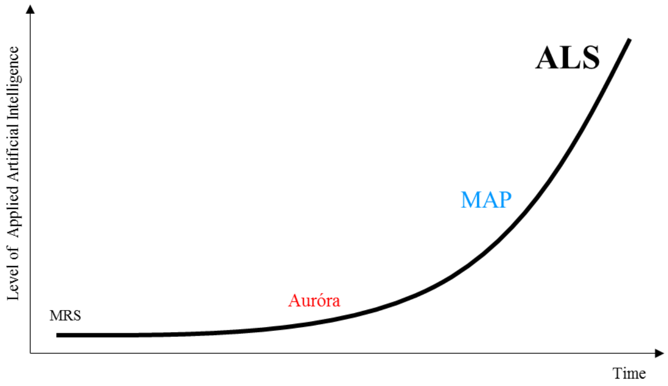


*Fig 5. Evolution of CEIT MRS [17]*

As shown in Fig 5, CEIT MRS Solutions are gradually progressing from relatively simple MRS systems, through the current Aurora phase, up to more complex mobile automated platforms, with the aim of a complex ALS system development.

### 3.1. Sensors

The MRS sensor system fulfils two main functions. The first of these is to monitor the external environment and to make decisions about external activities. The second one is to monitor the internal MRS environment (the neural system), which fulfils the tasks of controlling and decision-making concerning the internal MRS behavior.

2D laser scanners are employed in the role of the main safety component. Their purpose is to monitor that the MRS visual system has not entered a blind spot and also to ensure immediate identification of human presence or a barrier in its workspace and to communicate this information to the MRS control system, which either blocks the MRS, if necessary, or else moves around the barrier or the human.

Brand new 3D sensors have recently become available, which offer a nonconventional amount of spatial precision in identification and recognition of objects.

The rapid development and miniaturization of sensors leads to the availability of a vast assortment of sensor solutions, ranging from positioning and MRS localization, through measuring distance to other objects, measuring battery capacity, torque, to sensors able to detect whether the approaching object is a live, biological organism.

### 3.2. MRS Visual Systems

For visualization of the environment within which the MRS moves, stereo cameras with lenses known as fish eye are used. Cameras are placed at the top of the MRS and they enable

3D capturing of the environment and identification of possible barriers. These cameras have 360° vision and they are able to cover their entire surroundings. If these cameras are supplemented by laser scanners positioned at the crossroads of the MRS's routes, the MRS can see round the corner. Visual systems form a component of MRS navigation. The visual navigation solution from the Seegrid AGV Company (known as VGV – Visual Guided Vehicles, www.seegrid.com) has quickly spread over the US market. It uses patents of prof. H. Moravec from the MIT. Within the EU new visual navigation systems have been emerging on the market as a result of European research.

### 3.3. Navigation

In the field of navigation a really rapid development has been going on. The solutions have gradually moved from inflexible navigation systems based on inductive guide wires built into the floor to more flexible magnetic tapes, which need to be stuck to the floor and finally to tapeless applications, which allow the MRS to move freely within the logistic system.

The standard navigation systems that allow free movement to the MRS have required identification tags (markers), which have usually been placed at visible places within the logistic system (walls, columns, structures). A moving MRS would identify such markers and use the information to determine its own position.

New MAP solutions require navigation, which does not have to undergo further adjustments, modifications and which is able to go function in a new environment directly. Such solutions cannot rely on any markers, these have to be replaced with natural (already existing) objects, such as columns, windows, fixed structures, paths, stationary machines and similar. Such objects are recognized by the navigation system and they are associated with predefined tags from a tag library defined in the workshop's CAD layout. This information is combined with further information from sensors, odometry, etc. All signals and information are then aggregated (data fusion) using probabilistic methods such as the Kalman filter, extended Kalman filter, or the Particle filter. [1]

Such systems usually operate in two steps. In the first step (the prediction step) the position of the MRS is estimated, using the previous position and the measurements from internal sensors (typically odometry). In the second step (the correction step) the obtained position is corrected using other, external sensor systems, such as a laser scanner.

The new navigation systems are based especially on the technology of self-localization and mapping SLAM (Simultaneous Localization & Mapping), which uses an entire range of basic approaches to localization and mapping. Their principal feature is the ability to plan movement freely (i.e. they are not restricted to predefined routes). The standard MRS "navigation" systems have usually used predefined routes (e.g. using inductive guide wires). Every layout change would then require a redefinition of the routes and also modifications to MRS control. New approaches utilizing the so-called grids, split up the entire reference system into a grid (a network) in which the MRS searches for the shortest path, using the classical approaches to finding the shortest path through a network (Floyd, Dijkstra, etc.). Such solutions have a number of advantages. For an instance they allow the MRS to avoid barriers and overloaded paths, to eliminate potential collisions with humans and so on. An example of such a solution has been described in. [15]

If the manufacturing system as a whole is being changed and the entire layout has to be modified, the existing static (fixed) reference objects (markers) are invalidated and therefore an alternative navigation principle has to be employed. SLAM can be a solution in precisely such situations. SLAM systems no longer require the placement of identification tags (reflectors, markers) throughout the workshop. These systems are instead able to automatically select natural objects, which are already located in the reference environment (walls, columns, machines, etc.) as identification objects. This allows automatic creation of new markers and simultaneous localization of the MRS within the environment, thus enabling the MRS to move through a previously unknown environment.

The entire system must function as a Plug-and-Play platform. That is, the MRS should be able to utilize all available forms of navigation and select the form which applies best to the current situation.

New navigation solutions, or visual navigation systems enable a substantial reduction of MRS energy costs in comparison with manual vehicles, commonly even a reduction of 50 %. The costs associated with MRS implementation are reduced by as much as 90 %.

### 3.4. MRS and the Convergence of Technologies

As shown in Fig 6 a rapid development of information and communication technologies has brought about technological convergence. This is also visible in the case of MRS. The classical technology, extended with the most recent components of automation and ICT solutions (sensors, effectors, artificial intelligence etc.) have converged and they are giving rise to new technologies – the so called converged technologies.

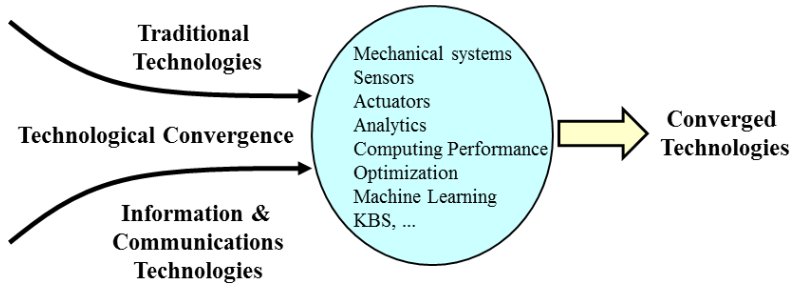


*Fig 6. Technological convergence [25]*

Extending the basic mechanical and electronical functions of the MRS with components of intelligence leads to the creation of smart products. Utilization of smart products creates the conditions for the improvement of the entire logistic chain. The MRS, as a fully connected product, is thus becoming a part of larger systems. It therefore has to provide support for fast connection and immediate operation (plug and produce), rapid reconfiguration (change of capacity and functionality), the ability to directly communicate with the remaining entities of the logistic system and also the ability to make decisions and optimize its behavior according to the immediate situation. [26]

### 3.5. MRS as a Smart Connected Product

Intelligent (smart), connected products are products whose basic hardware and software components are extended with components of intelligence and the ability to communicate, as shown in Fig 7.

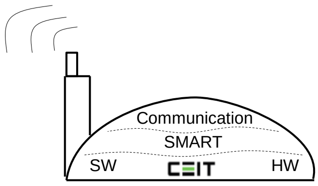


*Fig 7. MRS – smart connected product [25]*

Such products must have a set of new features and functions, starting with the ability to monitor their own state, and to use this information to control their own actions and to optimize them. These extensions also include autonomous behavior and the ability to quickly and easily change capacities and functionality (reconfiguration capabilities). This development is displayed in Fig 8.

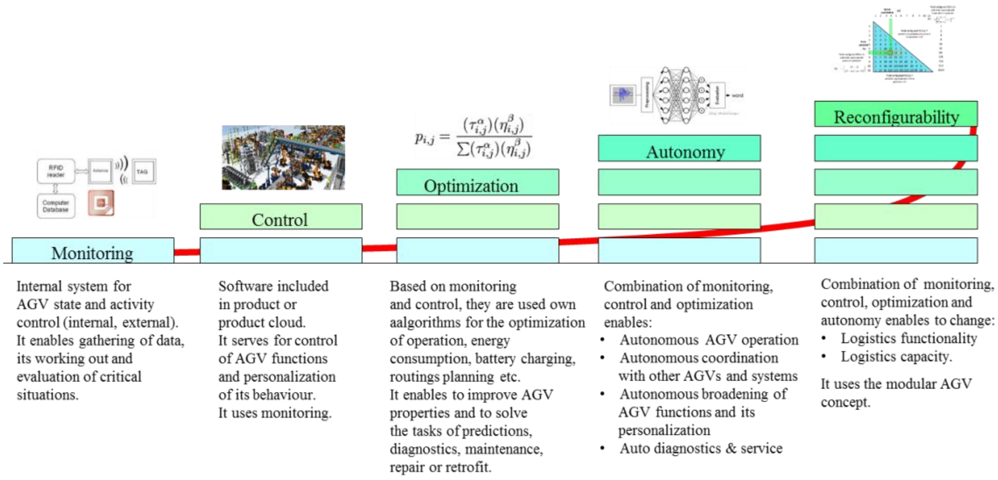


*Fig 8. Development of new features associated with connected product [25]*

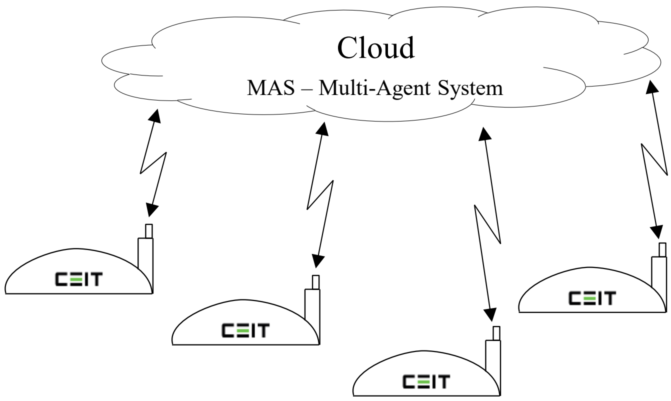


*Fig 9. Multi-agent MRS control system [25]*

Autonomy requires the ability of an individual MRS to react to emergent requirements. This requires a different way of controlling the activities of the logistic system (in comparison to the classical push system). The concept of agents and multi-agent systems (MAS) has emerged as the most suitable alternative. A set of smart connected MRS enables the use of multi-agent control system, as shown in Fig 9.

### 3.6. Forms of interconnectivity in the smart products

The interconnectivity used in CEIT MRS has multiple forms and its development is illustrated in Fig 10.

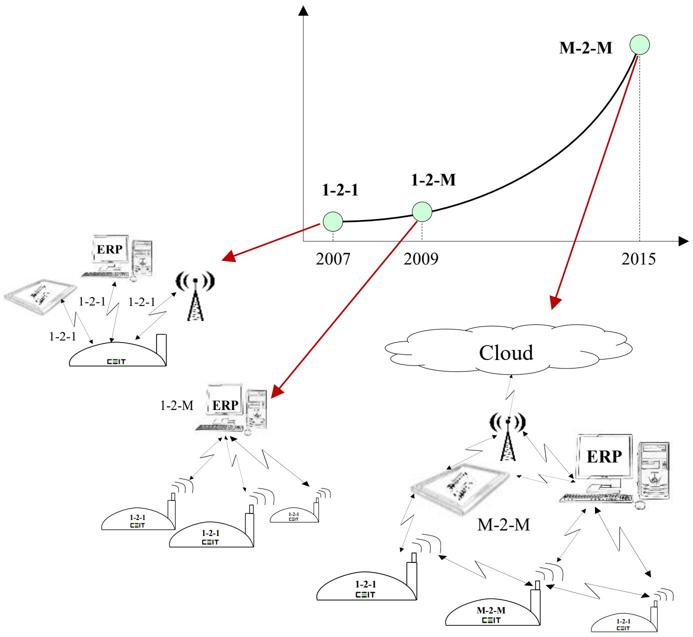


*Fig 10. Development of various connectivity forms of CEIT smart MRS systems [25]*

The first versions of CEIT MRS Connectivity were developed on the basis of direct connection of one individual MRS device to another device (communication, data collection) or to a control system (one-to-one). MRS was connected to other devices via a dedicated communication line, as outlined in Fig 11.

In 2009 the one-to-one connection was replaced by a new system, where all the devices were connected to one central logistics control system (one-to-many). Fig 12 demonstrates this method of connecting the devices and its obvious advantages (centralization, simplification of communication complexity and decision making).

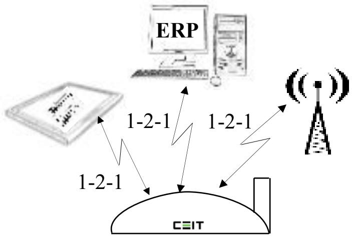


*Fig 11. One-to-one MRS connection [25]*

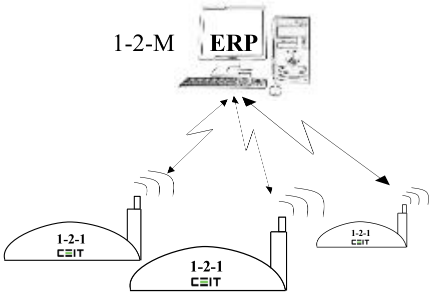


*Fig 12. One-to-many MRS connection [25]*

In the first quarter of 2016 the development of a new connection system, in which each MRS device will be able to autonomously and directly communicate with other devices, was finished (many-to-many). This way of connectivity was allowed by the development of mobile virtual sensor networks. The many-to-many type of connection (Fig 13) fully meets the requirements of emergent logistic systems.

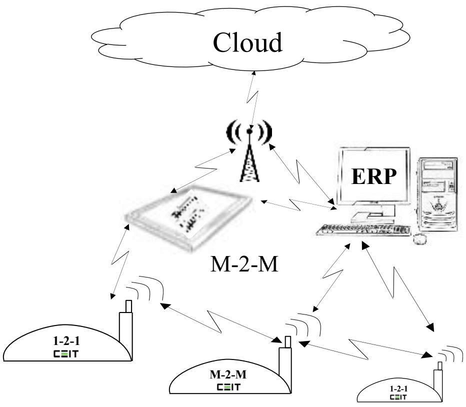


*Fig 13. Many-to-many MRS connection [25]*

Thanks to the development of new smart connected solutions concepts, hybrid forms of interconnection, which integrate several basic ways of linking the smart products, are emerging (Fig 14).

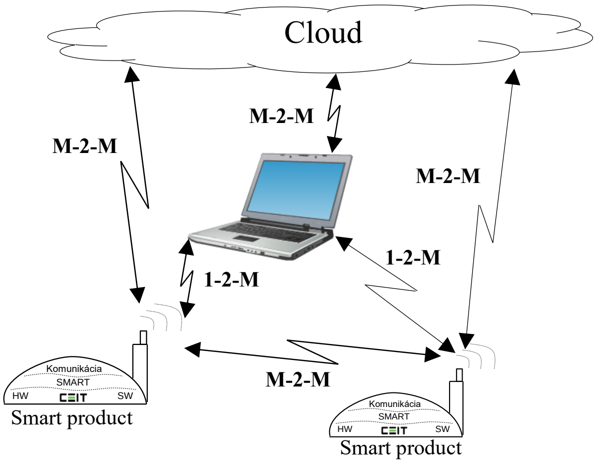


*Fig 14. Hybrid forms of MRS interconnection [25]*

### 3.7. Cloud MRS

The development in the area of ICT has brought significant, positive changes to the field of MRS in recent years. All data on the deployment of MRS (Fig 15) now exists in digital form (birth certificate of the product, product card, service book, etc.).

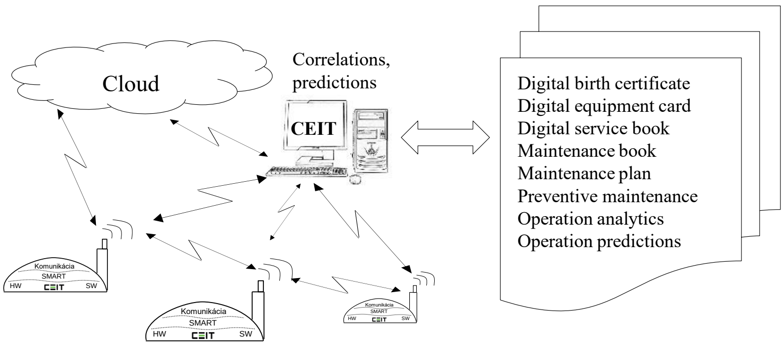


*Fig 15. MRSs working in cloud [25]*

Cloud technology allows for sharing of the information with all the other elements of the logistics system, production management system or ERP system.

### 3.8. CEIT Technology Stack

The term CEIT MRS Technology Stack (CEIT_MRS_TS) refers to a non-traditional way of organization and use of technology, which was made possible by new ICTs (cloud, IoT). Technology stack means combining individual technologies into an integrated unit that is available to the user as a technology package. Technology stack then represents such a way of organization and use of technology, in which the designer of the system continuously builds the system and makes it available to the customer. The customer on the other hand selects and uses all the appropriate technologies based on the actual demand. CEIT transforms its smart MRS into a smart connected product, which requires a whole new technological infrastructure. The technological infrastructure consists of several layers (levels), which are known as CEIT_MRS_TS.

An example of such a three-layer structure is shown in Fig 16.

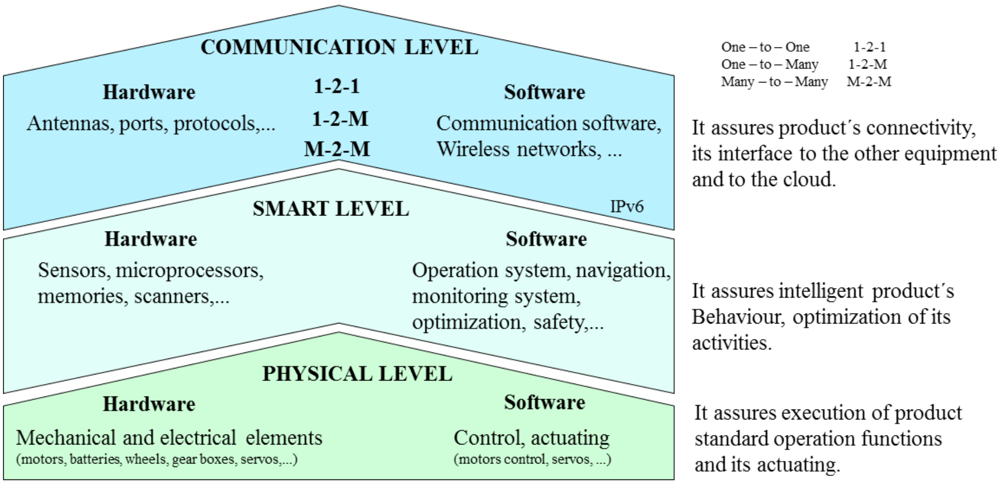


*Fig 16. CEIT_MRS_TS structure [25]*

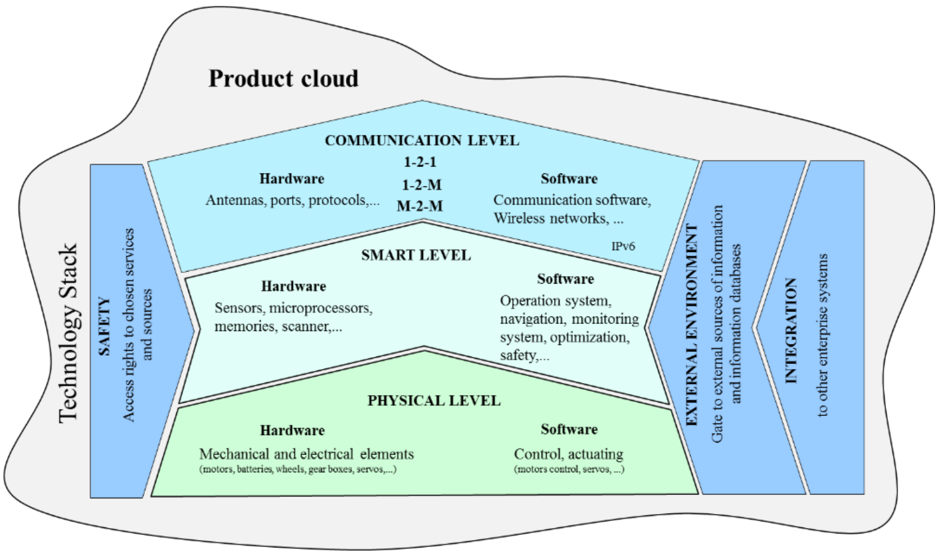


*Fig 17. Product cloud [25]*

MRS becomes a smart connected product which communicates with its environment. CEIT_MRS_TS consists of hardware, software and its own operating system (as a part of the truck), communication system (today its radio communication) and so called product cloud (running on the clients' server or a public cloud). Product cloud (Fig 17) contains a product database, platform for creation of software applications, rules mechanism, platform for analyses and its own smart product applications. Product cloud isn't embedded in product itself, but it forms an independent part of the whole system. All the data is stored in cloud and the whole communication runs through the cloud.

This new technology enables the formation of an environment that provides all the right conditions for a very swift implementation of innovations. Besides that, it allows to collect huge amounts of data about the product and its surroundings, which become a source for detailed analyses and optimizations of MRS operation as well as of the entire logistics system. The development of CEIT_MRS_TS requires significant investments and completely new knowledge and skills (systems engineering, AI, software engineering, sensor technology, big data, KBS, data analysis, security of ICT, etc.). Such capabilities and skills are rarely found in today's consumer industry. This makes room for new services that can be offered by CEIT to the industry, but it requires a change in the business model. An example of such a new business model is show in Fig 18.

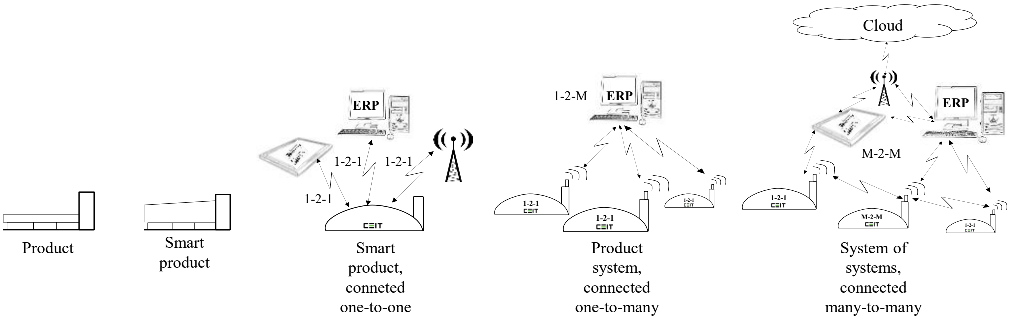


*Fig 18. New business model of CEIT MRS [25]*

The new business model brings different business processes into CEIT, in which new value for the customer is formed mainly by access to useful data. These can be further processed, analyzed and used for prediction. The gradual development brings higher-quality solutions (Fig 19), where the physical product provides the basic service (e.g. material supply), but most of the added value is generated through new functionality (software, maintenance, data, knowledge) which is usually offered as a service.

As it turns out, this approach is becoming the standard and most of the new system developers are taking it into account even in the early stages of smart connected products development.

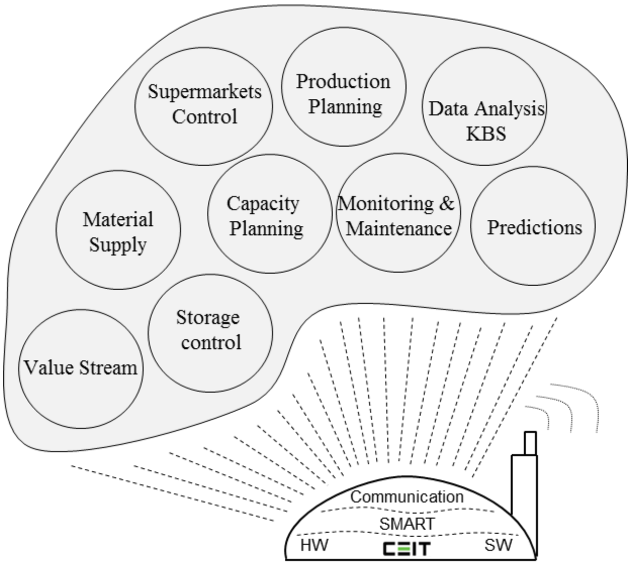


*Fig 19. Extended smart product and new value creation [25]*

### 3.9. CEIT Logistics Solutions

CEIT started to develop AGVs based on the requirements of automotive industry, in co-operation with VW Group. Fig 20 shows the principle of this logistics solution in automotive industry. The logistics solution utilizes automatic identification of AGV location, its own monitoring and control system, which is integrated to the production planning and control system. [27]


*Fig 20. CEIT Logistics Concept [28]*

CEIT Aurora program found its application mainly in automotive and electronics industries. In regard to its complexity it was used mainly for the solution of the most complicated logistics tasks. An example is its application for adaptive intra logistics connecting all important parts of value chain – press department, welding, painting and assembly in VW Slovakia (Fig 21).

*Fig 21. CEIT AGVs in VW Slovakia [28]*

Implementation of the Aurora system in automotive industry in Skoda Auto Mladá Boleslav (CZ) is shown in Fig 22.

*Fig 22. CEIT Aurora in Skoda Auto Intra-Logistics [28]*

## 3.10. Logistics Innovations in CEIT

The example of an innovative development using the advanced technologies of Internet of Things is an autonomous logistics system being developed in the framework of ZIMS project (Zilina Intelligent Manufacturing Systems). ZIMS is the research project (and the name of a laboratory) currently conducted in co-operation of the Central European Institute of Technology and the University of Zilina. [29], [16] ZIMS uses Aurora autonomous logistics AGVs shown in Fig 23.

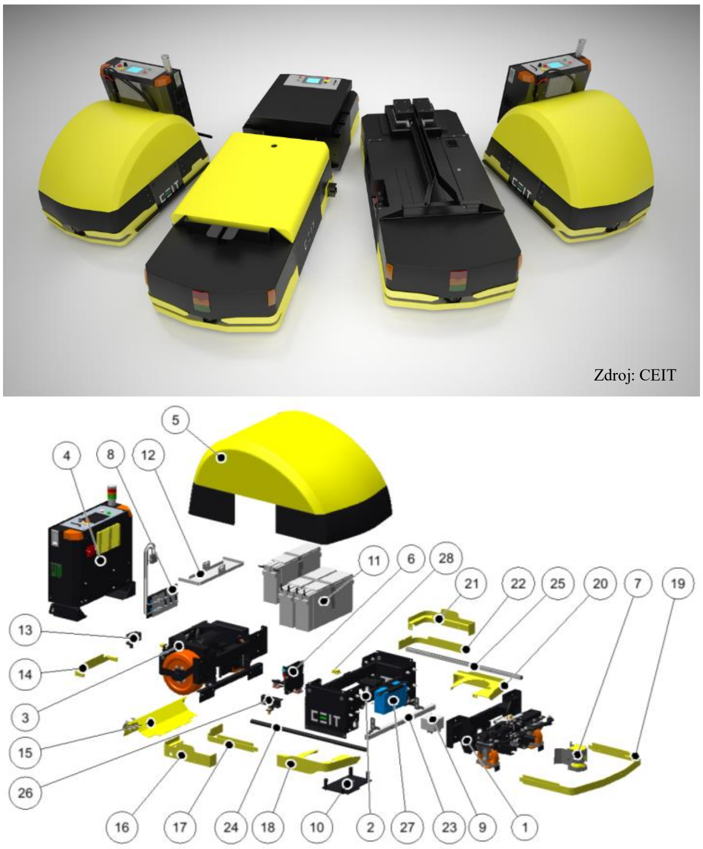


*Fig 23. Logistics AGVs from Aurora Program [28]*

### Modular Concept of AGV

As shown in Fig 24 the concept of CEIT AGV is modular. The modularity enables quick reconfigurability of the AGV system, in case of customer requirements.

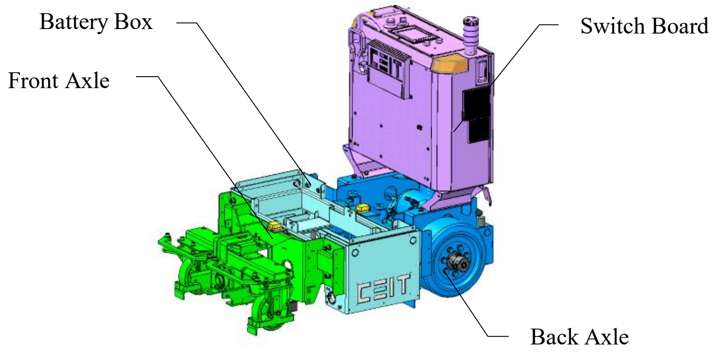


*Fig 24. Modular AGV´s Concept*

The single modules offer many options in creation of final product configurations (Fig 25).


*Fig 25. AGV´s Enhancing Modules Example*

This concept offers many possibilities for AGV´s functionalities enhancement, e.g. utilisation of hydraulics or pneumatics functions for AGV peripherals as shown in Fig 26.

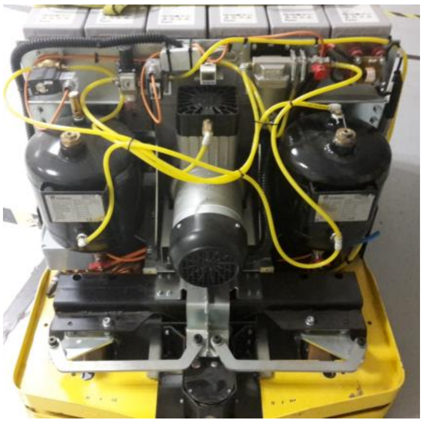

*Fig 26. AGV´s Pneumatics Functionality*

The AGV´s pneumatics enables it to control the functions of peripherals (e.g. C-Frame) as it is shown in Fig 27.

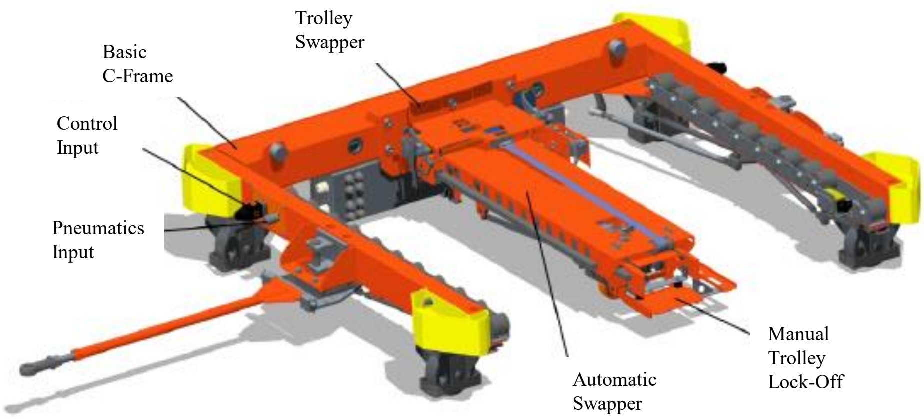


*Fig 27. Pneumatically Operated C-Frame*

AGVs navigation is the matter of a long term research. Many alternative approaches to AGV navigation are known. Among the most advantageous and practical definitely belongs visual and laser navigation (Fig 28).

AGV´s navigation enables vehicles to identify their current position. This information is used for AGV´s path planning and routing. The part of navigation systems is a Map Editor which enables user to simply design and edit an appropriate path network.

Laser navigation significantly simplifies ram up phase of AGVs implementation in industrial applications.

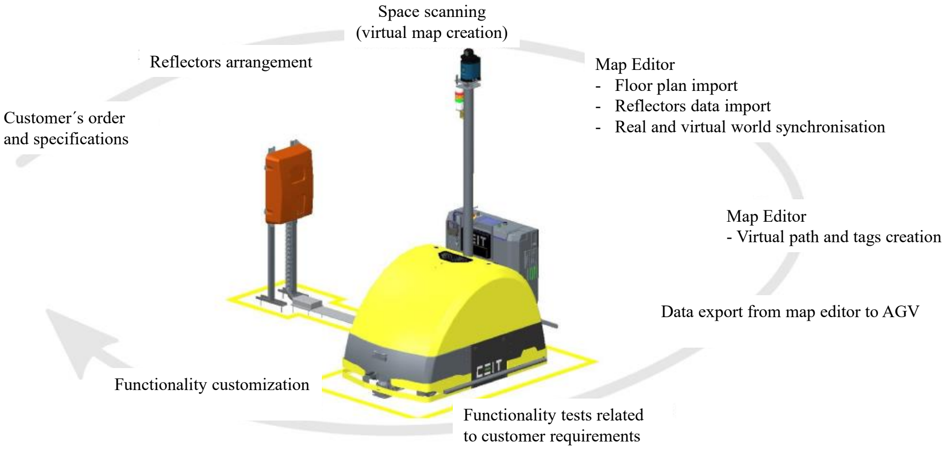


*Fig 28. AGV´s Laser Navigation*

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*multi-agent systems, AGV*

Lukáš ĎURICA, Vladimíra BIŇASOVÁ*

# 9 BIO-INSPIRED MANUFACTURING MULTI-AGENT SYSTEM FOR CONTROL AND COORDINATION OF AGV GUIDED BY MAGNETIC TAPE

## 1. INTRODUCTION

The international stance makes available such abstractions and know-how of agents, and the communications that place among them. These turn out to be important scientific abstractions for multi-agent systems. These abstractions no doubt have much conceptual appeal. Furthermore, there are simple pragmatic and technical reasons for considering them seriously. They are natural to humans, who are not only the designer and analysers of multi-agent systems, but also the end users and requirements specifiers and provide succinct description of, and help understand and explain, the behaviour of complex systems.

Multi-agent systems (MAS) have been applied to areas such as control, production planning, scheduling, resource allocation, vehicle routing, etc. [1] The advantage of such heterarchical architecture is the absence of superior unit, which in practice can be a single point of failure in the system. Individual agents communicate directly with each other. This allows scalability (no need to shut down production system in order to add or remove resources), increases flexibility, modularity and agility. [2]

The multi-agent system itself provides high fault-tolerance. A simple implementation of the control software ensures low maintenance needs [3] and transparency of the source code. The main disadvantage of heterarchical architecture is the phenomenon coming from emergent behaviour. The undesirable characteristics of emergence are, for example, the problem to achieve optimization and impossibility to predict future states of the system. [4]

## 2. MULTI-AGENT SYSTEMS IN INDUSTRIAL AUTOMATION

The current mass customization era requires increased flexibility and agility in the manufacturing systems to adapt changes in manufacturing requirements and environments. An ontology-based reconfiguration agent attempts to reconfigure the manufacturing system after realising changes in the requirements or the manufacturing environment. The benefit of approach is minimizing the overheads of the reconfiguration process by achieving rapid reconfiguration with minimum human intervention. [5] The agent uses ontological knowledge of the manufacturing environment for the purpose of reconfiguration without human

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intervention. The current mass customization era requires increased flexibility and agility in the manufacturing systems to adapt changes in manufacturing requirements and environments. [6] Ontologies play important role in knowledge sharing and exploration, particularly in communication in multi-agent systems. [7]

Sustainable production can be defined as production and use of products and services in a manner that is socially beneficial, economically viable and environmentally benign over whole product life cycle. [8], [9], [10]

The globalized economy is strongly influenced not only by economic cycles but also a rapid change in customer behaviour, which result in turbulences. [8], [11]

In the last two decades, the attention of experts is focused especially to a holonic and multi-agent manufacturing systems. [12]

The solution seems to be used the semi-heterarchical architecture, introducing hierarchies into the heterarchies [13], [14] propose a semi-heterarchical architecture composed by a supervisor (S) and subordinate decisional entities (E). In this approach, simulation-optimization mechanisms are used to reduce the subordinates' myopic behaviour. Semi-heterarchical architectures can merge the benefits of hierarchy in terms of global performance and heterarchy in terms of reactivity, adaptability and fault tolerance. [15]

Heterarchical control architectures are essentially founded on cooperation and full local autonomy, resulting in high reactivity, no master/slave relationships and local information retention. [16]

The current semi-hierarchical approaches propose structural changes, which are closer to the hierarchy as heterarchy. However, heterarchical architecture is not completely lost; the disadvantages of hierarchy overshadow the advantages of heterarchical principles. [17] Although heterarchical architectures have many advantages, they were rarely implemented due to the weaknesses. [18]

A possible solution to this problem is implementation of tools that allow adjusting the degree of autonomy of subordinate control units to the architecture, also controlling the temporal and social myopia and creating of dynamic semi-heterarchical control architecture.

Swarm Intelligence [19] can be used to eliminate some of the previously mentioned negative characteristics (derived from heterarchical architectures, multi-agent systems, lack of adaptability, etc.), using indirect pheromone-based communication.

The global market are imposing strong changing conditions for companies running their businesses, something comprising complex and large scale systems. [20], [21] Agent systems were introduced in automation and manufacturing when there was the vision of having distributable software components to resolve local tasks, comparable to the heterogeneous nature of the physical domain. Existing models of production, such as Flexible Manufacturing Systems (FMS) [22], Reconfigurable Manufacturing Systems (RMS) [23], [24], [25] is a basis for the application of multi-agent systems to solve and optimize the problems of production, due to the increase of introduced complexity. Among the several publications reporting the application of MAS in automation and production systems, the reader can consult the reference [26] to retrieve more information on this topic. [27]

The benefits of agent-based industrial systems are robustness, scalability, reconfigurability and productivity, which are transformed to a greater competitive advantage.

Multi-agents systems is pointed out as a suitable approach to address this challenge by offering an alternative way to design control systems, based on the decentralization of control functions over distributed autonomous and cooperative entities. However, in spite of their enormous potential, they usually lack some aspects related to interoperability, optimization in decentralized structures and truly self-adaptation. [28]

Product-driven control may enable manufacturing companies to meet business demands more quickly and effectively. But a key point in making this concept acceptable by industry is to provide benchmarking environments in order to compare and analyse their efficiency on emulated large-scale industry-led case studies with regard to current technologies and approaches. [29]

Lepuschitz [30] proposed the overview of the ontologies and their suitability for process automation domain and subdomains.

Leitao and Restivo [28] presents a holonic approach to manufacturing scheduling, where the scheduling functions are distributed by several entities, combining their calculation power and local optimization capability.

In Hsieh [31], the author defined a holarchy formation problem to lay a foundation to propose models and develop collaborative algorithms to guide the holons to form a holarchy that coherently moves toward the desired goal state with minimal costs.

Industrial requirements have clearly evolved from the traditional performance criteria, described in terms of static optimality or near-optimality, towards new performance criteria, described in terms of reactivity, adaptability and visibility. A growing number of industrialists now want control systems that provide satisfactory, adaptable and robust solutions rather than optimal solutions that require several hard assumptions to be met. [32], [33], [18]

## 3. CODESA-PRIME

### 3.1. Brief characteristic of CODESA-Prime

This section will briefly characterize the various technologies used in CODESA. CODESA is the reference technological model, suitable for directing and coordinating of decentralized systems. The application of this technological structure is possible in domains where control of non-linear, heterarchical, large-scale systems in dynamic, heterogeneous and unpredictable environment is needed [34]. The main characteristics of CODESA are:

- Fault tolerance (MAS, Swarm Intelligence, etc.).
- High level of modularity and reconfigurability (MAS, Service-oriented Architecture – SOA, Internet of Things - IoT).
- Enhanced interoperability (Domain ontology, SOA),
- Fast processing and storing large amounts of data (CLOUD, IoT).
- Autonomous and intelligent behaviour (MAS, Swarm Intelligence).
- The ability to predict future conditions, and proactively react (Swarm Intelligence).
- Adaptation of system and techniques of Bionic layer (Evolutionary Computing).
- Use of dual communication: (direct - modified CNP protocol and indirect - based on pheromones in a virtual environment (Software Platform, Swarm Intelligence), etc.

### 3.2. Proposal of logistics system CODESA-Prime

CODESA-Prime is a concrete application of framework CODESA in the manufacturing domain. Using technological structure designed for production management application domain CODESA-Prime, it is possible to manage manufacturing processes of planning, scheduling, routing product, mobile agents routing, and inventory management through optimization and prediction system [34]. The main part of CODESA-Prime is a multi-agent system. CODESA-Prime features of holonic terms are divided into five control levels:

- The first control level - looking for free capacities of production and logistics resources through intelligent agent's orders.
- The second control level - the routing of intelligent product [35], agent across production resources.
- The third control level - the routing of intelligent product agent across the logistics resources. [36]
- The fourth control level - the control and coordination systems through AGV path.
- The fifth control level - the control model, graphical representation, and physical models.

This part of paper is focused on the fourth and the fifth control level.

### 3.3. The fourth control level

The fourth holonic level performs function of control, coordination of holonic agent AGV searching and booking of paths to the target point. This level includes the following entities:

- Meta-scheme of AGV path.
- AGV path.
- Node.
- Segment.
- Intelligent Segment Agent – ISA.
- Logical segment.
- Critical logical segment.
- Avatar representing agent of AGV.
- Ant-agents of exploration colony.
- Ant-agents of information colony.
- Ant-agents of reservation colony.
- Pheromone container.

#### 3.3.1. Meta-scheme of AGV path and AGV path

One of the fundamental aspects of this level is the meta-scheme of AGV tracks. It is a reflection of the model paths from the fifth control level, represented by an oriented and evaluated graph that contains vertices (nodes) and edges (segments). Into meta-scheme can be inserted digital pheromones. The meta-scheme updates their intensity value, but also can modify their content.

AGV path is a part of meta-scheme composed of several nodes and segments. The concept of AGV path is typically used as an indication of the direction of individual entities through nodes and segments.

#### 3.3.2. Node

Nodes in the meta-scheme may be located at crossroads, but also outside them, while they distribute part of AGV path to the individual segments. The node is the inactive entity. It does not have decision-making capacity; therefore it is not represented by agents. The crossroad is the type of to which they are connected more than two segments.

Each node has a unique global identifier in AGV path, which is a non-negative integer. Each node is defined by the position - the point in the virtual 3D space. The nodes also include a list of all segments that are attached to them (i.e. they contain initial or end coordinates (position data) with the position of the node in space). The nodes comprise the pheromone container. [36]

#### 3.3.3. Segment

A segment is defined by two nodes in the virtual space. It has a unique ID (like a node) that is non-negative number. The segment can be extended by assigning a weight.
The segment has an indicative nature and that may be:

- Directed both directions.
- Directed from its beginning to its end.
- Directed from its end to its beginning.
- Undirected (i.e. it is not possible to navigate in any direction, generally performs a different function).

In the multi-agent system is a segment or group of segments represented by an intelligent segment agent (ISA).

#### 3.3.4. Intelligent segment agent – ISA

Intelligent segment agent (ISA) offers a service of running over his physical part (ie. its model). Unlike the node, ISA can communicate with other agents (through direct or indirect communication) in order to authorized crossing. ISA owns AGV crossings schedule.

In the case of indirect communication, this time is represented by pheromone container, which are stored reservation pheromones to allocate certain time slot (time slot) of AGV crossing.

#### 3.3.5. Logical segment

Logical segment is composed of more than one segment. Logical segment creates an intelligent segment agent and it shall not be less than the size of holonic agent AGV (including safety sensor). This means that the AGV can occupy two segments at a time, but in no case three segments.

Logical segment is mostly generated, if it follows consecutively more segments without crossroad. It is also used in areas where the AGV stops for a purpose. In this case, the logical segment is also created with segments connected to the crossroad.

#### 3.3.6. Critical logical segment

Critical logical segment is a critical type of segment that connects two nodes, and between the nodes there is no other path. These segments are defined by the user in the design of meta-scheme. All critical segments in paths must be reserved in chronological order. Holonic agent AGV found on this type of segment have the maximum priority for the next segment that is critical for the output from the logical segment. [36]

### 3.3.7. Avatar

Avatar is the representative of AGV agent on this holonic level of control and coordination of direct and indirect communication. Its function is searching and booking of the path to selected destination, while it communicates with the intelligent segment agents.

In the case of indirect communication is his task creating ant colonies, setting their properties (number of ants in one colony, the maximum number of passes through nodes - hops, ID colonies, etc.) and informing of agent about their results. Avatar does not have decision-making capacity. Unlike the agent, avatar can relocate at any point on meta-scheme. This feature is used when the AGV agent already has a path to the desired objectives and the selected one of the avatars it cyclically reserves, while the agent has additional transport requirements. In this case, the agent creates another avatar, which will move to where the holonic agent AGV ends the current path and through ant colonies books next path. Another use case for properties of the reverse is by the collection of information from ant-agents that have completed their life cycle. One AGV Agent can have multiple avatars.

In the event of termination of life cycle of the ant-agent agent (task completed or task failed), the avatar (who stood for the birth of his colonies) is moved to the place where extracted from ant necessary information concerning the path and in addition the pheromone on the success of tasks and possibly and because of its failure to fulfil. The information transmitted to AGV agent, which is also based on them firmly committed to another intention. [35]

### 3.3.8. Ant colonies

Due to the minimization of computational complexity, ant-agent can in every step only perform one of the following actions:

- Omit one step (ant-agent remains idle) (IDLE).
- Movement in the desired direction at a defined speed and collection of information about the path which pass through (MOVE_AND_GATHER).
- Insert pheromone (LAY_PHEROMONE).
- Observe already submitted pheromones (OBSERVE_PHEROMONES).
- Modify already created pheromones (MODIFY_PHEROMONE) and.
- Delete pheromones (WIPE_OFF_PHEROMONE). [36]

Ant-agent may be present in only one state of their life cycle:

- IDLE.
- MOVING_AND_GATHER.
- ARRIVING_AT_NODE.
- AT_NODE.
- LEAVING_NODE.
- ENTERING_SEGMENT.
- TASK_COMPLETED and.
- TASK_FAILED.

Inserting of pheromone is generally carried out in the state at node or in the state entering segment. If he is unable to complete its task, ant releases pheromone to the environment and with a short report containing justification why could not accomplish the desired task:

- NO_HOPS_LEFT.
- IMPASSE.
- PHEROMONE_NOT_FOUND.
- RESERVATION_IMPOSSIBLE.

Number of ant-agents in the colony, their service life (number of hops, respectively length of the life cycle), period of their creation is defined by agent that this information transmit to each of avatar.

The colonies are cyclically casted, and they travel through meta-scheme with several times higher speed than the actual holonic agent AGV. That means that any disturbances in conditions of the logistics system, the AGV agent has the necessary information in advance, and within reasonable timescales can change their decision.

Exploring ant colony (i.e. the information that is gathered and transmitted) is represented agent's beliefs in terms of BDI. Reservation colony represents agent's intentions in terms of BDI. [36]

### 3.3.9. Exploring ant colony of holonic agent AGV

Exploring ant colony of holonic agent AGV searches the meta-scheme in order to find specific segment or node, which its avatar agent of the holonic agent has selected. Each ant-agent in colony of the holonic agent carries its unique identifier that is composed of the following components:

- Unique name of AGV agent.
- A time stamp that is generated at the birth of ant colony.
- Unique identification of each individual (ant-agent) in the colony, which is represented by a non-negative integer and.
- Underscore between the mentioned part of the identifier.

Ant-agents store this identifier to each pheromone that is inserted into the environment. With this mechanism, the uniqueness of individual colonies and ant-agents is achieved. An example of a unique identifier of an ant colony is illustrated in Fig. 1. Using this generated mechanism is guaranteed by the uniqueness of the individual in a colony and each colony, and thus also the labelling of driven path.

The time stamp consisting of the date (yyyy-mon-dd) and time (hh: mm: ss.microsec). Time stamp granularity is in microseconds.

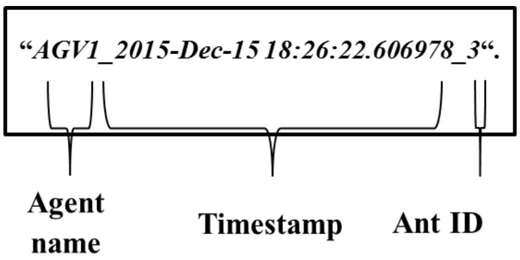


*Fig 1. The example of a unique identifier of an individual ant colony and also the pheromone of timestamp [36]*

Exploring ant-agents passing a meta-scheme can choose their way at random, or they may choose another direction (depending on user settings) by observing pheromones of the colony. Information about the path is recorded in each step:

- The total length of the path.
- The total travel time of a path.
- The cost of the path (from the valuation of individual segments).
- The earliest possible departure date of the holonic agent AGV.
- Additional custom information.

After passing the node the avatar extracts the pheromone giving information on the success of tasks, pheromone giving information on possible departure schedule, the total distance traveled and time from the ant-agent and the environment as well and forwards it to the avatar representing an intelligent agent segment. With every passing through the node the number of hops decrements.

Possible departure schedule pheromone contains reserved slots into which each intelligent agent segment shall pass information on the path by calculating the values of total distance traveled and the holonic agent speed of the ant-agent, thus giving information about the time it takes for the AGV to arrive. This time is then subtracted from the already reserved slots and then is passed to the possible departure schedule. Projecting time reservations of individual segments into the possible departure pheromone is shown in Fig 2. The ant with the updated pheromone goes on to the next segment until it finds the desired destination node, or until his life cycle ends. By sticking to this procedure it is possible to avoid inconveniences that may arise in the event that two holonic agents block each other. [36]

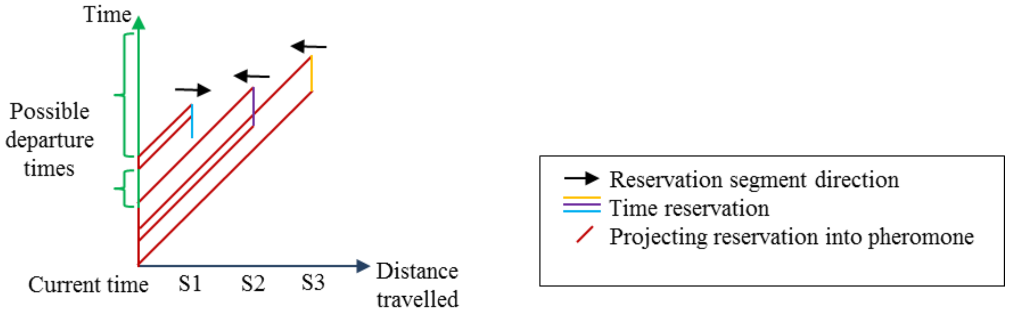


*Fig 2. Projecting time reservations of individual segments into the possible departure pheromone [34]*

### 3.3.10. Information ant colony of holonic agent AGV

After the holonic agent AGV agent decides which path to take based on information provided by the ant colony, the avatar sends out information colonies to inform intelligent segment agents of its decision. Ant colony responsible for conveying information usually consists of a single agent.

In the event the segment is already reserved, or another information colony having higher priority has passed through a given section already and reported on passing through the overlapping time interval, the segment refuses reservation.

If an intelligent agent segment has already been informed about passing the interval <t-5, t + 10> by the colony A, and then the colony B informed the intelligent segment about holonic agent AGV passing the aforementioned overlapping interval with higher priority, the agent A will find out about this only after trying to reserve the segment without much success. The agent A will begin the process of finding and reserving again.

Where the priority is the same, the intelligent segment agent keeps information of possible future reservation without modification. UIA can be used as an element through which the agent may change the order of reservations of the same priority in future.

If the ant colony passes through a critical segment, it assumes the maximum priority (ie. dynamic adjustment of priorities) and applies it to the next segment in the way. In this way, it is possible to avoid blocked holonic agent AGV in the event one of them comes out of the critical segment and cannot change its path.

Ant colony conveying information is a modification of the original delegated multi-agent systems. It was designed to bring the option of priority into the system. [36]

### 3.3.11. Rereservation ant colony of holonic agent AGV

The reservation ant colony is created by the agent, as is the case with exploring and information colonies. Ant colonies are usually made up of a single agent that passes through a meta-scheme and reserves the crossing through intelligent segments. In doing so he is guided by a pheromone placed by a member of exploring colony, which indicates a path to the destination node/segment selected by the holonic agent AGV agent.

An ant-agent of the reservation colony collects information about the already travelled path in the form of unique segment identifiers.

If the event the lifetime of any ant-agent comes to an end (task_completed, or task_failed), the avatar extracts information about the task from the last pheromone the ant-agent put into the environment. The avatar also extracts information from the ant-agent about any reserved segments, and then he presents information to holonic agent AGV agent. If the path to the destination node is successfully reserved, holonic agent AGV may leave the currently occupied segment.

The agent can reserve the travel time as needed, however, to do so he must know the full path (exploration colonies) to the destination node (in order to reserve segments in the direction to the destination node/ segment) if the path consists of the critical segment or if the reservation ends at the node that marks the beginning of the next critical segment and the agent intends to pass through it. In this case, the agent will be forced to inform and reserve the critical segment and the immediately following segment (on the path the agent decides to take).

### 3.3.12. Pheromone container

For the possibility of insertion of pheromones in the environment have some entities the pheromone container. The container has several features that allow:

- Reservation of required segment for a particular time slot.
- Searching of road sign by a unique identifier of ant-agent.
- Updating of the departures maps.

### 3.3.13. Pheromones

Pheromone is a form of indirect communication and is inserted in the environment, that can be observed and modified by ant colonies. The fourth control level contains six types of pheromones (Fig 3):

- The pheromone timestamp.
- The path signs pheromone.
- The reservation pheromone.
- The pheromone of the future reservation.
- The possible departure schedule pheromone.

The pheromone timestamp contains a time stamp and it also offers a possibility to leave a short message. Other pheromones sprung out from therefrom – they took over its properties. When a pheromone is inserted into the environment, the current timestamp as well as a unique identifier of the ant-agent who created it are incorporated into it. The path signs pheromone contains in addition to the time stamp also a path sign. The path sign is represented by a non-negative integer, indicating the following entity – a segment or node as needed. The sign can lead to a segment through which the ant-agent plans to go or through which he has already passed, or optionally a node that features an entity (source and so on). As a rule, signs are inserted into segments pointing to nods and vice versa. [34]

In addition to the information contained in path sign pheromones the reservation pheromone also contains the reservation date at which it was inserted into the segment. Reservation has three dates:

- Date of AGV's arrival to the segment.
- Date of AGV's departure from the segment.
- Date on which the entire AGV becomes present at the segment.

The pheromone of the future reservation contains the same information as the reservation pheromone; however, it is only informative and non-binding. The pheromone of promotion in addition to carrying a timestamp and path signs pointing to its source also contains brief information about the services that it promotes in – name of the agent providing the service, the name of the service etc. The possible departure schedule pheromone contains the projected intervals at which the AGV can leave the current segment. In the event the time interval that the agent projects into the segment already exists or overlaps with another one, they merge so there are as few pheromones in these intervals as possible. Allocation pheromone does not contain a timestamp and the dates of the start and end of the allocation of the required services or operations. The pheromone is used by ant colony for the third and the fourth levels.


*Fig 3. Inheritance in pheromones, descendants acquire properties of their parents [34]*

### 3.3.14. Other parameters of the fourth management level

Inertial parameter is very important for the fourth holonic level. As we have already mentioned, one of the advantages of indirect communication based on pheromones and their evaporation and renewal is a quick adaptation of the system to changes in production/ logistics processes. However, this adaptation may be too fast given the already allocated or scheduled tasks and consequently may degrade the overall system performance. Inertial parameter indicates how much the price of the new path must go down as opposed to the price of the current path.

The evaporation rate of pheromone is closely related to a period of ant colony founding. If the pheromone evaporation rate is higher than the rate of ant colonies founding, it may give rise to a situation where the reservation pheromone evaporates even before it is restored (reservation pheromone). This can cause problems if another holonic agent AGV reserves this path in a given time interval. Ultimately, the holonic agent AGV would be forced to choose a new path. However, it is undesirable in certain situations (in case there is no alternative path and holonic agent AGV are moving towards each other). However, if the pheromone evaporation rate is slow, it could bring the resulting effect onto the whole system and cause its rigidity.

In the event there is a rush order in the production, it is necessary that it passes along the whole production as soon as possible. Therefore, the priority parameter has been introduced. Higher priority decides what holonic agent AGV takes precedence. This means that if the information colonies with different priorities inform the segment agent about the future reservation, the agent gives priority to the colony with higher priority. [36]

# 4. LOGIC VERIFICATION OF THE VARIOUS SCENARIOS FOR THE FOURTH HOLONIC LEVEL

## 4.1. Decision making process of ant-agents at the node

Exploration colony decides at the nod what path to take (if possible) next. This decision can be random (generated by pseudo-random algorithm), or based on information in pheromones. In this case, certain parts of paths or entire paths of individual ant-agents are completely identical, failing to fully utilize the potential of exploration colony. In this case, it is necessary to have more colonies.

It is possible for an ant to make its decision based on information that another ant-agent from its colony already took the given path (segment). Therefore, the ant-agent may choose another free path. By doing so we would increase the explored area of the meta-scheme. However, we shall bear in mind that this would probably reduce the likelihood of achieving the optimum result.

Another possibility is cloning agents to cover the entire meta-scheme. That is, the ant at the node would clone itself that many times how many segments are connected to the node. The life cycle of the ant-agent would end (in case other than completing the task) in the event of a dead end or if an agent from the same colony has already passed through the node. Therefore, the ant does not need to clone itself. In that case, the demands on computing power would significantly increase. Example of possible decisions at the node is shown in Fig 4.

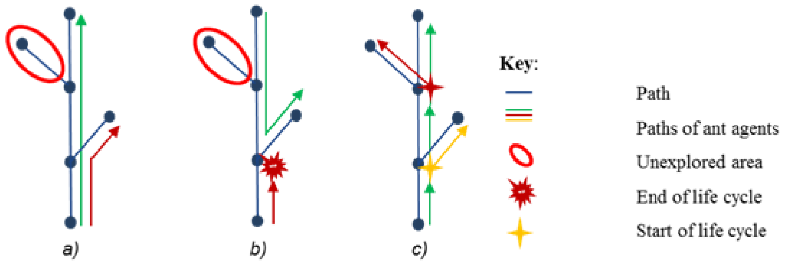


*Fig 4. Example of possible decisions at the node: a) decision-making takes place at random, b) decision-making takes place through pheromones left by the same colony, c) cloning ant-agents at each node [34]*

### 4.2. Nodes promotion

At previous holonic levels production agents promoted their services, helping exploration colonies to find their path towards them. It is questionable whether it is necessary (in the event they are represented in the multiagent system by an agent) to promote their position (or their direction). A large number of nodes could cause an increase in the required processing power.

However, in the event that nods representing production or logistic source were the only ones that are promoted at this level, the results of the finding process would improve. [36]

### 4.3. Dependence of reserved segments on the success of priority and future state predictions

The number of reserved segments is a parameter that contains a non-zero positive number indicating the number of segments the AGV agent will reserve on its way to a target node (segment). This number can be dynamically driven by the possibility to predict the expected future states of the system.

Estimated future states are formed by information and reservation colonies that have information about the future movement of the holonic agent AGV. The states that were estimated in the past are now compared with current states. Percentage ratio indicates success – the number of correct predictions against those that failed.

The higher the percentage of successful predictions, the greater the number of segments AGV agents can reserve. Conversely, the lower the number of successful predictions, the smaller the number of segments AGV agents can reserve.

This is a hypothesis that could help the system to adjust to the dynamics of the system. The more the system encounters unexpected changes, the lower would be the number of successful predictions and hence distances that agents would be able to reserve would shorten. This means that they would be prepared for changes much better.

An interesting option is the increased number of reserved segments in the case where the AGV agent has a higher priority. The agent would then manage to reserve segments in advance and thus get better choice when choosing its path. An interesting idea appears to be reserving all possible segments on the path leading to the target point without depending on predictions or priorities. However, in this case we can anticipate rigidity widening.

### 4.4. Merging of exploration and information colony

The original multi-agent systems were extended by the information colony due to a new feature - the ability to set priority on holonic agent AGV. This priority could be implemented well in the exploration ant colony, but if those ants beared the priority information (one exploration colony consists of several ant-agents), the situation in the system would have become less clear, since agents of the intelligent segment would change the order of crossings under this priority much more frequently. For this reason the information colony consisting of only one ant-agent passing the path chosen by the holonic agent AGV has been established.

To better illustrate the operation of the first holonic levels different scenarios for testing management and coordination of holonic agent AGV have been created. To make the situation even harder, the logical holonic agent AGV is not allowed to go back or rotate at the segment. It can move only forward or stand. Holonic agent AGV have in scenarios the same priority.

### 4.5. Reserving the initial segments

Initial segments reservation refers to a condition of reserving and occupying segments even before the holonic agent AGV finds, selects sand reserves the path. In this case, the knowledge base of the AGV agent fails to provide the intelligent segment agent with information about when he will leave the physical part he represents in the multi-agent system. The reservation is set to infinity (to a sign *not_a_date_time*). At the moment when the knowledge base knows the time of departure, it informs the segment. Until then the segment is impassable. The same applies if he occupies a group of segments.

Segment (or segment groups) is indeed impassable, but that does not mean that another holonic agent AGV cannot stop at the given place. For this situation it is necessary to calculate what portion of the segment (s) is being occupied by the holonic agent. This is calculated from its position and length.

If several holonic agent AGV s stand on a single segment (or a segment group) and there is no other alternative path to take, the length of the reservation is infinite. This means that none of AGVs standing in a row, except the first one, release its ant colonies to find a path because they do not know the possible departure time of the first standing holonic agent. If the first holonic agent chooses and reserves the first possible path, it changes the infinite reservation status of the segment (segment groups) that it currently occupies. The holonic agent that is second in the order receives information that the reservation is not infinite anymore, and the situation is repeated until the segment fully passable. During the infinite reservation the segment cannot be passed and reservations cannot be made (except for the first one in order).

### 4.6. A path in a restricted environment with a single loading and unloading area

This scenario features two holonic agent AGV represented on the fourth holonic level by avatars (Avatar A, located in the unloading area – node 1, and Avatar B, located in the loading area - node 2). They share the same path along which they move from loading into the unloading area and vice versa. Travel time is consistent with loading / unloading operations. Avatar A is to find a path to the loading area with the best price e and Avatar B is to find a path to the unloading area with the best price.

Imagine an initial situation in which the two avatars release their ant colonies at the same time. Since in this case there is no alternative path, exploring colonies will find only one possible path. The colony of the Avatar A moves from the loading zone through the segments in the specific order: 7, 2, 3, 4, 5 and 6. The colony of the Avatar B moves at the same time in the opposite direction starting from the loading area through the segments in the specific order: 6, 5, 4, 3, 2 and 1. The example of a possible scenario which includes two avatars, loading and unloading area is shown in Fig 5. Due to limited space they share one path.

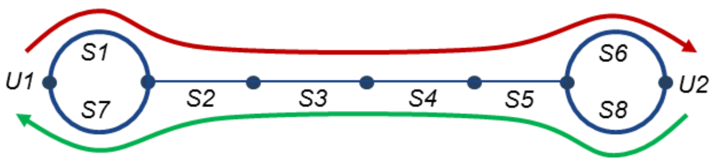


*Fig 5. Example of a possible scenario which includes two avatars, loading and unloading area. Due to limited space they share one path [34]*

In the case of the original character of D-MAS ant-agents should receive from each intelligent segment agent an answer to the question WHAT-IF: If the Holonic agent AGV comes at this time, at what time will he leave the segment? Exploring ant colony A would get an answer regarding the time at the segment 2 and segment 3. The answers would follow up on themselves, i.e. the Holonic agent AGV  could enter the segment 2 and leave it by going to the segment 3 without delay. The colony B is a similar case (segments 4 and 5).

However, if the colony A entered the segment 4 and at the same time the colony B crossed the segment 3, intelligent segment agents would inform them that time slots at which AGVs were supposed to enter the area are occupied. Therefore they move the reservation to the place in their schedule where the passing Holonic agent AGV  (for the segment 3 it would be the Holonic agent AGV  A and for the segment 4 it would be the Holonic agent AGV  B) should have already been present. [36]

Having this information, the ant colony would continue and adapt the inquiry aimed towards intelligent segments agents according to information received at the segments 3 and 4. After the discovery of the loading and unloading area by both ant colonies, an avatar would extract information about the desired segment and possible time reservations at segments that have already passed through.

Holonic agent AGV avatars would then send out ant reservation colonies (each should consist of one ant reservation agent) which would then reserve the segments for specified time intervals.

After passing information about successful reservation of all segments that are needed to achieve the goal, both Holonic agent AGV s are supposed to go out from their places. However, they would meet at the node between segments 3 and 4 (at best) thanks to their safety sensors that give information about free path ahead (to a certain distance). The sensors would detect each other and stop until the operator resolves the situation by manually withdrawing one of Holonic agent AGV s out of the way. Such behaviour of the logistics system is undesirable.

One approach to solve this situation is to assign segments 2, 3, 4 and 5 (segments which follow each other without intersection) one intelligent segment agent (i.e. to draw them into a coherent logical segment) while its orientation would change with the change of the reservation direction (in a given period of time the segment can be passed only in one direction).

### 4.7. A path in a restricted environment with a single loading and unloading area with an intersection in the middle

We can extend the previous scenario by including an intersection – adding additional segments to the already existing node (join segments S9 and S10 to U3 node). This scenario with added intersection is illustrated in Fig 6.

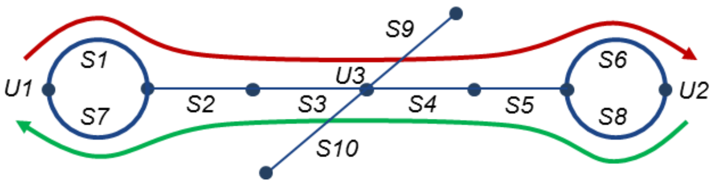


*Fig 6. Previous scenario with added intersection [34]*

In this case, it is possible to create logical segments out of the segments S2 and S3, S4 and S5, S9, S10. By doing this we once again arrive to the situation outlined in the previous chapter. The solution to this situation would be marking the logical segments in question as critical. In that case, the agent would have to reserve the entire path composed of critical segments in the following time sequence: one Holonic agent AGV after another will pass through S2 to S5 segments respectively according to their given priority / UID.

### 4.8. Slowdown on the way

Imagine a scenario where Holonic agent AGV s are on their way slowed down or stopped because of an unexpected blockade or obstacle. The Holonic agent AGV has reserved a certain path and repeats the reservation during its journey.

If the Holonic agent AGV slows down or stops, it still sends its ant colonies out to search for the path but now with updated arrival time for next segments. If the obstacle is removed, it will select the earliest possible time from the possible departures schedule.

## 5. APPLIED CASE STUDY – RESULTS AND DISCUSSION

The authors have proposed the technological structure to eliminate these disadvantages and to add more useful features for control distributed systems. This new abstract architecture for control and coordinating decentralized systems is named CODESA and is shown in Fig 7.

Application of this technological structure is possible in domains where control of non-linear, heterarchical, large-scale systems in dynamic, heterogeneous and unpredictable environment is required. [36]

This technological structure consists of three layers: Ubiquitous Computing Layer, Virtual Environment Layer, Bio-Inspired Layer.

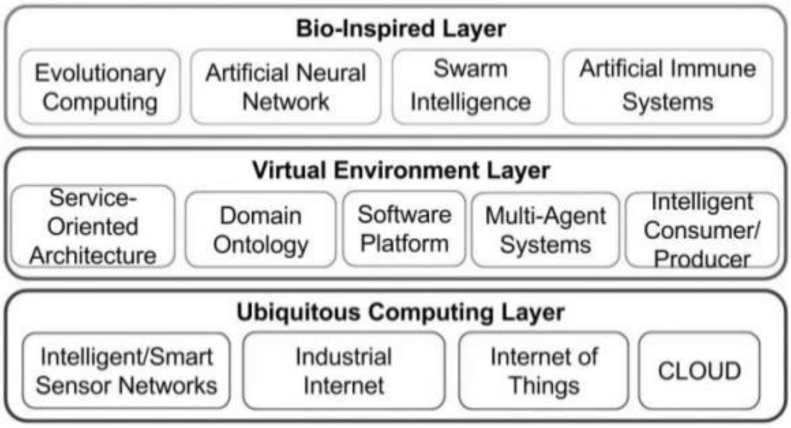


*Fig 7. New abstract technological structure CODESA [36]*

### 5.1. Ubiquitous computing layer

Ubiquitous environment is the concept of software engineering and computer science, where computing can be applied to natural interface, context-aware, and automate capture. The term potential of ubiquitous computing means everywhere-presence information technology and computing power that is present in everyday objects that we use. The idea of integrating computers seamlessly into the world at large runs counter to a number of present-day trends.

Even the most powerful notebook computer, with access to a worldwide information network, still focuses attention on a single box. This potential of ubiquitous computing can be applied to whole areas of industrial production and private daily activities. This situation is made possible thanks to technological advances, availability, small size and price of computing devices. This layer provides industrial ubiquitous internet of things with a unique identity, communicating in real time with the possibility of processing and storing data on the side of the device or on the side of high-performance-computing system – the CLOUD.

### 5.2. Virtual environment layer

Virtual environment layer provides virtual entities, which can reflect the entities in real world. These entities are autonomous, intelligent and capable of decision-making, communicating with each other using the domain ontology and integrating sub-systems and systems into self-organizational structure. Lepuschitz [30] evaluated the overview of the ontologies and their suitability for process automation domain and its subdomains.

This layer provides a picture of the real factory in a virtual environment. Agents can be located in the Software Platform or can be merged with devices (resources, products, etc.).

The target cost of route of the services c (1) in routing intelligent products and allocation of production capacities based on weights of the following priorities:

- W_time is weight of time.
- W_qos is weight of quality of service.
- W_envimp is weight of environment impact.

To determine target (lowest) cost of all services in route(c) defined by weights:

$$c = \frac{\sum_{S i \in r} (c\_time(s_i)) \times w\_time}{V_{r\ j \in P}((\sum_{S i \in r_j} (c\_time(s_i)))} + \frac{\sum_{S i \in r} (c\_qos(s_i)) \times w\_qos}{V_{r\ j \in P}((\sum_{S i \in r_j} (c\_qos(s_i)))} + \frac{\sum_{S i \in r} (c\_envimp(s_i)) \times w\_envimp}{V_{r\ j \in P}((\sum_{S i \in r_j} (c\_emvimp(s_i)))} \tag{1}$$

Where w_time, w_qos, w_envip ∈ R, 0 ≤ w_ x ≤ 1, $s_i$ is target service, $r_j$ is specific route, W is the set of all possible routes, c_time is cost for time, c_qos is cost for quality of target service, c_envimp is cost for environment impact. The higher is the weight of given priority, the lower is the total price, and therefore more acceptable. Target cost of route (2) in routing the logistics resources through the network of roads is based on weights of the following priorities:

- W_dist is weight of distance.
- W_time is weight of time.
- W_qos is weight of quality of service.
- W_envimp is weight of environment impact.

To determine target (lowest) cost of route(r) defined by weights:

$$r = \frac{\sum_{S i \in r} (c\_dist(s_i)) \times w\_dist}{V_{r\ j \in P}((\sum_{S i \in r_j} (c\_dist(s_i)))} + \frac{\sum_{S i \in r} (c\_time(s_i)) \times w\_time}{V_{r\ j \in P}((\sum_{S i \in r_j} (c\_time(s_i)))} + \frac{\sum_{S i \in r} (c\_qos(s_i)) \times w\_qos}{V_{r\ j \in P}((\sum_{S i \in r_j} (c\_qos(s_i)))} + \frac{\sum_{S i \in r} (c\_envimp(s_i)) \times w\_envimp}{V_{r\ j \in P}((\sum_{S i \in r_j} (c\_emvimp(s_i)))} \tag{2}$$

Where *w_dist* $\in R$, $0 \leq w\_x \leq 1$, $s_i$ is one segment of route, $r_j$ is concrete route and *P* is the set of all possible routes. The higher is the weight of given priority, the lower is the total price, and therefore is more acceptable. Then *c_dist* is cost per distance, *c_time* is cost per time, *c_qos* is cost per quality of service, *c_envimp* is cost per environment impact.

### 5.3. Bio-Inspired Layer

Bio-Inspired Layer represents a set of biologically inspired techniques and technologies. Swarm Intelligence can be used to eliminate some of the previously mentioned negative characteristics (derived from heterarchical architectures, multi-agent systems, lack of adaptability, etc.), using indirect pheromone-based communication.

As mentioned, the application of technological structure of the CODESA is possible in areas where it is necessary to control non-linear, heterarchical, large-scale systems in dynamic, heterogeneous and unpredictable environment. Possible application domains are: CODESA-Prime is compatible with the Industry 4.0, transportation, agriculture, healthcare, military, power grids, etc. With technological structure designed for manufacturing domain CODESA-Prime, it is possible to control, plan, schedule, manufacturing, optimize processes, route product and mobile agents, manage inventory, create prediction, etc. [36]

### 5.4. CODESA-Prime: Virtual factory layer

In CODESA-*Prime* is Virtual environment layer called Virtual factory layer. Three main types of agents characterize *Prime*:

- Intelligent Order Agent (IOA).
- Intelligent Product Agent (IPA).
- Intelligent Resource Agent (IRA).

These three types of agents form the Holon Smart Factory. The relationship is shown in Fig 8.

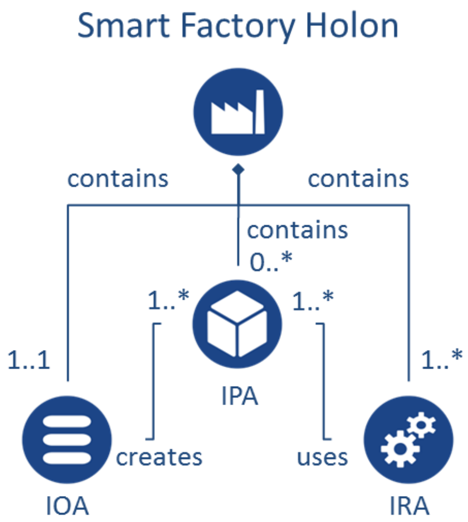


*Fig 8. The relationship between the main types of agents in the architecture CODESA-Prime [36]*

Shown in Fig 9 are defined the properties by merging technologies used in CODESA-Prime structure. Agents in this layer can communicate indirectly, through pheromone-based approach. Decision making in this layer is based on the Contract-New protocol (CNP).

Smart Factory Holon stores information s of Intelligent Resources Agents (IRA) about services offered by them. In this way list of the Holon´s services is created. By merging agents and holons into corresponding holon, layers of services can be created, which is compliant with SOA and at the same time with philosophy of the holonic systems. Intelligent Order Agent (IOA) receives from user or upper control layer an instruction to produce the product. If the product consists of other parts (other IPAs), IOA can use a simple algorithms for optimizing the production processes.

Then it creates and initializes the Intelligent Product Agent (IPA), which downloads information about its manufacturing process (which may be checked after every manufacturing operation and change product properties during its manufacturing) from CLOUD. IPA represents voice of the customer and exists during all phases of the product´s life cycle. Subsequently IPA negotiates and allocates services offered by Intelligent Resource Agent (IRA). IPA informs its status to IOA. IOA communicates this information to the user or upper control layer. [36]

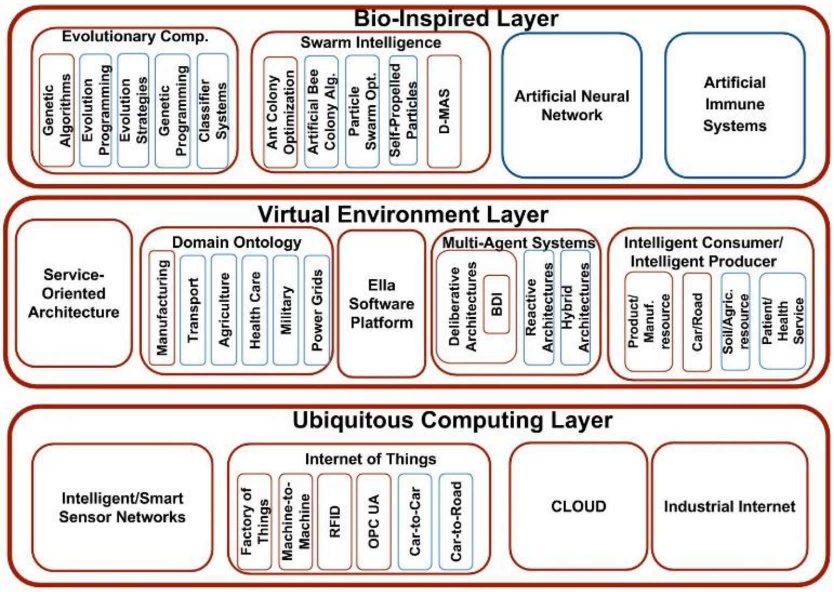


*Fig 9. Prime - concrete application of CODESA in manufacturing domain (technologies and techniques in red) [36]*

CODESA-*Prime* has been tested in simulations for Automated Guided Vehicle systems (Holonic agent AGV s), which have been tested basic aspects of multi-agent systems in Ella Software Platform. The example from the simulation is shown in Fig 10.

Each Holonic agent AGV is represented by an Intelligent Resource Agent and presents its service to Intelligent Product Agent. Agent Holonic agent AGV reserves a different path segments, which are also represented by the agent (Intelligent Agent Segment).

However, such encapsulation of the services must be dynamic. Ella Software Platform provides services, such as the virtual environment that is the model (reflection) of the real factory, in which the agents can travel through, base for dual communication, and meta-schema through which ant-agents can move and indirectly communicate using pheromones.

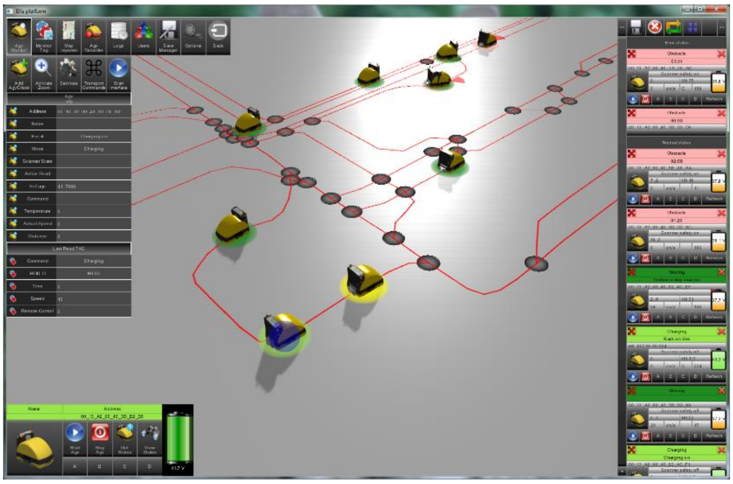

*Fig 10. Testing of CODESA-Prime for Holonic agent AGV in Ella Software [36]*

The connection of scheduling capabilities for logistics systems and routing through production optimize the use of logistical resources, as well as individual road segments. Simulation has been verified that the CODESA-Prime has proved for logistics systems. CODESA-Prime: Bio-Inspired Layer Agents can create (cast) lightweight agents, also called ants or ant agents, and delegate them across the virtual environment that can be represented as graph.

These lightweight agents have a short life (defined by agents) and can perform only certain specific activities. This means that these ant-agents are computationally efficient. They can deposit, locate, observe and modify digital pheromones in the graph (virtual environment). These digital pheromones represent indirect communication.

Pheromon-based communication is suitable to control social and temporal myopic behaviour that is needed to handle uncertainties in manufacturing processes. As mentioned, CODESA uses dual communication. Indirect communication belonging to Bio-Inspired Layer has the following properties:

- It is inspired by food foraging in ant colonies.
- Replaces direct communication.
- Communication is done through virtual environments (represented by weighted graphs) by depositing, observing and modifying the pheromones.
- Delegated, lightweight agents called ants deposit pheromones in virtual environments. These ants are casted periodically by main agents (IPA, IRA).
- Pheromones decay in time. In graph (meta-scheme) are relations between individual main agents (or theirs avatars) are represented by graph´s edges, meta-schema (Fig 6).
- Ants deposit pheromones at graph´s vertices.
- Each ant has temporary memory, limited processing power and limited life.

## 6. INFORMATION AND COMMUNICATION TECHNOLOGY ENABLED ENERGY EFFICIENCY IN MANUFACTURING

The changing customer demands put great emphasis on the flexibility of production, innovation and flexibility to respond to changes. [37], [38], [39]

The globalized economy is strongly influenced not only by economic cycles but also a rapid change in customer behavior, which result in turbulences. [36], [40] Reducing energy waste in manufacturing enterprises helps reduce manufacturing costs, and helps keep our industries competitive.

The recognition that sustainable natural eco-systems result from cyclic functioning led to the concept of sustainable manufacturing being proposed Unquestionably, IMS technologies, architectures, management and control approaches will be useful for sustainable industries. [41], [42]

Future miniaturization of dimensions will focus more and more on increasing a product's sophistication, performance, and market penetration. [43]

Industrial requirements have clearly evolved from the traditional performance criteria, described in terms of static optimality or near-optimality, towards new performance criteria, described in terms of reactivity, adaptability and visibility. A growing number of industrialists now want control systems that provide satisfactory, adaptable and robust solutions rather than optimal solutions that require several hard assumptions to be met

The main task of manufacturing system reconfigurability lies in hardware and software components changing. [44], [45] Reconfigurable manufacturing systems are proposed as a solution to unpredictable fluctuations in market demand and market turbulence.

Realising cost-effective energy efficiency potentials will be beneficial not only for individual energy consumers, but also for the economy as a whole. [46] Tomorrow's energy efficient manufacturing will require additional processing power at all levels of its infrastructure. [46]

The biggest savings is generally from the avoided new materials production, but the difference between new manufacturing and remanufacturing can also be significant. [47]

To gather a better understanding of the current state of research and gap analysis of research and technology development activities specific to information and communication technology usage for energy efficiency in manufacturing, the methodology for reducing the energy intensity is proposed.

The verification of the methodology is realized in rubber industry. Energy efficiency in manufacturing can be improved by a wide variety of technical actions including:

- Maintaining, refurbishing and returning equipment to counter natural efficiency degradation and to reflect shifts in process parameters.
- Retrofitting, replacing and retiring disused machine and equipment, process lines and facilities to new and state of art technologies.
- Using heat management to decrease heat loss and waste energy by, for example: proper use of insulation; utilization of exhausted heat and materials from one to other processes.
- Improving process control, for better energy and materials efficiency and general process productivity.
- Streamlining processes-eliminating processing steps and using new production concepts.
- Re-using and recycling products and materials.
- Increasing process productivity.
- Decreasing product rejects rates and increasing materials yields. [40]

Policy facilitates those technical efforts. A policy of energy efficiency should also be able to exploit the potential in various fields, in particular in the industrial sector where efficiency means greater competitiveness and thus trigger a virtuous circle for the country's economy. [48]

The successful use of policy for energy efficiency improvement depends on how policy can finally give incentives for each possible technical improvement, directly or indirectly, to industry sector. [49], [50], [51]

**Reduction the energy intensity of production processes**

Before an implementation of the methodology of improving energy efficiency in production processes need to be addressed by including achieving energy efficiency in business strategy - management decision, that this area will be developed and will be included in the strategic objectives of enterprise, because energy must be regarded as valuable resources needed for business. [43], [44]

All enterprises can save energy by using appropriate principles and techniques of industrial engineering, which are used in business for key resources such as raw materials and work practices.

This management must include full managerial responsibility for the use of energy. Management of energy consumption and eliminate wasted loads then brings cumulative savings. The first part deals with the methodology of the evaluation process energy efficiency of production processes. This includes [44]:

1. **Step: energy planning of measurement of energy consumption**, which is the basis for energy management in production processes for decision-making of measures for improvement and optimization of increasing energy efficiency.
2. **Step: implementation and control of increasing energy efficiency in production processes**, the proposal of factors and indicators of energy efficiency, analysis of energy cost reduction.
3. **Step: the need for subsequent re-configuration management system**, in which will be realized by monitoring energy consumption and propose corrective action (***CODESA-Prime*****: Intelligent Product Agent**).
4. **Step: checking and improvement,** management review for continual improvement and controlling.

The second part of the methodology involves enabling and supporting energy efficiency of production processes. In addition, information and communication technologies (ICTs) and standardization will play an important role and are essential in creating energy-efficient production. For example, ISO 50 001:2011.

The purpose of this international standard is to enable organizations to establish the systems and processes necessary to improve energy performance, including energy efficiency, use and consumption.

Digitizing, modeling, simulation and emulation are used to understanding of comprehensive manufacturing processes and creation of new knowledge, which is used for optimization of real production systems. [45] Depending on the model, especially lightweight materials are used for the individual parts, for example, aluminum in the front end and chassis.

Methodology for improving energy efficiency of production processes consists of two mentioned basic parts. [44], [45] Also, the implementation methodology should be treated as a unique project; therefore it is necessary to use methods of project management. These enabling assumptions are for every manufacturing enterprise different depending on the financial, tangible, intangible and human resources. By merging agents and holons into corresponding holon, layers of services can be created, which is compliant with SOA and at the same time with philosophy of the holonic systems. [45]

For confirming the correctness of the methodology for reducing the energy intensity of production processes was selected manufacturing enterprises. These enterprises are engaged in manufacturing, selling tires and conveyor belts for the rubber industry. In selected manufacturing enterprises was verified the methodology for reducing energy intensity of production processes. For large content of data and breadth of verified methodology, we present the final conclusions and benefits:

- Implementation of information campaigns to raise awareness about the opportunities and benefits of reducing energy consumption has led to optimization of production process in terms of energy use and increasing the overall equipment effectiveness.
- Creating space for mutual communication and cooperation of production teams and energy management teams led to the development of optimization measures in the production processes, such as how to reduce emission.
- Optimizing the use of information from the installed operating energy software has allowed generate monthly reports of energy consumption in the production process and has enabled the graphical visualization at visual management boards as tool for monitoring key performance indicators in production.
- Application of standards for the promotion of energy efficiency of equipment and staff training for their correct implementation (setting state of hibernation mode of equipment, the implementation of autonomous maintenance, switch off lighting during breaks, etc.) allows reduction of energy consumption of individual facilities.
- Introduction of information system has contributed to the exchange of experience about the possibilities of rational use of various energy devices.
- Energy management team (based on established energy monitoring) has created the project to purchase additional diagnostic equipment and innovative technologies with high energy efficiency in the production processes. [40]

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