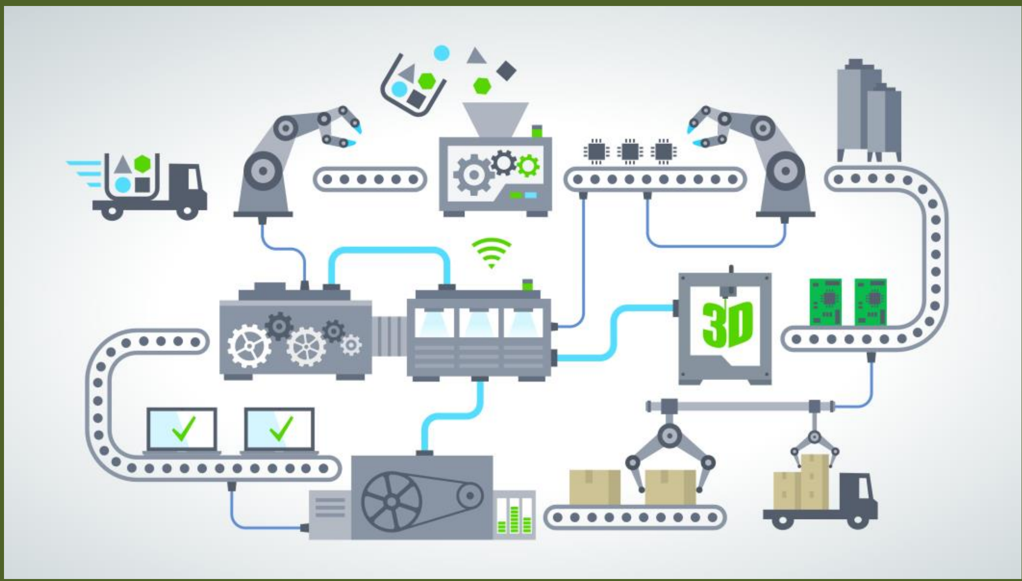
Edited by Martin Krajčovič

# Advanced Industrial Engineering



## NEW TENDENCIES IN PRODUCTION DESIGNING

Bielsko-Biała 2016

# ADVANCED INDUSTRIAL ENGINEERING

new tendencies in production designing

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## new tendencies in production designing

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# Contents

# Foreword

Development of the industrial sector in recent years requires significant changes even in the design, optimization, planning and control of production systems and processes. The current approach of Industry 4.0, regarded as a new industrial revolution, brings new insights into the factory ant its functioning. The idea of "smart" factories means the explosive use of digitization technologies, automation, robotics, cybernetics, autonomous control and cloud-based solutions. This has significant influence on understanding and evolution of Industrial Engineering. Classical IE methods remain the basic building blocks of Industrial Engineering. This knowledge base must be complemented by methods of advanced industrial engineering (AIE), which reflect the changes brought by industrial transformation in the EU and in the global level.

This monograph brings looks at chosen topics of advanced industrial engineering, responding to the challenges of Industry 4.0 and is focused on the design and planning of production and service processes. The main goal was to describe the research realised in Central European universities, to determine the strategic direction and goals in industrial engineering and, consequently, to transfer this knowledge into industrial practice.

First chapters describe new trends in the production and logistics systems design and planning. Second part of the monograph is focused on the use of advanced methods and technologies (digital factory, laser scanning, genetic algorithms, holonic systems) in the layout design. Last part of the monograph is dedicated to progressive trends in maintenance.

We do hope that this publication will increase interest of the advanced industrial engineering and new approaches in production design and planning.

Martin Krajčovič
Editor

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# 1 FUTURE TRENDS TOWARDS AN ASSEMBLY SYSTEM

*Branislav Mičieta*

## 1. DESIGN PROCESSES FOR ASSEMBLY SYSTEMS

To manage assembly systems that are dynamics, flexible, reconfigurable, and autonomous assembly systems were proposed and partly realized in the last two decades. The flexibility and adaptability is realized by clustering the assembly system into subsystems and modules which get a certain degree of autonomy and control themselves in a decentralized way. This keynote paper will present autonomous processes in assembly systems. Different approaches for design and autonomous operation of assembly will be explained and future trends parts and products will be discussed.

Due to increasing market dynamics, planning, optimization and control of assembly has become more challenging for manufacturing enterprises. Today, plans and schedules have to adapt quickly to a variety of products and changing market demands. But conventional structures and methods cannot handle changes, unpredictable events, and distrunces in a satisfactory manner.

To manage these dynamics inside and outside an assembly system, a number of novel concepts for both the physical system and the control system was proposed and partly realized in the last two decades. The most popular ones are:

- Flexible manufacturing systems.
- Reconfigurable manufacturing systems.
- Holonic manufacturing systems.
- Biological manufacturing system. [1]

The recent concepts have a common characteristic:

- Consisting of a network of assembly stations or cells, buffers, transport systems, etc. (is clustered into subsystems and modules.
- These subsystems and modules get a certain degree of freedom to react on changes by themselves and adapt to new demands – they are more or less autonomous.

- Autonomy in general means the independence of a system in making decisions by itself without external instructions and performing actions by itself without external forces.
- Approaches for (partly) autonomous systems are, e.g., mobile autonomous robots, moving assembly stations, or dexterous robots with intelligent sensors. [2]

These examples show that autonomy is not an absolute characteristic but relative to similar subsystems that act in the same hierarchical level of the entire system. That means the degree of autonomy of a subsystem is given by the ability of the subsystem to use this given freedom of action.

The benefit of introducing autonomous subsystems within an assembly system is reduced complexity of both the physical structure and the information system.

For the autonomous control of subsystems, only local information is repuired. Due the self-x characteristics such as self-configurability, self-optimisation, etc., autonomous subsystems are more flexible, adaptive, robust, and fault tolerant. They enable rapid response to customer needs. [3]

These self-y characteristics will be reached by different methods from Artificial Intelligence and Artificial Life, e. g. multi-agent systems and swarm intelligence.

The application of autonomous subsystems can be realized by recent information and communication technologies such as radio frequency identification (RFID), sensors technologies, wireless communication networks etc. These Ubiquitous Computing technologies enable a high flexibility and changeability of assembly systems to manage today´s increasing requirements.

In parallel to the trend of enhanced automation using Ubiquitous Computing technologies and Artificial Intelligence methods, there is currently a shift back form automation toward more human involvement in planning and execution tasks.

Studies showed that the introduced automation is often not flexible enough to handle the dynamic demand of the market. The required flexibility and adaptability of the assembly system can only be achieved by manual assembly.

People are the most flexible resource of a company if a satisfying education and life-long learning is taken into account. [4]

This keynote section will give a survey of concepts with autonomous characteristics and will present the state of the art about autonomous processes in assembly systems. This topic is embedded into the following large research fields:

- Reconfigurable manufacturing systems inclusive assembly systems.
- Production planning and control inclusive distributed approaches.
- Intelligent computation methods inclusive multi-agent systems.

An overview on Reconfigurable Manufacturing Systems was given keynote paper by Koren et al. [5]

On overview on intelligent comturation methods for manufacturing was given by Botti et al. [6]. In traditional manufacturing when a product was designed the manufacturing process to build the product was of little consideration. The development was expended on integration of part design and manufacturing to improve downstream processes and product quality.

The key of options for the proposed energy management positioning are shown in Tab 1.

*Tab 1. The evolution of manufacturing paradigms – adapted from* [6]

| **Manufacturing paradigm** | **Flexible Manufacturing Systems** | **Recongfigurable Manufacturing Systems** | **Autonomous Manufacturing Systems** |
|---|---|---|---|
| Period of time | 1980s | 1990s | 2000s |
| Market demands | Variety of products, small volume per product | Customized products, fluctuating demand | Personalized products, turbulent markets |
| Requirements to manufacturing systems | Flexibility | Adaptability, Changeability | Self-adaptation, Self-optimisation, Self-organisation |

*Tab 1. The evolution of manufacturing paradigms – adapted from* [6] *(continued)*

| **Manufacturing paradigm** | **Flexible Manufacturing Systems** | **Recongfigurable Manufacturing Systems** | **Autonomous Manufacturing Systems** |
|---|---|---|---|
| Manufacturing concepts | CIM, flexible automation | Holonic manufacturing systems, reconfigurable systems | Ubiquitous Computing, autonomous systems |
| Control Concepts | Central control system, hierarchical structure | Central and decentralized controls, dynamic structure | Autonomous control, heterarchical structure |
| Realization | Monolithic PPC systems | Multi-agent systems | Ubiquitous computing technologies |
| | CNC machining centres, Robots | Modularity, standardized interfaces | Integration of control into sub-systems, machines, components, and parts |

Today, every avenue of optimization and continuous quality improvement must be explored to create a lean manufacturing environment that produces low costs with high productivity at all levels. In the design of parts, assemblies, and manufacturing processes what must be considered is how parts and assemblies are produced to develop most efficient manufacturing systems. Automation applied to processes that create digital data required by automated fastening systems simplifies these processes.

## 1.1. Sustainable manufacturing and assembly processes

Sustainability of the production lies in the ability to build such a production schedule that will be the purpose of preparing a marketing standpoint, this means that producing such products, which are demanded by the market and at the same time are chosen such means of production, production systems and processes to enable production program of provide market perspective. Sustainability of the production is a specific area that addresses whether it is properly constructed production program that is sustainable and the market will demand products. It is a combination of marketing, strategic decision making and consideration of technical progress, technical capabilities, which allow the market to provide products.

In industrial production, sustainability of the production is somewhat issue an administrative decision relating to the choice of the production program and a forecast of market development needs.

## 1.2. Assembly Tools and instrumentation

**Assembly Tools** – the selection of assembly tools can be classified:

- The electric screwdriver torque controlled tools in the industry.
- The pneumatic screwdriver selection of torque controlled in the industry.
- The torque controlled impulse screwdrivers and nutrunners in the industry.
- The pistol grip impact wrenches featuring award winning ergonomics and performance.
- Automated fastener systems.
- Programmable tools.
- Robotic screwfeed systems – turnkey solutions for high volume manufacturing.
- Pistol grip, inline, and angle cordless screwdrivers with each style featuring award winning ergonomics and performance.
- Torque nutrunner.
- Screw presenter – helps easily add automation to assembly process. Accelerate the speed of screw tightening jobs. Free operator hands and eliminate the need to manually handle screws.
- Automatic screw feeder - screw feeder system is customized to application to ensure accuracy to help improve your productivity and is sold as a Turn Key Solution.

For example, the user friendly **MT Focus 400 screwdriver** system (Fig 1) from Atlas Copco is easy to set up and use, bringing precision and quality to your tightening. The smart Auto-set functionality makes it possible to set torque directly from the front of the controller. [7]

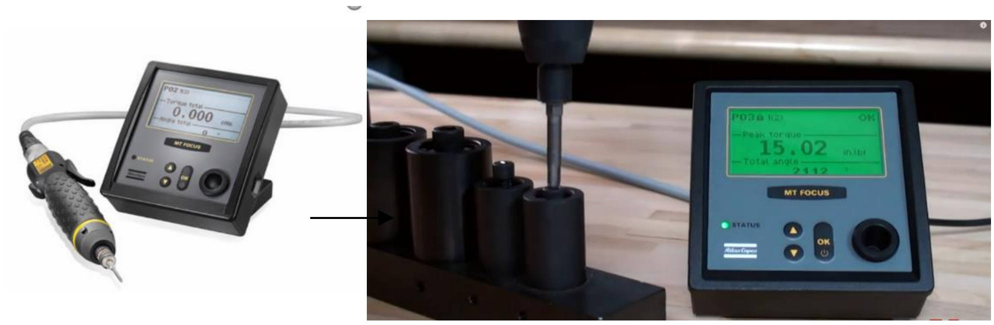


*Fig 1. The example of screwdriver system [7]*

**Torque Instruments –** the selection of assembly tools can be classified:

- Dial Torque Wrenches, Digital Torque Wrench, Electronic Torque Wrench, Click Torque Wrench, Preset Torque Wrench, Adjustable Torque Wrench models.
- Complete line of torque tester data collectors, digital torque meters, torque gauges, torque analyzers, desktop torque testers, and bottle cap torque testers.
- Torque Multiplier.
- Bottle Cap Torque Tester.
- Calibration Systems.

This flexible tool can be customized for a wide variety of production and quality environments as a stand-alone instrument or connected through management software. Features include traceability for entire tightening operations including torque, angle and yield control. Operators can check residual torque, perform joint analysis and tighten hard to reach bolts with various torque and angle strategies. STwrench, a transducerized hand-held torque wrench with modular design from Atlas Copco is shown in Fig 2.

*Fig 2. The example of transducerized hand-held torque wrench [7]*

**Handling & Lifting Systems**

- Air balancer.
- Arm systems.
- Jib cranes.
- Rail systems.
- Material handling devices.
- Electric hoist.

**Force Measurement**

- Force gauge.

**Workplace Accessories**

- Tool support systems.
- Tool balancer.
- Air tool oils.

**Engineered Systems**

Flexible Assembly's Engineered Systems offers cutting edge automation solutions for today's growing manufacturing sectors. Ranging from Solar Power to Automotive and Defense (Fig 3). The engineered systems can help streamline the process and make your operation more productive and safe.

Expert and reliable service – team of industry experts, engineers and technicians are at service to make sure project requirements are properly met. Customization – Flexible designs and builds custom automation equipment and solutions for a variety of industries. The design team can built a strong reputation for consistently delivering reliable machines within budget, on time, and to exact specifications.

Quality – Flexible is a customer driven company. The success is a product of unwavering dedication to providing quality products and creative solutions, which exceed customer expectations. [7]

*Fig 3. The example of using solar energy [7]*

## 2. PRINCIPLES OF AUTONOMY

Autonomy of a system implies two basic characteristics:

First, independence from neighbor systems and from its environment, and second, the ability to control itself. The first characteristic can be reached by clustering with assembly shop into subsystems and modules with standardized interfaces. The second characteristic requires the decentralization of the control system according to the granularity of the subsystems and modules.

The adaptive assembly has, for example, very close to the intelligent product. The assembly can be adapted to production and material requirements of the product. The system can be adapted to the production (ideal quickly).

The adaptive assembly allows changing the production operations, or the parameters (product size, roughness etc.).
Manufacturing is the dominant sector of the European economy and it exerts a strong technology pull on research and innovation, so the EU depends strongly on the dynamism of its manufacturing industry. The competitive and sustainable reaction to such changes and challenges requires a transformation of Industry.

An intelligent product is a physical and information-based representation of an item, which possesses a unique identification, is capable of communicating effectively with its environment, can retain or store data about itself, deploys a language to display its features, production requirements etc., is capable of participating in or making decisions relevant to its own destiny. [9]

Tecnomatix platform is a standard PLM commercial product. In the Department of Industrial Engineering, we have huge experience with this software platform. With the help of these tools, we can verify the synergy between design and management tools, and then perform some experiments with their use. The aim is to link PLM systems with real automation.

For example, the automaker Mercedes through virtual commissioning has built a completely new assembly hall. Before starting the actual operation, the reliability algorithms and control systems fully was verified in the virtual space. This has brought great savings in time because the programmer can in a virtual environment reflecting the reality of control systems without being required to do on real devices. Moreover, in the industrial practice is verified the operation of control systems mostly in the real application. The project of virtual commissioning is one of the solutions using Tecnomatix platform from Siemens and individual project planning tools such as Process simulate, Process designer, etc. that we will form to our mini factory. Real control systems are linked to the virtual space of the OPC server or other communication protocols and are verified their functions.

With Tecnomatix assembly simulation and validation, you can use virtual assembly to simulate and validate your assembly sequences, including all required human and machine interaction. When you use assembly planning tools to digitally validate production systems, you can reduce tool installation time and minimize system try-out costs. This ability to digitally optimize assembly processes and validate assembly feasibility can also significantly increase productivity. [10]

Optimizing the assembly process upfront, prior to the start of production, results in right-first-time manufacturing plans and improves time-to-volume-production. You can reduce your overall planning process time, shorten production setup, achieve faster ramp-up and deliver high-quality products right the first time. Control engineering is critical for the achievement of system performances and for logic specifications [10]: complex control logics must be developed in a short time on previously designed electro-mechanical hardware. In practice, the control system development is generally carried out only during the final stages of the design process. It is often realized directly on the assembled system and it still continues during the production ramp-up phase (commissioning).

The mechanical engineer is the engineer, who can do a wide range of concept and design of manufacturing systems, construction, industrial engineering and management. Control engineer is basically a programmer, either PLC, C ++ and he know creating a control code for example code of decentralized management etc.

This paper is structured in the form of four main sections, where are demonstrated concepts contributing to the development of AAMS in order to accomplish enhanced adaptability to unstable environments through increased sensing capability and comprehensive control logics, able to self-optimize manufacturing performance and to realize intelligent and adaptive behaviour in assembly processes. In section 2 a literature survey is presented for supporting the analysis of new knowledge in adaptive assembly and virtual commissioning. In section 3 a detailed explanation of the problem is given. In section 4 our method for mechatronic design of adaptive assembly system is proposed and the required tools are described. Section 5 reports the case study of adaptive assembly. Finally, a short summary and an outlook are given in the conclusion.

## 3. LITERATURE SURVEY

An objective of this research is a visible contribution to realizing the vision of an adaptive assembly and manufacturing system while simultaneously reducing the demand for losses as well as increasing the efficiency of resources in assembly processes.

Future manufacturing and assembly systems must enable product and process innovations and rapid changes performing cost-effective flexibility and adaptability to environment variations and changes.

The adaptive behaviours defined by the control logics are then physically performed by electro-mechanical hardware, previously designed. Mutual interactions between adaptive behaviour control logics and electro-mechanical hardware should be accurately evaluated, since they often causes commissioning time delays and imperfect optimization of the adaptive manufacturing systems.

Adaptive manufacturing systems can be regarded as complex mechatronic systems. According to Burmester et al. [11], these systems continuously perform three actions that are shown in Fig 4.


*Fig 4. Three actions of adaptive manufacturing system [11]*

Concluding, automation industry asks for novel engineering methods focused on mechatronic design of adaptive manufacturing systems. Such methods are requested to introduce the design and validation of control logics during the first steps of the mechanical and system design, in order to mediate conflicting requirements and to exploit synergistic solutions. This approach should aim to enhance the role of behavioural simulation in engineering, to virtually explore all the solution spaces of the mechatronic systems design variants.

In most case studies of automation technology application, the story typically revolves around the selection of a new technology to solve a production or cost issue. But as supply chains grow increasingly connected through use of specific technologies, it has become more common for manufacturers to switch technologies at the request of a customer. [12]

As pointed out by Bradley, mechatronic systems [13] are technical systems combining technologies applied in mechanical and electrical engineering as well as in computer science. Future mechatronic systems are expected to be composed of interacting systems rather than isolated solutions for individual devices. Networking and ever increasing local computational power will enable sophisticated mechatronic systems, which will not merely feature more advanced digital control, but also include rather complex software coordination and information management capabilities. To handle the resulting complexity, each single unit of such composite systems must be able to react autonomously and flexibly to changing environmental settings.

The adaptation capabilities may range from online parameter adaptation [Zouriktuev 2008] to structural adaptations. [14] These methods need the creation of a knowledge base where processes are mathematically modelled in their detailed behaviour and the related parameters are sensed. [15]

Rapidly changing demand and mass customization require highly flexible and adaptive manufacturing systems. Manufacturing operations have evolved in order to keep up by organizing themselves into smaller units of specialized production processes that are combined in different ways to create different products. Human workers are integral in the manufacturing systems and they too must be flexible and adaptive. [4], [16]

Flexibility has become one of the most useful and necessary tool in today's competitive markets. Manufacturing flexibility is widely recognised as a critical component to achieving a competitive advantage in the marketplace. [17]

Virtual reality (VR) assembly tools create an immersive VR environment with 3D representations of a product, the human operator and the work environment. Advanced 3D human-computer interaction (HCI) interfaces are used to simulate the manual assembly process. Grid technology has been recognised as a promising paradigm for the next generation manufacturing systems. Researchers have attempted to apply grid technology to product design, manufacturing resource integration and sharing, enterprise management, enterprise collaboration, resource optimal allocation and scheduling, and to enable the digitalisation of enterprise information as an implementation methodology. [18]

For example, the companies IBM and NVIDIA continue to be in lock step in bringing its latest GPU technology to the cloud. [19]

An effective design of such complex systems requires interdisciplinary knowledge and advanced software tools. PLM platforms enable engineers to concurrently design a product and its manufacturing process, thanks to CAE (Computer-Aided Engineering) and CAM (Computer-Aided Manufacturing) tools embedded in CAD (Computer-Aided Design) 3D environments.

Traditional Product Lifecycle Management (PLM) solutions focus mostly on the product data management and design house-keeping aspects to maintain complete and consistent product information during product R&D. Thus, PLMs are not necessarily keen on supporting quick-to-market and mass-customization. Research overcomes the current PLM deficiency by enabling the Modularized product Design for Assembly (MDfA) and Collaborative Design Process (CDP). [20]

CAE and CAM tools allow by now the validation of very complex mechanical behaviours. The CAE systems are used as analytical, computational and simulation capabilities in the field of engineering. For instance, the robustness testing components, testing their strength, thermal stress, and flow and kinematics simulation related to the casting and making components. They are mainly used for decision support design teams in the sectors of automotive, aerospace and shipbuilding. The aim is reducing the cost and time of product development, increased security and durability of production components. In any case, the CAE systems are able to verify the design of computer simulation without performing tests of a physical prototype. [21]

## 4. PROBLEM DEFINITION

With the level of automation increases the complexity of the production facilities and thus is associated with the problematic commissioning. For reducing
the time required for the implementation of new facilities, but also on existing facilities is appropriate to apply the methods and technologies of the Digital factory (DF). Digital factory is a virtual image of the real production that shows the production processes in a virtual environment. DF is mainly used for planning, simulation and optimization of the production of complex products. Digital factory concept is based on PLM systems based on conventional CAD/CAM systems. According to CIM (Computer Integrated Manufacturing) data reputable agency the implementation of the Digital factory achieves significant benefits:

- Cost savings through better use of resources of 30 %.
- Cost savings achieved by optimizing material flows 35 %.
- Reduction of the number of machines, tools and workplaces by 40 %.
- Total manufacturing production growth of 15 %.
- Reduce time to market for new products by 30 %. [15]

An example of comparison between conventional production line and technologies of the Digital factory is shown in Fig 5.

*Fig 5. Example of then and now manufacturing (real vs. virtual production) [15]*

Generally, it deals with the creation and management of virtual model of an existing or planned system (equipment, production and assembly lines, and layout). Terms of an efficiency of engineering processes are mainly about design and simulation. This concept, where we have a virtual model of replicating real, but it is possible and desirable to also be used for visualization and especially for emulation system. The visualization is focused on the current online data in a virtual system.

On the other hand, the emulation allows interface of real control algorithms emulsified in a virtual system that can respond to real data from the process. Emulation in the pre-production stage of the process automation is referred to as Virtual Commissioning. The concept of Virtual Commissioning is particularly suitable to verify the functionality, reliability and safety of programmed control algorithms in a virtual environment. While in normal deployment of automated or robotic system, the phase of programming and commissioning begins only when the physical hardware is created, using Virtual Commissioning is possible to skip the stage of the production system and move to the designing of a model in a CAD/CAM. From this point of view, Virtual Commissioning with regards to Industry 4.0 are directly related to PLM systems and connects the virtual with the physical world. [22]

One of the most popular PLM systems implemented the concept of Virtual Commissioning is Tecnomatix from Siemens. Tecnomatix enables interconnection real managing hardware (PLC) with a virtual system in the tool Process Simulate. Department of Industrial Engineering at the University of Zilina built the future development of AGV logistics systems on the concept of Virtual Commissioning. CAE are systems that simulate design solutions before starting the real production. These systems belong to the range of (CIM) software tool and support the engineering work in the developmental stages of design. [23]

The integration between mechanical, electronic and control software simulations is a field of many recent researches [24]. The evaluation some important requirements for a virtual simulation environment: multi-domain simulation, modular modelling and software reuse, build-in model libraries and customization, reliability and efficiency of numerical simulation, integration with CAD, interfaces for pre- and post-processing, simulation paradigm and object orientation.

Mechatronics is a dynamic, multidisciplinary subject combining three engineering fields: mechanical, electrical and software engineering. This highly integrated approach creates smart, inventive and ever more efficient solutions for a wide range of high-tech engineering problems. Adaptive manufacturing systems achieve intelligence and adaptation capabilities through the close interaction between mechanics, electronics, control and software engineering. The mechatronic design of intelligent manufacturing behaviours is of paramount importance for the final performances of complex systems and requires deep integration between mechanical and control engineering that is shown in Fig 6.

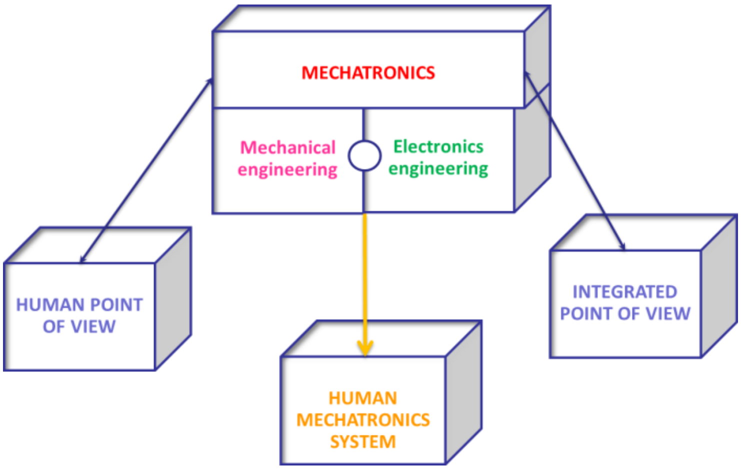


*Fig 6. The request for integration of mechanical and electronics engineering [6]*

Therefore, the research questions in this context are following:

**Human**

- What is easy for people to use?
- What makes people happy?
- How could it be helpful to people?

**System**

- What is necessary to resolve problems?
- What is the optimum combination of product and service?

This research question is based on two hypotheses:

- Hypothesis 1: The best challenge to solve with Virtual Commissioning is the request to embed all the product and process knowledge possessed by the mechanical engineers into the control system development, simultaneously, to enable the mechanical engineers to evaluate the real mechatronic and dynamic performances of the assembly manufacturing system designed and the adaptive behaviours formulated, so to involve control engineers into the earlier mechanical design.

- Hypothesis 2: Virtual reality and modern pattern recognition system as a support tool in the assembly process are important enablers for measuring, controlling and improving adaptive assembly.

Holistic approaches to design and operate modern green production systems are required to cope with those challenges adequately. To analyse production systems with respect to economic, ecological and energy objectives, a specific set of data is necessary as an informational basis. The definition of input and output flows is a prerequisite to determine required economic, ecological and energy information on production systems. [25]

Common industrial practice very often follows a sequential process (Fig 7A) hiding synergy. Mechanical engineers manage the design process because they are generally the most expert on product and process know how, they are able to deploy the manufacturing system layout (developed through CAD, CAE tools) and to define the knowledge base that will rule all the mechatronic adaptive behaviours. [10] Mechanical engineers identify the adaptive behaviours to realize and then plan custom adaptive strategies. The system is then progressively developed in its mechanical hardware and provided with the necessary mechatronic modules.

In common practice, control engineers are marginally involved in the manufacturing system early design and layout development. Control engineers are really involved just in the final stages where they are asked to develop control strategies to accomplish the cycles specifications, previously defined by mechanical engineers (the product and process know how experts) and to program all the mechatronic systems. In fact the real complex control logics will be really designed in detail by control engineers only during the last stages of the manufacturing system development, or even during final commissioning.

This common practice often experiences a lack in communication between mechanical, electronic and software engineers about the product/process knowledge base with subsequent delays and not optimized manufacturing operations.

In any case, the control engineers have only reduced possibilities to operate changes in the mechanical layout to optimize the control and the final performances of the adaptive manufacturing system. The drawbacks of this common practice are evident and well-studied [6] especially when the logic behaviours and control strategies become complex and sophisticated. On the other hand it must be underlined that it is fundamental to focus on the creation of the knowledge base that rules the process behaviour and this can be effectively carried out only by the product and process know-how experts, the mechanical engineers. Then, the state of the art of mechatronic manufacturing system design suffers the need to integrate the control engineering activities into the early stages of the design. This is fundamental to validate and optimize the mechatronic systems choices and mechanical layout design variants with the real performances of the software and control systems, really evaluating the real adaptive behaviour and cycle performances of the mechatronic system.

New Virtual Commissioning tools are now available: they provide behavioural simulation environments where software control algorithms can be evaluated on virtual prototypes without waiting for the manufacturing system assembly (Fig 7B), then virtually emulating the commissioning process. Virtual Commissioning provide then interdisciplinary environments where mechanical and control engineering activities can finally communicate and where their synergistic contribute can be numerically evaluated.

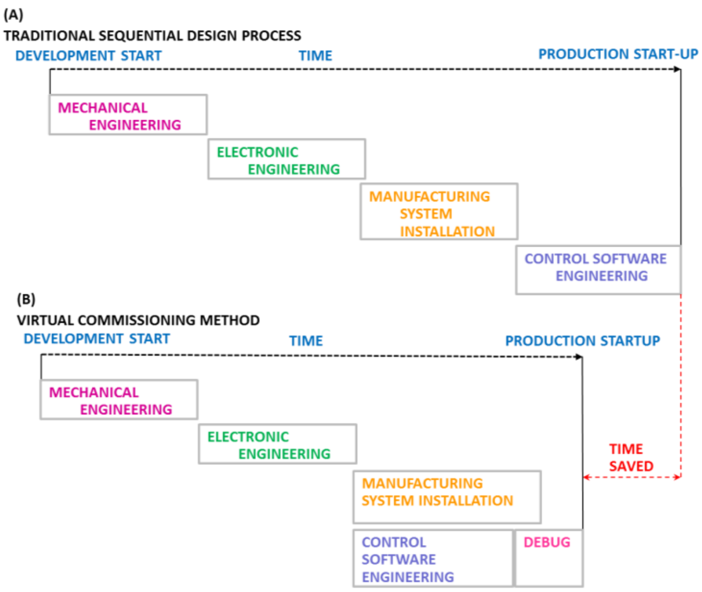


*Fig 7. Traditional sequential design process vs. virtual commissioning method [10]*

## 5. DESIGN METHOD

### The use of Augmented Reality (AR) in the assembly process

Augmented reality (AR) is a combination of the real world with the virtual environment. Among the limitations of virtual reality in the assembly process may be classified:

- Complexity and computational complexity of virtual reality.
- Calibration of virtual reality.
- Collision detection.
- Lack of feedback – directly experience and perception of reality.

Nowadays, most research in the field of augmented reality is directed to the use of real-time capturing video that is digitally processed with adding computer-generated graphics.

The resulting image, which occurs by mixing video with capture digital content can be displayed on HMD (Head Mounted Display – the display placing on the user's head) or on the monitor. [26]

The use of augmented reality in the assembly process (Fig 8) eliminates the need for additional installation procedures. A worker in his view sees not only the actual physical assembled parts but at the same time the structure in virtual form, which is displayed him by assembly process. There are several software programs to create augmented reality, for example Metaio Unifeye Design, BuildAR, Artista or DART.

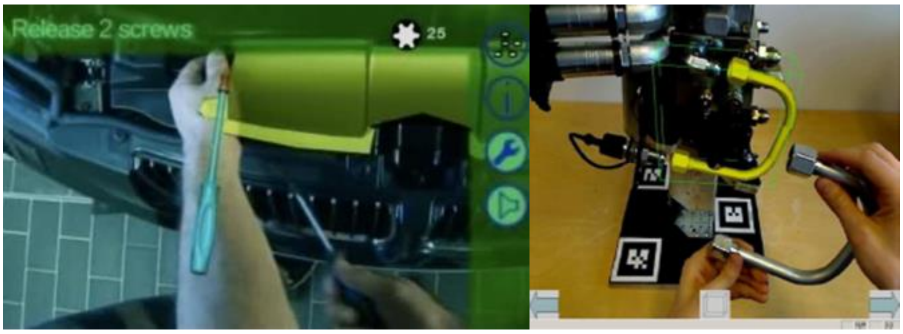


*Fig 8. The use of augmented reality as a support in assembly [49]*

Design of the adaptive assembly and manufacturing system should be taken into account two dimensions:

**Dimension 1: Input to new assembly system (planning of new structure)**
The methodology provides the support for detailed processing of existing practices from the viewpoint of the effectiveness of assembly processes in the design stage (cooperation mechanical and control engineering for Virtual Commissioning).

**Dimension 2: The implementation of restructuring (adding, changing, and reducing)**
Using the tools of industrial engineering allows you to search the potentials of improvements in existing factories. To ensure the long-term sustainability of production is required to be able to control of assembly processes (the use of Digital factory).

### The modern pattern recognition system as a support tool in the assembly process

In the industry are mainly used 3D camera systems operating on the principle of scanning the profile of line illumination on moving objects. The advantage of this principle of acquiring 3D information about objects is achieved high speed scanning profiles and subsequent processing speed of the information obtained. Smart cameras can be deployed in a variety of industries (Fig 9).

### Virtual Commissioning tools

We propose a design method based on virtual simulations since conceptual design stage. Instead of using Virtual Commissioning tools only to validate control logics, we used them also to create, model and share the product and process knowledge base, to search for new solution spaces and to evaluate the behaviour resulting from the interaction of mechanical, electronic and software design solutions. Then, control logics and software design phase can start coarsely in the early design process and be strictly integrated with mechanical engineering. We developed the method specifically aiming at adaptive manufacturing system design. For this reason we evaluated Virtual Commissioning tools focused on PLC controls, and we chose to use Tecnomatix from Siemens.

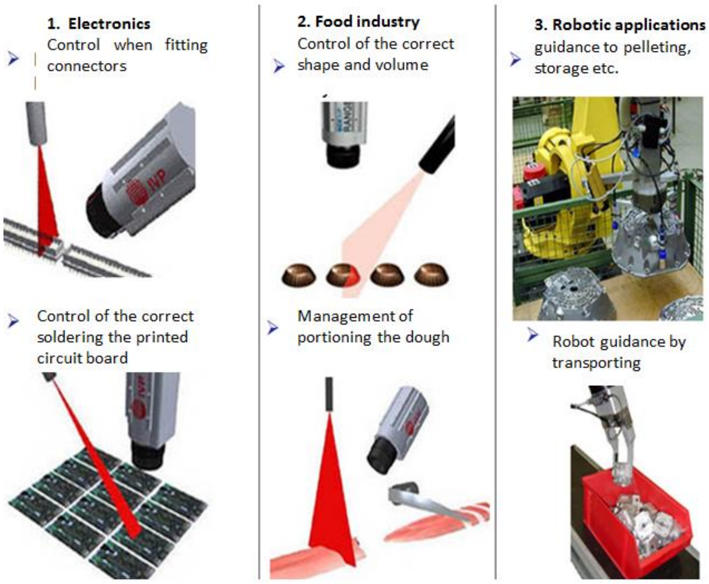


*Fig 9. The use of intelligent smart cameras as a support in assembly [3]*

Tecnomatix is a comprehensive portfolio of digital manufacturing solutions that help you realize innovation by synchronizing product engineering, manufacturing engineering and production. The Tecnomatix process design (Fig 10) and management solution allows design and manufacturing engineers to concurrently develop product and process planning definitions.

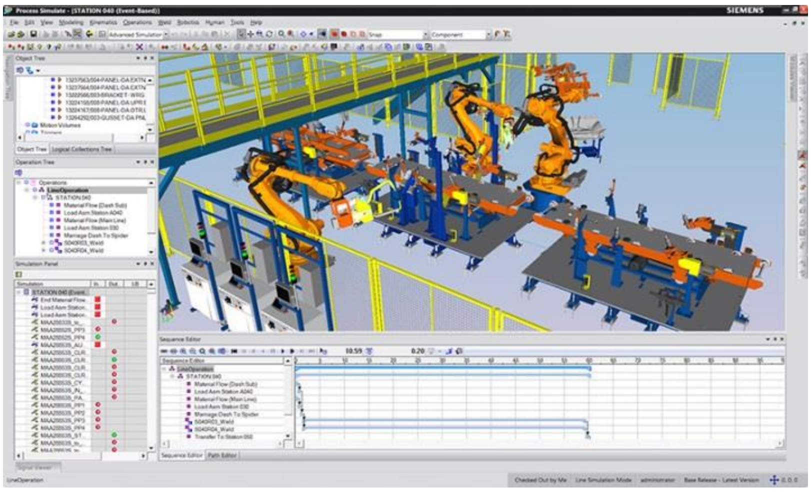

*Fig 10. Process Designer – module for design of production processes [15]*

This tool integrates, as part of a PLM platform, different domain activities within a common virtual environment. Mechanical engineers can now become really aware of the actual structure and behaviour of the device they design. In this way both the mechanical and control engineers can use the same tool in a user friendly environment to develop a mechatronic virtual prototype where they can effectively explore all the solution spaces and then proceed to a real final optimization. We believe the greatest challenge to solve with Virtual Commissioning is the need to embed all the product and process knowledge possessed by the mechanical engineers into the control system development and, at the same time, to enable the mechanical engineers to evaluate the real mechatronic and dynamic performances of the manufacturing system designed and the adaptive behaviours formulated, thus to involve control engineers into the earlier mechanical design. Actually, the knowledge base, developed for the adaptive and self-optimizing behaviour of mechatronic systems is just a small part of the whole product or process knowledge at the foundation of the knowledge base algorithm calculated.

**Pick by systems in the assembly process**

Use of augmented reality in the assembly increases human performance and reduces the time required to meet the mounting tasks, reduce waste and reduces the cognitive workload. In this context of improving the quality of the assembly processes are used Pick by systems. The group Pick by includes systems:

- Pick by light (Fig 11).
- Pick by voice.
- Pick by vision.
- Pick & work.

*Fig 11. Example of Pick by light system [49]*

## 6. CASE STUDY

### Final Virtual Commissioning

The design process of the state of the art adaptive manufacturing systems is mainly focused on the identification of adaptive behaviours opportunities and their knowledge base creation. For this reason, Virtual Commissioning tools represent a strategic advantage in validating and selecting solutions really actionable with robust mechatronic solutions inside the cycle time specifications. Early virtual evaluation of conceptual design solutions for the adaptive manufacturing system is shown in Fig 12.

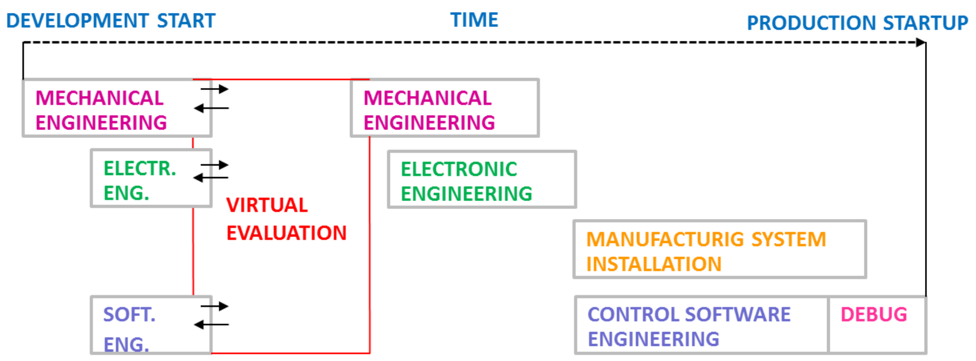


*Fig 12. Early virtual evaluation of conceptual design solutions for the adaptive manufacturing system [10]*

A good example of a modern approach to design and testing logistics and assembly systems supporting virtual reality and simulation solutions is developed by CEIT (Central European Institute of Technology, Zilina, Slovakia), tradename is CEIT Table (Fig 13) well analysed by. [27]

The users can simply moving your hand to change the project of logistics concept of assembly system. The system automatically evaluates the length of material flow, transit times, transport capacity and a number of other parameters.
The team (mechanical and control engineers, planners, manufacturing engineers, industrial engineers etc.) can show especially quickly in their view, which option is the best, even in a 3D environment.

Already in the phase of deployment of machinery and equipment we can eliminate any collisions that in 2D environment may not be reflected.

*Fig 13. Example of Pick by light system [27]*

We can use also the mobile information system based on augmented reality technology that is shown in Fig 14.

*Fig 14. Augmented Reality Mobile Information System [28]*

**Adaptive assembly process**

First prerequisite of adaptability is a functional modularity of assembly system, which is often the condition for rapid reconfiguration of assembly system. Modularity is a sufficient condition for reconfiguration, but assembly system can be reconfigurable, unless it does not fulfil the conditions of modularity. The individual elements of the assembly system must be designed so that from a technical (hardware, mechanical, energy), as well as from a software site (control) were able to cooperate and communicate.

The resulting modularity of assembly elements allows scalability and adaptability of the whole assembly system. Adaptive assembly systems use a wide range of advanced technologies. Individual elements of the assembly system are equipped with small, powerful computers, so-called Embedding Intelligence to extend their functionality and autonomy. The ability to mutual communicate is supported by a new generation of Wireless sensor networks utilizing intelligent information infrastructure, Internet of Things and cloud services.

Adaptive assembly systems require clear identification of all objects (static and dynamic) that are located in the assembly system. In every time and in every place to be each assembly unit clearly identified. This requirement is especially necessary at a solution where assembly activities are controlled by the specified product. In this dynamic environment will create a lot of randomness and the needs of alternative strategies to solve transportation and manipulation, which will require permanent reprogramming of available resources. For uniquely identify of objects are most often using RFID technology (Radio Frequency Identification technology).

The features of adaptive assembly systems can be simply defined as the ability to be autonomous, active and quickly adapt to sudden and unexpected changes that arise in their area and are beyond the originally defined system functions. Adaptive assembly system must therefore possess the ability to change its structure, its functions and its capacity. These abilities ensure a rapid, cheap and easy way to adapt to change. One of the new technologies (supporting the adaptability of systems) is a technology of reconfiguration. It allows changing the structure of systems to adaptation functionality and capacity of the system to changing requirements of the system environment.

We propose an engineering method for the mechatronic design of adaptive assembly systems which fully integrates the Virtual Commissioning environments in the design and development process (Fig 9), setting up behavioural models and simulations that will be intensively used to virtually explore all new solution spaces interactively since earlier system design and concept validation stage. The design of adaptive manufacturing system architecture is shown in Fig 15.

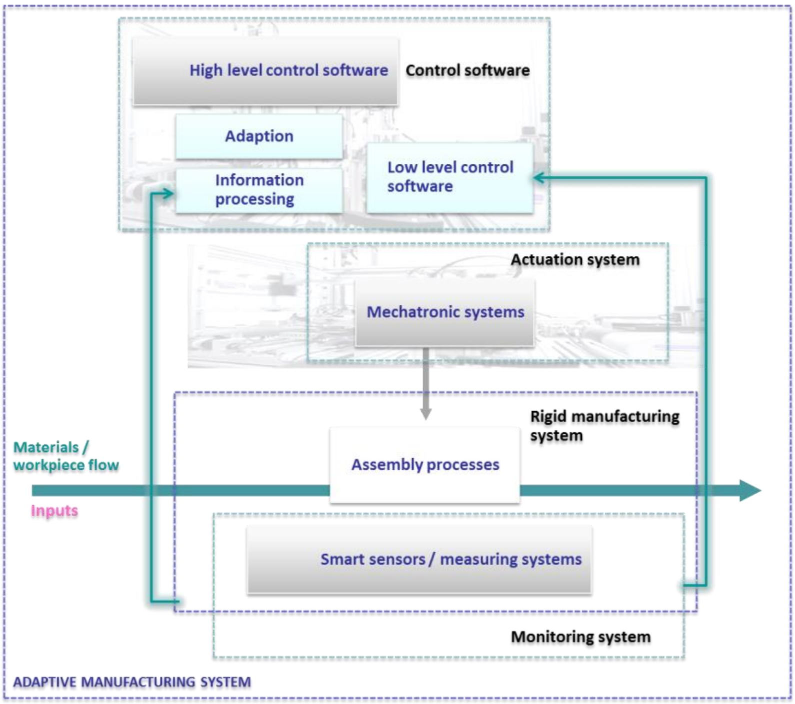


*Fig 15. Adaptive assembly system [35]*

Adaptive manufacturing systems (Fig 15) accomplish enhanced adaptability to changeable environments through increased sensing capabilities and complex control logics, able to self-optimize manufacturing performances and to realize intelligent and adaptive behaviours. The ability to quickly adapt operations, supply chains and products is essential to achieving manufacturing excellence in today's globally competitive markets. The enterprises that can quickly adjust to changing conditions and new market opportunities can seize the moment to gain competitive advantage and improve operating margins. Commissioning includes all functions of electronic devices, ranging from testing the sensors and actuators, various functions of production and distribution of electric drives through parameterization of frequency inverters and booster to test command exchange by application of the device such as control of welding or gluing.

The first phase of Virtual Commissioning ends with the **test relevant manual features of equipment.**

This is followed by the **implementation of automatic functions** in accordance with simulated processes of equipment.
Then is continued **optimization phase** which provides the course of the designed device parameters such as cycle time and availability. In this respect, it plays an important role in the current documentation concerning the various stages of the commissioning process.

New features of adaptive assembly are:

- Holonic autonomous logistics management system in real time. [22]
- Modular structure supporting reconfiguration (plug and produce).
- Mechatronic systems and embedding intelligence, sensors and actuators of equipment (systems for internal shares). [29], [30]
- Sensor technology for the surroundings of the assembly system (for external actions). [31]
- Simulation-emulation systems for decision support. [32]
- Standardized interfaces (mechanical, electrical, electronic, software, network etc.
- Learning system (prior to the event, in action after the event).
- Knowledge base.
- Base of best practices. [33], [34]

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# 2 PROACTIVE PRODUCTION PLANNING SYSTEM

*Peter Bubeník*

## 1. PRODUCTION PLANNING

Production planning is an important task in managing a production system. Complex decisions must be made which impact global objectives such as meeting delivery due dates and maintaining inventory costs. Attempting to consider all of the variables which determine the effectiveness of a particular schedule is highly interrelated and has not been possible in most manufacturing operations. But, as the expense of manufacturing increases, there are major productivity improvements to be realised by making the production scheduling process more effective. The quality of a production schedule involves many, sometimes conflicting, objectives. [1], [2]

While maximising throughput is certainly an important consideration, an ideal schedule will also have the following characteristics:

- Delivery due dates are met.
- Inventory costs are maintained at acceptable levels.
- Equipment, personnel and other limited resources are well utilised and have balanced workloads.
- Adaptations can be made quickly in the event of an unexpected change (equipment failure, raw material shortage, etc.).

It is difficult to optimise a schedule over all these characteristics in practice. Most production schedules choose one to emphasise depending on current production objectives. Generally, a trade-off must be made to reach a balance between the objectives. Production scheduling is done in many ways in practice.

The most common methods of scheduling are purely manual techniques. In the most straightforward form, the department foreman, or the machine operator, selects the job to run next from those jobs waiting in front of the machine. The criteria which are used in this circumstance often reflect the measures by which he is evaluated, and may not reflect overall business objectives. Job status control boards are also used visually layout schedules.

More analytical approach to scheduling is sequencing by dispatching rules. This method uses rules which prioritise the jobs waiting for processing. The effectiveness of the schedule may vary widely depending on the particular rule selected, the type of production facility, and the mix of jobs to be produced. It is difficult to predict the performance of dispatching rules by traditional methods. They are also limited in the scope of what they consider and are often hard to implement on the shop floor.

MRP (Material Requirements Planning) is one of the earliest computerised techniques for factory management. In its earliest form, it generated unconstrained production schedules, which were based on a Bill of Materials and estimated production time requirements. MRP II (Manufacturing Resource Planning) expanded the scope of MRP to consider many other facets of production facility management. In addition to sophisticated factory accounting capabilities, modules for capacity planning and shop floor data collection were also provided. These techniques are effective for longer term scheduling and order launching but lack the detail necessary for effective day to day production scheduling. [3], [4]

Production planning and scheduling play a key role in helping management achieve its goals in this ever changing and competitive environment.

The primary objectives of production planning and scheduling in modern manufacturing environment are next:

- Produce on time what has been planned and promised.
- Minimize work in process.
- Minimise inventory of finished goods.
- Maximise the utilisation of capital assets and other resources.
- Increase throughput by reducing makes time.
- Minimise the cost of production.

Traditional planning systems such as ERP (Enterprise Resource Planning) utilise a stepwise procedure to allocate material and production capacity. This approach is simple but cumbersome and does not readily adapt to changes in demand, resource capacity or material availability. Materials and capacity are planned separately, and many systems do not consider limited material availability or capacity constraints. Thus, this approach often results in plans that cannot be executed. However, despite attempts to shift to the new system, attempts have not always been successful, which has called for the combination of management philosophy with manufacturing.

Unlike previous systems, APS (Advanced Planning and Scheduling) simultaneously plans and schedules production based on available materials, labour and plant capacity.

APS may be applied where one or more of the following conditions are present:

- Make-To-Order (as distinct from make-to-stock) manufacturing.
- Capital-intensive production processes, where plant capacity is constrained.
- Products 'competing' for plant capacity: where many different products are produced in each facility.
- Products that require a large number of components or manufacturing tasks.
- Production necessitates frequent schedule changes which cannot be predicted before the event.

## 2. PROACTIVE PLANNING SYSTEM

Series of processes after receiving an order up to its realisation are interdependent. They communicate important information with each other and are processing it with appropriate algorithms. Information flow is defined by
a structure of these processes and by a sequence of their execution. Starting with individual processes is managed by predefined rules.

Depending on a characteristic of the proactive approach, some changes of processes may start before the system begins to respond to individual occurring events. In a real world, the correctness of using of selected planning actions, methods and techniques of planning depend on reality, by reviewing if changes in processes were started correctly and if required goal was reached at the end.

Proactive approach controls given situation by active influence on given process before an unwanted situation occurs. Opposite approach is characteristic by reacting on the situation after it happens. Based on aforementioned characteristics we can conclude that proactive approach in knowledge-based systems for manufacturing planning assumes that manufacturing planning system will play an active role in fulfilling objectives based on requirements defined by company management. [5], [6]

The proposed system of proactive planning consists of: planning module (PM), system for transformation and analysis of selected indicators, knowledge
the expert system for the design of a proactive manufacturing plan contains analytics module (AM) and for modelling previously unknown situations it is used simulation module (SM) (Fig 1). The simulation module enables to simulate the resulting variants for newly created problems. [7]

The system of a proactive plan is possible to be set by the expert system, whose knowledge base acquires knowledge gained by data mining (DM) from the data warehouse (DW), to which access is controlled via interference mechanism (IM).

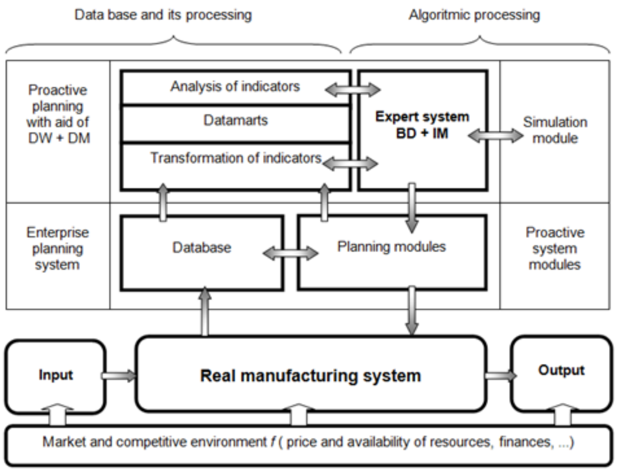


*Fig 1. Proactive production planning system [5], [6]*

## 3. PLANNING MODULE (PM)

It is difficult to optimise a schedule overall characteristics in practice. From most production schedules choose one to emphasise depending on current

production objectives. Generally, trade off must be made to reach a balance between the objectives. Production scheduling is done in many ways in practice.
The most common methods of scheduling are purely manual techniques. In the most straightforward form, the department foreman, or the machine operator, select the job to run next from those jobs waiting in front of the machine.

The criteria used in this circumstance often reflects the measures by which be is evaluated, and may not reflect overall business objectives. Job status control boards are also used visually layout schedules.

A more analytical approach to scheduling is sequencing by dispatching rules. This method uses rules, which prioritises the jobs waiting for processing. The effectiveness of the schedule may vary widely depending on the particular rule selected, the type of production facility, and the mix of jobs to be produced. It is difficult to predict the performance of dispatching rules by traditional methods. They are also limited in the scope of what they consider and are often hard to implement on the shop floor. Managers have historically disliked that they had to wait a long time for analysis. With the computing capabilities and graphics constructs that are now available managers not only can get a quick response for analysis of work order scheduling or work order release, they can also receive the information in an easily understood form. [8]

Major advances in databases technologies have been mad and the computer is now a common sight on the shop floor. These improvements make the access and manipulation of data for real-time factory control a real possibility. Therefore been designed electronic planning board. The production planning process has two layers (Fig 2). Data of order (customer, order number, batch size, due date) are downloaded from ERP system into PM and all information of product operations (processing times, set-up time) are held in the PM database (Fig 3).

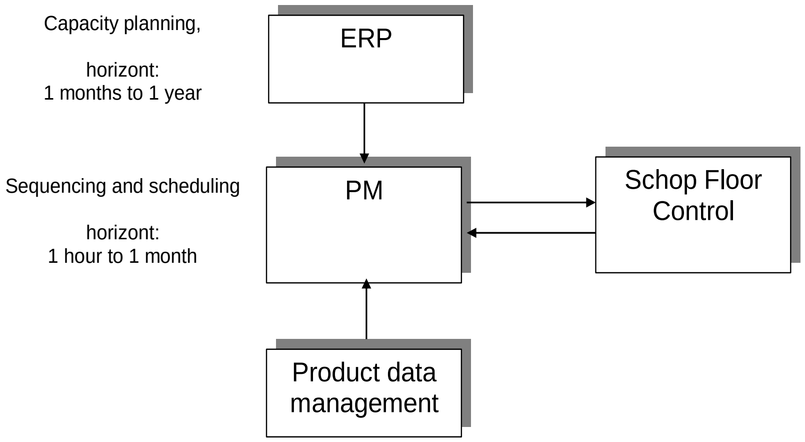


*Fig 2. Production planning process [8]*

The top layer represents long-range scheduling or traditional production planning and control. This layer, forecasters estimate the capacity and resources needs to be based on estimated sales or orders for a relatively large time horizon (information loaded from ERP system).

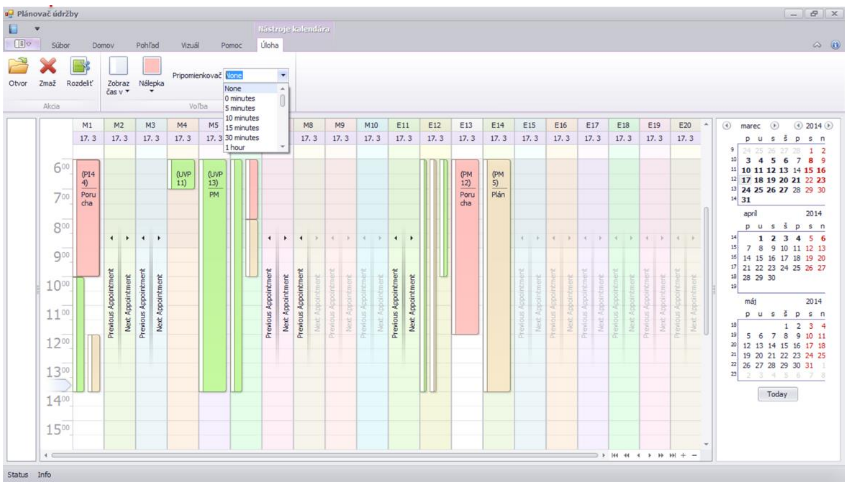

*Fig 3. Planning module - long-range scheduling [9]*

The second layer represents detailed or operational scheduling; here the time frame is on the order of hours to several days and hours. Exact sequencing is determined for each machine. The scheduler concentrates most of his effort on this layer (Fig 4).

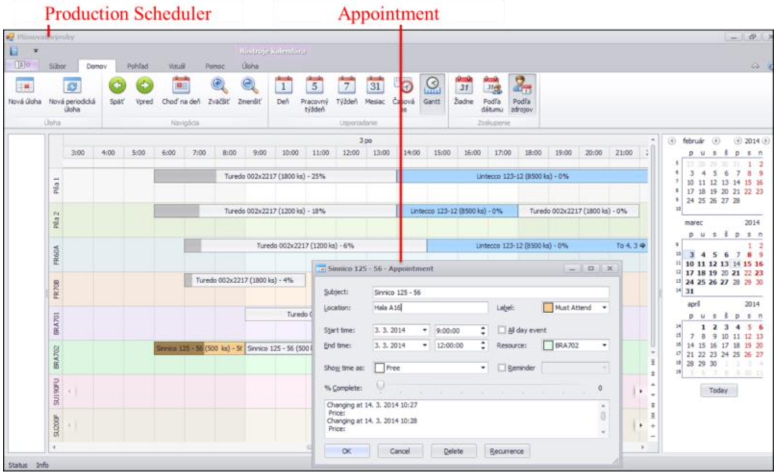


*Fig 4. Planning module – Sequencer [9]*

Planning module can be used as a graphical MPS (Master Production Schedule) where orders are loaded with product information, which provides a finite schedule. This step is performed repeatedly until the schedule meets a prescription objective. This objective may be handed down from management, such as minimising production costs, short lead times.

The heart and soul of planning is the sequencer (Fig 4). The sequencer is essentially an electronic planning board where resources and the operations scheduled for processing on each resource are displayed. In the bottom half of screen, the sequence overview displays each resource and the operations scheduled on them in an easy-to-read Gant format.

Above the sequence overview, individual resource windows with colourful icons used to represent the loaded operations.

Sequencer process [8]:

1. System loading orders with product information (number of orders, quantity, bill of materials, due date, technologies).
2. System sequencing orders by type of production technologies, due date.
3. Making batches from orders by a minimising amount of set up time.
4. Forwarding jobs all batches on the timeline for each machine, when a machine is not busy, jobs waiting.

5. System analysing objective (meet of a due date, a minimum amount of set-up time, work in process, lead time).
6. If the schedule does not meet a prescription objective, it possibilities unloads jobs and changing a sequence, operators changing batches, variants of technologies and enter actual operation times.
7. When a schedule is ready to be released, RV offer you basic alternatives of printed reports available
8. New orders added, back to step 1 (Fig 5).

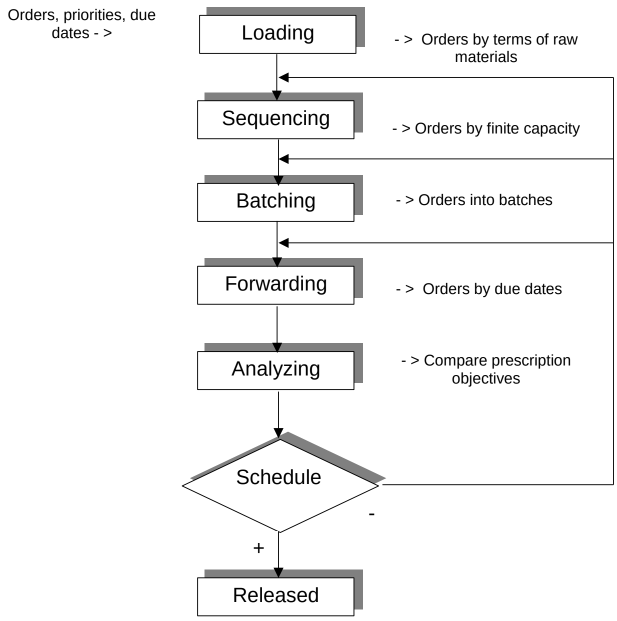


*Fig 5. Sequences of planning in (PM) [8]*

To improve the structure of the plan is appropriate to use historical data and perform online analysis that advises scheduling rule. This role provides analytical module (AM).

## 4. DATA MINING IN MANUFACTURING ENVIRONMENT

Data mining can be characterised as an interdisciplinary subfield of computer science. It is a computational process and its goal is usually to find patterns in large data sets.

These patterns can be presented, stored and used as actual knowledge, and therefore aid decision processes. [10] Disciplines that are considered to have a large impact on data mining are:

- Artificial intelligence (AI).
- Machine learning (usually also considered as part of AI).
- Statistics.
- Database systems.

There have been numerous examples of applying data mining techniques and algorithms in various fields of human endeavour.

However, as it is with almost every method, data mining also has some initial requirements in order for analysts to use it.

Analysed data should be:

- Complete (at least during analysed time frame).
- Consistent (significant changes during the analysed time frame should not occur).
- Correct (deprived of the influence of human factors as much as possible).

There are several tasks which data mining is considered to be able to solve. We can aggregate those tasks into following groups:

a) Anomaly detection.
b) Detection of unwanted events treatment of outliers in data.

Association rules mining:

- Discovering groups of products frequently bought together.
- Predicting possible defects.

Clustering:

- Group technology coding.
- Analysis of stock items.

Regression:

- Predicting demand.
- Modelling of indicator relationships.

Classification:

- Decision support.
- Items sorting.

Summarization:

- Visualisation of performance.
- Discovering cyclical factors.

Data mining is the process of applying these methods with the intention of uncovering hidden patterns in large data sets. It bridges the gap from applied statistics and artificial intelligence (which usually provide the mathematical background) to database management by exploiting the way data is stored and indexed in databases to execute the actual learning and discovery algorithms more efficiently, allowing such methods to be applied to ever larger data sets.

Knowledge exists in all business functions, including purchasing, marketing, design, production, maintenance and distribution, but knowledge can be notoriously difficult to identify, capture and manage. [11] Simply stated, data mining refers to extracting or mining knowledge from large amounts of data. [12]

Due to large amounts of data generated and collected during manufacturing execution, manufacturing is a promising area of application for data mining to extract knowledge for optimisation purposes. [13]

## 5. SEARCH AND FORMALIZATION OF KNOWLEDGE THROUGH DATA MINING ALGORITHMS

Following data mining algorithms were used to seek knowledge in the dataset:

- Neural networks.
- Random forests.
- Linear regression.

Data Transformation is next very important step in data mining workflow. Here users join various data from different sources, fix missing data, specify and convert types, bin continuous variables and aggregate data by various parameters. These data are being prepared for the next stage, which is Analytics and Data Mining.

This is the most important step because it represents the core of the analysis, where data are being mined in order to acquire knowledge. Various algorithms such as aforementioned Decision Trees and Association Rules are applied right at this stage in the form of mining nodes. Next stage of Data Visualization offers various types of graphical nodes, which are able to plot many dimensions of interest at the same time (Fig 6).

Acquired knowledge which is formalised as a result of data mining nodes can be exported as a report, written into a database. [14]

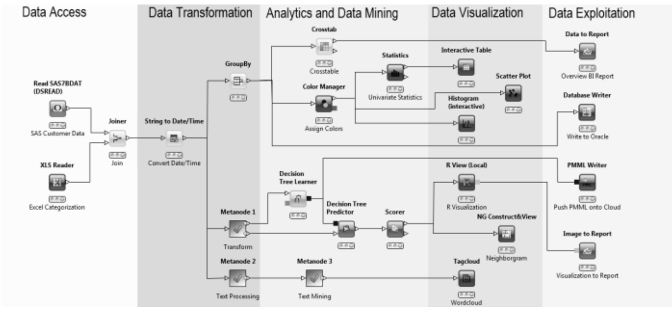


*Fig 6. Data processing stream and knowledge acquisition using KNIME [5]*

Acquired knowledge [15], [16] can be written in PMML format and added to the knowledge base, which is together with inference mechanism and the user interface capable forming of functioning knowledge system.

## 6. ANALYSIS MODULE (AM)

The Proactive planning system allows historical information obtained from the realised production orders, from their proposed plans and the actual behaviour to be utilised for repeated use in the design of the production plan. This production plan can be called "proactive" because it will be constructed with knowledge of expected known and unknown events. This interconnection of information technologies enables to detect problems early and to avoid them.

The proposed system is based on planning modules, and the concept also allows acquiring these data from the existing ERP systems.

The resulting data of realised business cases, purchases and realised production, but also the resulting economic evaluation of the performance of manufacturing company is transformed into indicators at the end of the business case. The module captures the change of indicators and their development also after changes in the input parameters. The dynamics of the system are captured and indicators can assist in the design of a new production plan. Algorithm of the module describes the transformation of the data to indicators that reflect the state of the manufacturing system at a given time in Fig 7.

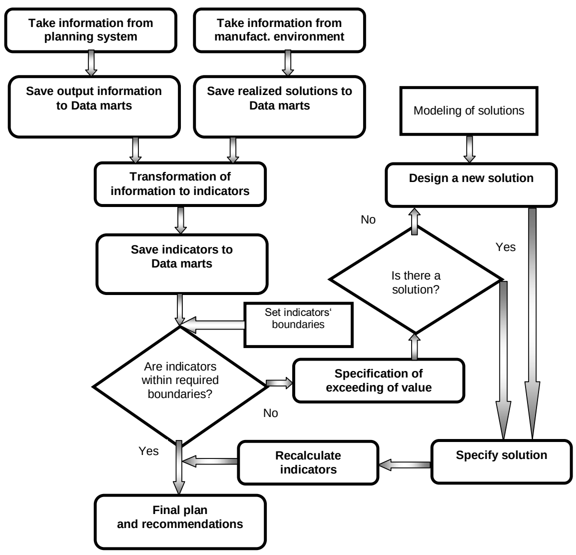


*Fig 7. Algorithm of Analysis module (AM) [5], [6]*

The result of individual steps is the evaluation of implementation of the proposed plan using the required economic indicators as well as customer requirements, which clearly determine the suitability or unsuitability of the decision made. In the case of using modelling tools, the module enables to define the upper and lower boundaries of individual indicators or the definition of warning about potential failure caused by the decision.

Hierarchy of indicators is designed in the way that it could describe as accurately as possible what is happening in the company and what is the development of customer requirements, in order to satisfy him in terms of time, volume and quality.
Finding a suitable setting of indicators and searching for known and less known causes and relations to successfully plan production in this concept ensures
the top module, which will search and recommend best plan variants based on historic and present values of indicators.

The best variant is characterised by required values of selected parameters, which will be adjusted by production planner, market analyst and chief economist.

On exceeding of the boundary set for selected indicators, the system would respond by querying the data warehouse using data mining techniques to help find a solution based on our knowledge of the processes we have so far. After implementation of the selected solution, the system as an expert would make a conclusion making an entry into the system. The content of the entry would be a result that brought the decision.

Proactive production planning with a support of data technologies requires a high-quality database platform with an integration of techniques for data mining. Great emphasis is put on the design and type of information, their location and how to work with them to make gradual information processing leading to usable knowledge that would be used by the expert system for further work in order to design a more suitable plan.

This structure ensures that comprehensive information on the status and development of indicators for a selected business case are available at given time and that it is possible to determine which parameters and their development and indicators caused the adverse conditions. Or in another case, which warnings were issued with enclosed record of action taken or not taken by the responsible manager.

## 7. SYSTEM OF INDICATORS

Companies create a number of indicators for monitoring the performance of individual processes. The existing system of indicators and their influencing parameters is necessary to be arranged in a suitable structure for the purpose of further use.

Selected indicators from the system of indicators are for example. [17], [18], [19], [20] The present module in Fig 8 is considering a group of selected indicators, which will be constantly updated through the data warehouse. Emerging situations will be analysed by data mining methods such as decision tree learning.

The resulting knowledge of the behaviour of the indicators in a given situation will be entered into a knowledge-based system for further use.

Production engineering indicators:

- The number of documents processed per employee.
- The processing time for a single document.
- The number of defective / returned documents.
- The number of unrealized orders.

Planning indicators:

- Production capacity utilisation.
- Downtime of machinery.
- Product range composition.
- The number of overdue tasks.

Size of the work in progress:

- Average time to complete order.
- The average delay time.
- The average number of requests per workplace.

Manufacturing indicators:

- The average number of items produced per department, per order.
- The degree of standardisation, mechanisation and automation.
- The average number of items planned per worker.
- Average time to process orders.
- The cost of production order.
- The cost of downtime.
- The cost of maintenance.

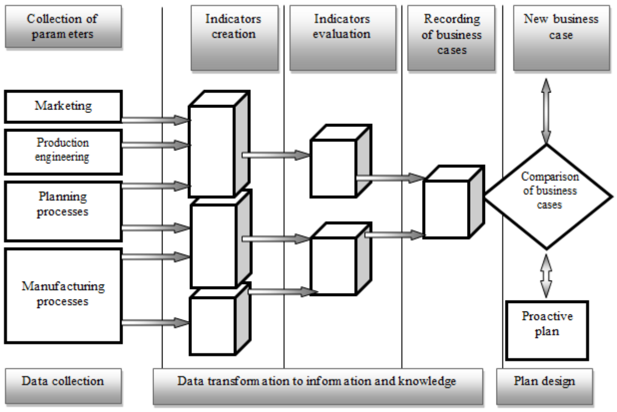


*Fig 8. System of transformation of indicators of Analysis module (AM) [5], [6]*

## 8. SIMULATION BASED SCHEDULING

Historically, simulation techniques have been highly successful and used extensively for the planning and analysis of current operations or proposed designs. A simulation is an analysis tool that can effectively be applied to a variety of shop floor design and real-time shop floor control problems. [20], [21], [22] The simulation will support longer term system design evaluation involving resource requirements, and sensitivities to a variety of product demand and equipment performance probabilities. The simulation will also support shorter term decisions involving equipment scheduling, shop order release and work order scheduling.

- On-line simulation analyses are feasible and can be cost effective, however, applications of simulation in this mode have been few.

- On-line applications of simulation for real-time shop floor control purposes can only be applied effectively if the data supplied to the simulation models are accurate, organised, and timely.

Major advances in databases technologies have been made and the computer is now a common sight on the shop floor. These improvements make the access and manipulation of data for real-time factory control a real possibility. A modeller can now construct a simulation model of an operating unit and supply this model with accurate and timely data describing the performance of machines and operators and the expected demands on the system. With these inputs to the model, accurate and usable results can be provided in the short term that will help to control the process. Other data processing improvements that facilitate the use of simulation for on-line analysis involve computing power graphics.

Managers have historically disliked having to wait a long time for analysis. With the computing capabilities and graphic constructs that are now available managers not only can get a quick response for analysis of work order scheduling or work order release, they can also receive the information in an easily understood form. The major use of simulation in manufacturing is for facility design. That is, changes to existing systems may be evaluated or completely new systems can be developed and their performance predicted using simulation. [23], [24], [25] Most of these models are used once and they discarded.

Simulation practitioners are familiar with the ability of simulation models to predict system behaviour in great detail. It is a natural extension to want to apply simulation on a day to day basis to predict schedule performance and resolve problems before they occur. Simulation is well suited to that type of analysis and, with proper support, can be used successfully to create and evaluate production schedules. The simulation model forms a computer replica of the department in the factory. The model plays the schedule and provides the details of feasible schedule, given the constraints specified in the model. The detailed interaction of various production limitations can be included at any level of detail.

The scheduler may have many options for selecting the transfer batch size in a production order. He may process the entire order at each operation or he may split the order into two, or more, separate loads and allow them to move independently through his operation. The simulation would allow him to contrast alternatives and select the one which provides the best performance. Because this analysis is performed on a computer, many alternatives can be explored with relatively little expense. Simulations models can represent all factors critical to a manufacturing system's performance in as much detail as necessary. The influence of tooling, personnel and other resources can be evaluated in the output reports of the model. All resources have limited capacity so schedules are realistic. Capacity changes, such as a machine breakdown or a scheduled maintenance, may also be included in the model.

Most simulations languages have the modelling features available necessary to represent production systems. But there are many additional needs scheduled which are not typically provided. To be effectively used for scheduling, simulation models must provide reports which can be readily understood and used by the production scheduler. Preferably, reports should be provided which serve as actual job performance schedules for equipment and personnel. Also, a strong user interface is needed to support the scheduler and allow him to create schedules and other reports easily. He should not have to interact with the details of a simulation model but be able to use it easily. Most simulation languages do not provide these features. Traditionally, simulation models of production facilities have been too expensive to build and too cumbersome for use on a daily basis. The modelling process required a highly trained and experienced analyst with a solid understanding of both the simulation language and the system under study. Even after the model is completed, detailed models could take too long to execute to be useful in production scheduling.

## 9. SIMULATE MODULE (SM)

Simulations lend meaning to data and can be updated and adapted as further data come in. [14] It often happens, that provided historical data are not sufficient to derive relevant knowledge.

This occurs for a number of reasons, the most common ones are:

- The unpredictability of external factors affecting the operation of the production system.
- Inadequate recording of the data needed for analysis.
- Incorrect data caused by human factor.
- Incompatible corresponding resolution of analysed data.

- Lack of data due to the newly implemented system.

In such cases, it is possible to use simulation, in which the listed historical data are used, if possible, in the following tasks:

- Elimination of attributes that do not affect the target parameter.
- Setting the probability distribution of the process attributes.
- Simulation model validation.

If the historical data are not available at all, as often happens in a case of designing new production systems, simulation is the only way to obtain data necessary to derive applicable knowledge.

The heart of data mining is knowledge discovery, as it enables to discover relevant objects and the relationships that exist between these objects, while simulation provides a vehicle to represent those objects and their relationships. [10]

Proposal of the service activities model comes out of the present theoretical knowledge basis, analysis of the present situation within the area of service activities and best practices.

The basis for this model proposal is the knowledge of Facility Management structures, which is the area directly following the history of services development and particular support functions development. Workflow to build up the model is as follows:

- Creating the environment, i.e. unifying the principles of planning, decision-making, performing and controlling of such activities, as well as making the unity of understanding the service activities as a meaningful function of organisations.

Removing sizable differences among various sections, divisions, departments, subsidiaries or joint ventures within a group/holding (not just from the organisational point of view) when the responsibilities, respectively sponsorship and consequent activity coordination (for example the coordination in terms of investment procurement, maintenance, practicing the unified technical policy, etc.), are highly questionable:

- Eliminating various disproportions (organisational, technical, controlling, etc.) to increase overall effectiveness, respectively to reduce overall expensiveness/costliness of an organisation and to increase the motivation for performing the service activities in this way.

- Defining the rules of monitoring by designing the key performance indicators (KPI-s) and setting their calculations up, we can measure and assess the performance and effectiveness of service activities.

For the fulfilment assessment of objectives, the key performance indicators are defined to evaluate the increasing effectiveness of particular Service Activities System items.

## 10. VERIFICATION PROACTIVE PRODUCTION PLANNING SYSTEM AND THEIR BENEFITS FOR MANUFACTURING PLANNING AND CONTROL

Planning and control of manufacturing process is a complex task because it is influenced by many factors which have an impact on time and quality of delivery of required product. Employees at the manufacturing control level are responsible for fulfilment of defined performance indicators.

Every day they are forced to solve problems related to insufficient quality or performance at the workplace [30]. Employees or information systems monitor and record information about process states, which is later additionally discussed with manufacturing operators. A usual feature of manufacturing is variability in performance and quality. Same order assigned to different manufacturing teams produces different values of performance and quality. This fact creates a question if there is a variant of manufacturing plan, in which planner/supervisor assigns manufacturing task to workplaces and operators so that he can reach highest possible effectivity of production process.

We tried to find the answer by experiment in a manufacturing company, where the final product, with 70 possible variants, is manufactured by pressing. This company owns three machine presses and operates two shifts. Final production can be characterised by the occurrence of 15 types of defects, which together create defected items of approximately 15 % of all items produced.

The aim of the experiment was to find out if poor production quality of selected range of products is caused by a particular press, and to what extent is this poor quality dependent on particular operator. By applying data mining methods to 20 most defective variants, we concluded that defectiveness of particular variant is very likely to be dependent on the selection of particular press, as shown in Fig 9. These dependencies can also be seen from visualisation of a relation between defectiveness, particular variant and selected press, as can be seen in Fig. 4. By using data mining methods, the specific support system can be created, which could help planner in decision-making processes. [5], [6]

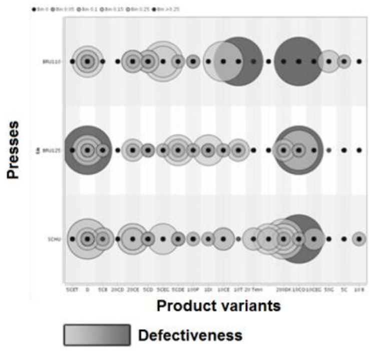


*Fig 9. Relation between defectiveness, variant and press [5], [6]*

The similar situation can be observed when we visualise defectiveness in a relation of operators to particular presses as shown in Fig 10. Three different operators perform differently while producing the same products on the same machines, which can also be knowledge, used either for investigating possible reasons for differences in defectiveness of items among operators, or to simply accept this distribution and use it for prioritization of operators based on their ability to produce lowest amount of defective items.

The result of data mining process, which can partially be seen in Fig 11, is a model that can be used for creating the most efficient plan based on given circumstances, which then increases a probability of lower defectiveness in future. This model was created by inputting historical manufacturing data into decision tree learning algorithm.

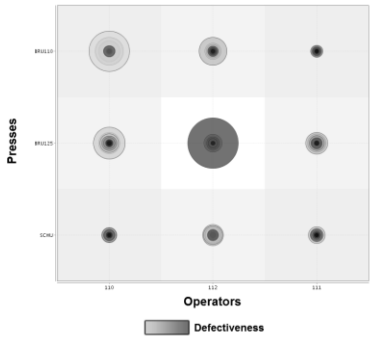


*Fig 10. Relationship between defectiveness, operator and press [5], [6]*

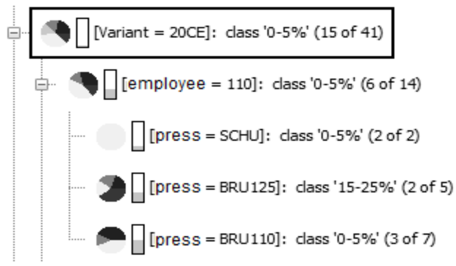


*Fig 11. Proposed model for assigning production tasks [5], [6]*

If a planner considered these sets of knowledge during the creation of production plan, a company could significantly lower its amount of defective products. For instance, during the production of variant 20 CE by assigning employee 110 to press SCHU the probability of occurrence of defects lowers to 5 %. The scheduler would then prioritise assigning employee 110 to presses SCHU, BRU125 and BRU110 respectively. [5]

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# 3 DEVELOPING OF THE LOGISTICS STRATEGY

*Ľudmila Závodská*

## 1. STRATEGIC MANAGEMENT

Strategy is about planning as distinct from doing. It is about formulating a long-term plan for the supply chain, as distinct from solving the day-to-day issues and problems that inevitably occur. The term logistics strategy combines two important areas of the business environment - logistics and strategy. In both cases, there is not one valid, globally accepted definition that would accurately reflect their importance.

### 1.1. Strategy

There is no united opinion on the process of strategic management and also on defining the strategy itself. The strategy, above all, answers the question How.

- How to gain required outcomes?
- How to overcome rivals?
- How to create and keep competitive advantage?
- How to strengthen long-term position of the enterprise on the market?

The corporate strategy is being created at the top management level. The business strategy is being created lower, at the level of business units, and further at the level of functional areas there are functional strategies to be made.
There are various levels of strategies which are depicted in the Fig1 [1]:

- **Ownership strategy** – expresses the interests of the owner; determines the structure of receivables, liabilities, sources of income, the range of investment, responsibilities and competences of the top management; it represents a starting point for managing the business at the top level.
- **Corporate strategy** – embodies the effort to manage a set of business areas where the enterprise takes actions for the fulfilment of its goals; it addresses the issue of investment distribution into individual businesses, removal of marginally profitable businesses, extension of the business portfolio, reinforcement of existing businesses; it is formulated at the top

management level; it is approved by the corporate owners (board of directors, supervisory board).

- **Business strategy** – it is a strategy of business unit which relatively independently operates on the market; it deals with the question how to strengthen competitive position of the unit and with specific issues that are typical only for the particular business unit (extension of the production capacity, renewal of obsolete production equipment, focus on research...); it is formulated by the head of business unit.
- **Competitive strategy** – it is a part of business strategy; it answers the question how to compete; it is oriented inward industry whereas business strategy reacts also to factors outside the industry; it determines methods and techniques of competing and both, offensive and defensive measures to ensure the position ahead of competitors or protection of the current position.
- **Functional strategy** – supports business and competitive strategy; its task is to design a way how to fulfil goals of functional area; it is formulated for all significant functional areas such as marketing, production, finance, human resources; it determines how functional activities will be managed; the responsibility for creating this strategy goes to the head of functional area; it is being approved by higher management level.
- **Operational strategy** – adds substantial details and completes the hierarchy of strategies; it refers the closer strategic initiatives in management of key business units (e.g. plants and distribution centres) and in solving daily operation tasks that are strategically significant (commercial campaigns, material procurement, inventory management, maintenance ...).


*Fig 1. Hierarchy of strategies in company [1]*

### 1.2. Strategic management model

Strategic management consists of four basic elements:

- Environmental scanning.
- Strategy formulation.
- Strategy implementation.
- Evaluation and control.

Fig 2 illustrates how these four elements interact; Fig 3 expands each of these elements and serves as the model for this book. This model is both rational and prescriptive. It is a planning model that presents what a corporation should do in terms of the strategic management process, not what any particular firm may actually do. The rational planning model predicts that as environmental uncertainty increases, corporations that work more diligently to analyse and predict more accurately the changing situation in which they operate will outperform those that do not. Empirical research studies support this model. [2]

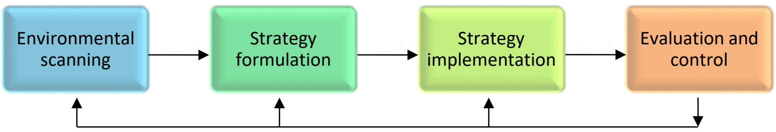


*Fig 2. Basic elements of the strategic management process [3]*

Environmental scanning is the monitoring, evaluating, and disseminating of information from the external and internal environments to key people within the corporation. Its purpose is to identify strategic factors – those external and internal elements that will determine the future of the corporation. The simplest way to conduct environmental scanning is through SWOT analysis. SWOT is an acronym used to describe the particular Strengths, Weaknesses, Opportunities, and Threats that are strategic factors for a specific company. The external environment consists of variables (Opportunities and Threats) that are outside the organization and not typically within the short-run control of top management. The internal environment of a corporation consists of variables (Strengths and Weaknesses) that are within the organization itself and are not usually within the short-run control of top management. These variables form the context in which work is done. They include the corporation's structure, culture, and resources. Key strengths form a set of core competencies that the corporation can use to gain competitive advantage. Strategy formulation is the development of long-range plans for the effective management of environmental opportunities and threats, in light of corporate strengths and weaknesses (SWOT). It includes defining the corporate mission, specifying achievable objectives, developing strategies, and setting policy guidelines. Strategy implementation is a process by which strategies and policies are put into action through the development of programs, budgets, and procedures. This process might involve changes within the overall culture, structure, and/or management system of the entire organization. Except when such drastic corporate wide changes are needed, however, the implementation of strategy is typically conducted by middle- and lower-level managers, with review by top management. Sometimes referred to as operational planning, strategy implementation often involves day-to-day decisions in resource allocation. Evaluation and control is a process in which corporate activities and performance results are monitored so that actual performance can be compared with desired performance. Managers at all levels use the resulting information to take corrective action and resolve problems. Although evaluation and control is the final major element of strategic management, it can also pinpoint weaknesses in previously implemented strategic plans and thus stimulate the entire process to begin again. [2]

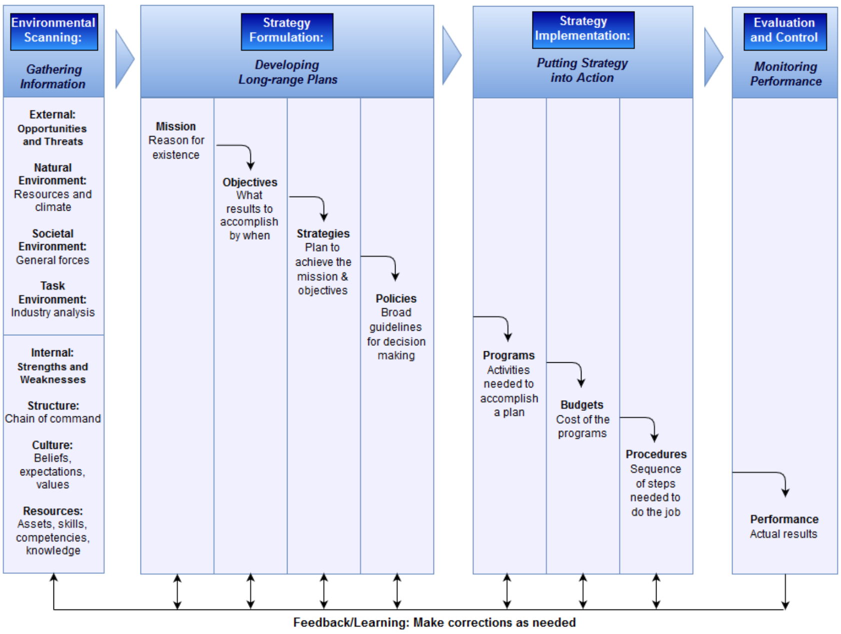


*Fig 3. Strategic management model [2]*

### 1.3. Logistics strategy

The term logistics has a commonly used definition: management of the flow of product from source to point of use. But the concept of a logistics strategy and how it relates to all components of logistics is often confusing for practitioners. If you ask ten managers what are the key issues which should be involved in logistics strategy you would get ten different answers. Useful framework for creating and thinking about logistics strategy is the logistics strategy pyramid (Fig 4). [1]

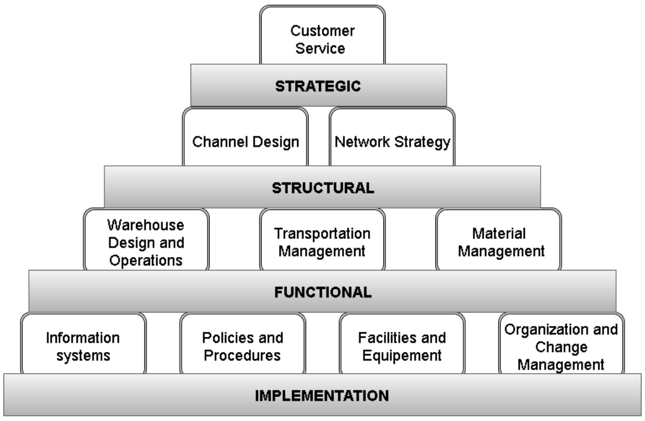


*Fig 4. Logistics strategy pyramid [1]*

Each part of this pyramid is influenced by a lot of factors from internal and also external environment. For example, transportation management is influenced by modern types of handling equipment, new technologies used in warehouses etc. Extending the concept of strategy from Hayes and Wheelwright (1984).

Logistics strategy is the set of guiding principles, driving forces and ingrained attitudes that help to coordinate goals, plans and policies, and which are reinforced through conscious and subconscious behaviour within and between partners across a network. [4]

## 2. PROCESS OF LOGISTICS STRATEGY MANAGEMENT

Making quick, informed decisions can save a company up to 40 % on logistics costs, so one of the best practices in logistics management is to implement a fine-tuned logistics strategy. Developing and implementing a formal logistics strategy will add flexibility to the decision making process and increase error-response time. A deliberate strategy will let a company predict service disruptions and know how and when to respond to them to ensure service levels stay at peak performance. [5]

## 2.1. Environmental scanning

Before an organization can begin strategy formulation, it must scan the external environment to identify possible opportunities and threats and its internal environment for strengths and weaknesses. When we speak about logistics strategy, we must take into account factors which influence logistics processes. Internal scanning can be performed by logistics audit. There are mainly technological and ecological factors in external environment which have a great impact on logistics.

### 2.1.1. Scanning of the external environment

The origin of competitive advantage lies in the ability to identify and respond to environmental change well in advance of competition. A corporation's external strategic factors are the key environmental trends that are judged to have high probability of occurrence and a high probability of impact on the corporation. Regarding logistics, it is the most affected by technological change and ecology. There are described in the text below some of current technology trends and green logistics.

**Big Data in Logistics**

The combination of large, fast-moving, and varied streams of big data and advanced tools and techniques such as geoanalytics represents the next frontier of supply chain innovation. When they are guided by a clear understanding of the strategic priorities, market context, and competitive needs of a company, these approaches offer major new opportunities to enhance customer responsiveness, reduce inventory, lower costs, and improve agility. Companies can optimize distribution, logistics, and production networks by using powerful data-processing and analysis capabilities. They can also improve the accuracy of their demand forecasts, discover new demand patterns, and develop new services by sharing data with partners across the supply chain. In addition, they can increase asset uptime and expand throughput, engage in preventive maintenance of production assets and installed products, and conduct near real-time supply planning using dynamic data feeds from production sensors and the Internet of Things. But with so much available data and so many improvable processes, it can be challenging for executives to determine where they should focus their limited time and resources. Companies are typically in the early stages of exploring how to benefit from their growing pile of data, and put this data to good use. According to recent research, only 14 % of European companies already address Big Data analytics as part of their strategic planning (Fig 5). And yet almost half of these companies expect a yearly data growth in their organization of more than 25 %. [7], [8]

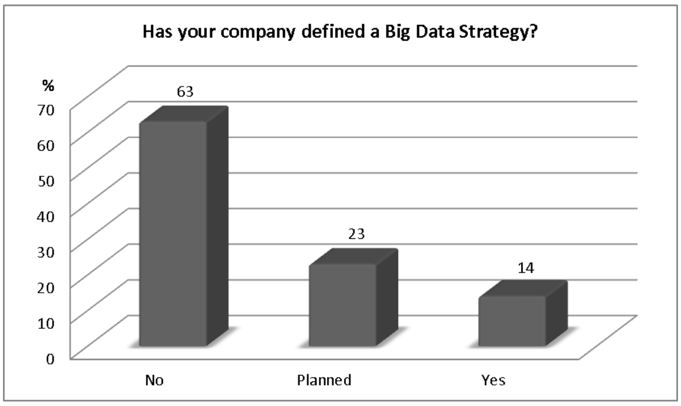


*Fig 5. Results of research about big data strategy [9]*

**Augmented reality in Logistics**

Although AR is in relatively early stages of adoption in logistics, it could offer significant benefits (Tab 1). For example, AR can give logistics providers quick access to anticipatory information anytime and anywhere. This is vital for

the prospective and exact planning and operation of tasks such as delivery and load optimization, and is critical to providing higher levels of customer service. In logistics, the most tangible AR solutions are systems to optimize the picking process. The vast majority of warehouses in the developed world still use the pick-by-paper approach. But any paper-based approach is slow and error prone. Furthermore, picking work is often undertaken by temporary workers who usually require cost-intensive training to ensure they pick efficiently and without making errors. Systems by Knapp, SAP, and Ubimax are currently in the late field-test phase and consist of mobile AR systems such as a head-mounted display (HMD), cameras, a wearable PC, and battery packs that provide enough energy for at least one work shift. The vision picking software offers real-time object recognition, barcode reading, indoor navigation, and seamless integration of information with the Warehouse Management System (WMS).

A key benefit of vision picking is its provision of hands-free intuitive digital support to workers during manual picking operations. [7]

*Tab 1. Augmented reality in logistics operations [7]*

| **Logistics operation** | **Description** | **Main objectives** |
|---|---|---|
| **Pick-by-Vision: Optimized Picking** | The solution offers digital navigation to find the right route and item more efficiently, while reducing training time. | Reduce picking errors and search time |
| **Completeness Check** | AR devices register if a delivery is complete and ready for pick-up. Automated confirmation of pick-up by AR after the correct number of undamaged parcels is recognized. | Time savings, completeness check, damage detection |
| **Dynamic Traffic Support** | Replacement of navigation systems in delivery vehicles with AR devices (glasses or windshield projection). Analysis of real-time traffic data and display of relevant information (e.g. blocked or alternative routes) in the driver´s field of vision. | Improvement of driving safety, minimizing of driver distraction |
| **Freight Loading** | Loader receives load plan and instructions (which pallet to take next and where to put it) directly on their AR device display. | Speed up the freight loading process |
| **Parcel Loading** | Through AR, all parcels are overlaid with critical information (e.g. weight, destination) and handling instructions, and parcels are loaded intelligently into the vehicle. | Improve parcel handling, ensure load optimization |

## Autonomous vehicles in Logistics

There is a strong case for suggesting that the logistics industry will adopt self-driving vehicles much faster than most other industries. The best and most common method today and in the future is to rely on a mixture of depth cameras and lasers on the vehicle; these devices constantly scan and capture the environment to identify the vehicle's position and any obstacles. Vision guidance technology relies completely on cameras that perform 360-degree depth scans of the environment in order to create a 3D map which the vehicle then uses for navigation. These are the next generation of self-driving vehicles in warehouses and they have complete, flexible navigational authority, enabling a much larger range of potential applications and autonomy. Self-driving vehicles in warehouses have the ability not just to transport goods but also to combine other process steps such as loading and unloading in order to increase the overall efficiency of an entire process. In addition to providing efficiency gains, self-driving vehicles can also significantly increase safety in transport and loading processes. [7]

**Automatic logistics systems**

For automatic distribution of material in logistics process of manufacturing enterprise are used automatic logistics systems. They increase automation and productivity of logistics and contribute to reducing business costs. AGV system automates pulling wagons with material by a predefined path with the help of logistics trucks in industrial halls. System as a whole improves efficiency of logistics processes while decrease logistics costs. Automated Guided Vehicles are recommended for applications wherein long-distance horizontal transport of materials is required from or to multiple destination points and/or the requirements for material transport include repetitive/predictable and/or dangerous tasks. AGVs also have several advantages inherent to their design, such as the reduction of product damage from removal of human error, the ability to travel into hazardous areas without concern for operator safety, the ability to automatically track and record product movement, the reduction of labour, and the flexibility and adaptability especially prevalent in laser guided systems. One of the main benefits of the AGV is reducing costs by reducing work-in-process, as well as cost savings for employees who are required to operate the truck by manual logistics. [10], [11]

Calculations from a case study of employees of Zilina University show that the total annual costs of manual logistics are 182 160 € while total annual costs of implementation AGV are 89 456 €. The case study was conducted in conditions of subcontractors for the automotive industry, where for supplying was used three forklifts operated by employees. [12]

## Warehouse technologies

Besides various types of manipulation equipment in warehouses are used technologies which help by preparation of orders or materials. There are systems like put-to-light, pick-to-light intelligent glasses, RFID codes and picking by the voice. These technologies can increase productivity of workers by tens of per cent. They are clearly described in
Tab *2*.

*Tab 2. Warehouse technology for productivity increase [13]*

| Warehouse technology | Description |
|---|---|
| **Put-to-light** | Light displays guide the operator to put stock in an order. In Put-to-Light systems light displays instruct the operator where and how to allocate stock to orders, allowing efficient picking from bulk stock. The operator scans each product and flashing light displays at each location indicate which containers require that product and how many items to put. Confirmed put results are updated to the system in real time for host system updates. |
| **Pick-to-light** | Light displays direct operators to specific stock locations. Pick-to-Light systems use light displays to direct operators to specific stock locations. Each product location can have an individual numeric or alphanumeric display with a light, an acknowledgement button, and a digital readout for indicating quantity. Other configurations allow fewer or more simplified displays to reduce the total cost. |
| **Pick-by-voice, Voice recognition system** | Pick-to-Voice relies on voice instructions through headphones and a microphone. Without the need to handle wireless data terminals and paper lists eliminated, the order picker can focus entirely on retrieving the required items. The operation is streamlined – and productivity increases (by 10 % to 20 %). |
| **Intelligent glasses** | Revolutionary paperless picking technology that functions with augmented reality: Virtual information and images coalesce with the real environment. This technology is already being used in the auto industry. The employee wears a special picking headset with a see-through display on which all the relevant information for the picking process is precisely superimposed. Both of the employee’s hands are free for picking. [14] |
| **RFID (Radio Frequency Identification)** | RF handhelds have been in widespread use in warehouses since the early 1980´s when radio transmitters and bar code scanners were integrated into portable handheld units to enable real time data collection when operators perform tasks in the warehouse. RF devices remain the most flexible technology because they can be used across all functional warehouse operations (not limited to order picking). |

Tab 3 shows which technologies are suitable for certain volume of picked pieces of material. The last row shows which handling system is used in these cases. For example, pick-to-light technology is mostly used by picking 200 to 400 items per man-hour and usually is applied in flow racks. Classification of SKU into A, B, C and D category is based on SKU turnaround time. To the A category belong units with the fastest velocity. [15]

*Tab 3. Using of different technology in warehouse depending on number of picked items [15]*

| | Velocity in Order Lines Selected per Paid Man Hour | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Movement category | SKU Velocity Category | 0 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 | 1100 | 1200 |
| | A | | | | | | | Automated / Semi-Automated Picking Technologies (e.g. A-Frame, KIVA…) | | | | | | |
| | A | | | | Horizontal Carousel | | | | | | | | | |
| | A&B | | | Pick-to-light | | | | | | | | | | |
| | A&B&C | | Pick-by-voice | | | | | | | | | | | |
| | A&B&C | | Visual picking | | | | | | | | | | | |
| | C&D | RF Picking | | | | | | | | | | | | |
| | C&D | Paper Picking | | | | | | | | | | | | |
| | | Racks and Static Shelving | | | Pick to Belt Carton & Pallet Flow | | | Carousels & Semi-Automated Systems | | | | | | |

## Green logistics

The green logistics means sustainable ecological orientation in logistics processes. Measuring and controlling the energy efficiency in manufacturing processes is the first step for evaluating and implementing improvement measures. [16]

New energy efficient technologies, clean technologies can contribute to higher energy efficiency of enterprises. The further research will include the development in area of clean technologies, therefore the important terms in the area of environmental and energy sustainability and eco-innovation in logistics systems. Energy efficient logistics is also called green logistics. Concern for the environment is still increasing, so enterprises must take into account the costs related to ensuring of logistics, which is environmentally friendly. When we extend environment with the society as a whole it is possible to speak about sustainable logistics ( Fig.6). [17]

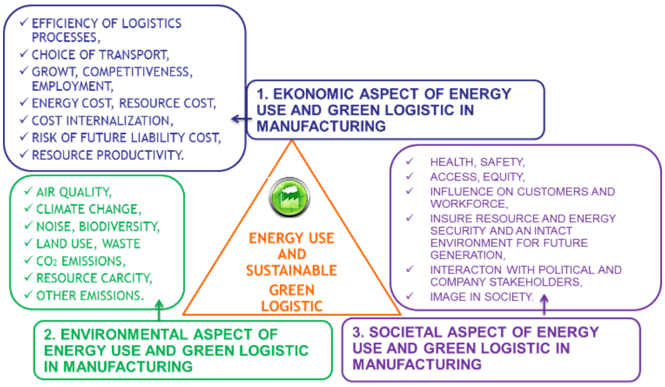


*Fig 6. Contribution of energy efficiency manufacturing and green logistics to the three main aspects of sustainable manufacturing [10]*

### 2.1.2. Scanning of the internal environment

Internal scanning, often referred to as organizational analysis, is concerned with identifying and developing an organization's resources and competencies. In
the area of logistics it means to analyse logistics resources and competencies of logistics. [2]

Main goal of logistics audit is description of current state of corporate logistics and determination the specific activities to change and improvement of logistics processes. Logistics audit or potential analysis examines the capabilities and capacities of operating locations, logistics processes, and the structure of the entire logistics network. [3]

General procedure of implementation logistics audit can be described based on following steps [3]:

1. **Presentation of methodology of logistic audit.** Before starting audit, an auditor has to inform the customer by appropriate form with the basic principles and methodology by which the audit will be carried out.
2. **Preparation of logistic audit.** In this step, it is necessary that the auditor to becomes familiar with the company, its departments and focusing. The main task of auditor is to define main and support processes in company.
3. **Setting the goals of audit**. Before starting the audit it is necessary to determine the goals which have to be achieved by audit.

4. **Audit processing.** In this step, it is necessary to identify all relevant processes in the company and describe its course or compile a process map. This step consists of two phases. The first phase is analysis of current state of company. The auditor by means of observation, communication with employees and company management creates objective view about material, financial and information flows. The second phase is evaluation of current state. Auditor prepares and evaluates obtained data on the basis of established qualitative and quantitative indicators.
5. **Results evaluation.** After determination so-called constraints or bottleneck, auditor suggests measures for its removal. He also may order the activities for application in company. These activities will be carried out according to priorities.

Tab.4 presents a checklist of the most important subject areas and questions to be asked during the logistics process analysis. [6]

*Tab 4. Example of Questions in Process-analysis Checklist [6]*

| Subject Area | Questions |
|---|---|
| **Load units** | Which load units (bins, boxes, pallets, containers, and similar equipment and packaging) do you use in your internal and external logistics chains?<br>Are the dimensions and capacities of the load units harmonized?<br>Are the load units optimized to achieve the best equipment utilization?<br>Who is responsible for the selection and adjustment of the load units in the different stages of the supply chain? What criteria do they use?<br>Are you properly managing the empty equipment and packaging? |
| **Logistics master data** | Are the logistics master data, which are necessary to execute, control, and optimize the logistics processes, complete, up-to-date, and correct?<br>Who is responsible for the management of the logistics data, including data entry, updates, and ensuring accuracy and completeness?<br>Who ensures that the company's logistics data are compatible with the corresponding data of suppliers and customers?<br>Is the exchange of logistics data between internal stations, suppliers, and customers organized correctly?<br>Are you using the most appropriate and efficient technology (for example, EDI or XML) for the data exchange? |
| **Time management** | Is on-time performance in line with the demands of the market?<br>Are you making the most effective use of the available time?<br>Are the possible time strategies, such as synchronization, postponement, or just-in-time, applied in the correct manner?<br>Do you have an efficient system for developing, implementing, and controlling optimal time strategies?<br>What are the time-killing bottlenecks, failure points, and points of delay? |

*Tab 5. Example of Questions in Process-analysis Checklist [6] (continued)*

| | |
|---|---|
| **Logistics costs** | Do you have an effective way to control logistics costs?<br>Who determines whether the costs for internal logistics services and the prices for external logistics services are acceptable?<br>What are the logistics costs per article item or stock-keeping unit, per customer order, per category, per supplier, and per customer?<br>Where and how can you reduce logistics costs without reducing service and performance? |
| **Inventory and stocks** | Who determines the availability level for the storekeeping articles?<br>Are the inventory levels at the different stages in the network necessary and appropriate?<br>Are the buffer and safety stocks sufficient to ensure efficient utilization, uninterrupted operations, and market-driven delivery performance? |
| **Service and logistics quality** | Do you provide the required services with adequate levels of quality?<br>Do you have a quality management and assurance system in place?<br>Are internal and external quality defects regularly recorded?<br>Which quality deficiencies are assessed penalties, and how high are the fines?<br>Are the quality management and control processes sufficiently flexible to meet the changing demands of dynamic markets?<br>What are the failure, delay, and fault points in the supply chain? |
| **Interfaces and connections** | How well do the supply chain partners cooperate?<br>Are the dimensions and capacities of exchanged load units harmonized?<br>Are the flows of material and information between different stations free of interruptions and disturbances?<br>How efficient are communication and the exchange of information along the supply chains? |
| **Scheduling and process control** | Are the available resources and capacities used efficiently?<br>Are the right strategies applied for order scheduling, inventory management and replenishment, and production scheduling?<br>What tools, methods, and programs are used for scheduling, process control, and information exchange and control, and are they applied correctly? |
| **Logistics processes** | How efficient are the current inbound and outbound logistics processes?<br>Are the logistics processes complete and optimized for the different flows of material, parts, and finished goods?<br>What are the strategies and criteria for developing and implementing logistics processes?<br>Are you employing all available strategies, such as optimal bundling and sequencing, and are you getting the greatest possible advantage from them? |
| **Outsourcing** | Which parts of the logistics operation are your company's core competencies?<br>Which services and activities can be efficiently outsourced to suppliers, system providers, or logistics service providers?<br>Who decides whether or not to outsource, and on what criteria do they base that decision? |

## 2.2. Logistics strategy formulation

Once environmental scanning is completed, situational analysis calls for the integration of this information. Now the company knows which are its strengths and weaknesses and which opportunities and threats have an influence on logistics processes.

Logistics strategy formulation is about definition of objectives and policies. Objectives are the end results of planned activity. They should be stated as action verbs and tell what is to be accomplished by when and quantified if possible. Objectives should be SMART: Specific, Measurable, Achievable, Realistic and Time-bound. For example: „to decrease the logistics costs in 2010 by 10 % over 2009. Policies define the broad guidelines for implementation. Flowing from the selected strategy, policies provide guidance for decision making and actions throughout the organization. They are the principles under which the corporation operates on a day-to-day basis. [2]

## 2.3. Logistics strategy implementation

Strategy implementation is the sum total of the activities and choices required for the execution of a strategic plan. It is the process by which objectives, strategies, and policies are put into action through the development of programs, budgets, and procedures. Although implementation is usually considered after strategy has been formulated, implementation is a key part of strategic management. Strategy implementation involves establishing programs to create a series of new organizational activities, budgets to allocate funds to the new activities, and procedures to handle the day-to-day details. [2]

## 2.4. Evaluation and control of logistics strategy

The fact if the implemented strategy is effective should be controlled through measurements of the logistics processes performance. Key Performance Indicator (KPI) is a performance measure, a yardstick for tracking progress and a tool to achieve a goal. KPI encompasses all areas of Business – Demand Management, Supply, Conversion and Delivery. The scoreboard (Tab 6) indicates the Key Performance Indicators of a supply chain and compares the performance of a typical organisation with that of the best-in-class as a benchmark. [18]

*Tab 6. Key Performance Indicators of a typical organisation and the best-in-class [19]*

| No. | Attributes | Typical | Superior |
|---|---|---|---|
| **1.** | Delivery performance | 50% | 95% |
| **2.** | Fill rates | 60% | 98% |
| **3.** | Order fulfilment | 50% | 90% |
| **4.** | Production flexibility | 45 days | 20 days |
| **5.** | Logistics costs to sales | 10% | 3% |
| **6.** | Inventory days of supply | 60 days | 22 days |
| **7.** | Inventory turns | 6.5 | 12 |
| **8.** | Nett asset turns | 3 | 19 |

Key performance indicators are influenced by the type of an organization. For example, 2015 Warehouse Education Research Council Survey reports the top 10 DC (Distribution Centre) metrics [20]:

1. **On time shipments:** The percentage of orders shipped at the planned time.
2. **Internal order cycle time:** The average internal time between when the order was received from the customer and order shipment by the supplier.
3. **Dock to stock cycle time:** The dock to stock cycle time equals the time required to put away goods. The cycle time begins when goods arrive from the supplier and ends when those goods are put away in the warehouse and recorded into the inventory management system.
4. **Total order cycle time:** The average end to end time between order placement by the customer and order receipt by the customer.
5. **Order picking accuracy:** This measures the accuracy of the order picking process where errors may be caught prior to shipment such as during packaging.
6. **Average warehouse capacity:** The average amount of 6 warehouse capacity used over a specific amount of time.
7. **Peak warehouse capacity used:** The amount of warehouse capacity used during designated peak seasons.
8. **Back orders as a percent of total orders:** The portion of total orders that are held and shipped late due to the lack of availability of stock – measured in PO’s.
9. **Back orders as a percent of total lines:** The portion of total orders that are held and shipped late due to the lack of availability of stock – measured in line items.

10. **Percent of supplier orders received damage free:** The number of orders that are processed damage free as a percentage of total orders.

Key Performance Indicators, (KPI), have the potential to put the company to the right, but also to completely wrong direction. The following paragraphs include several most frequent problems related to the use of KPI [13]:

- KPI are not in harmony with strategic goals of the company, e.g. the management wants to raise the quality of service and the satisfaction of the customer, but operation and logistics have set aggressive goals of costs reduction that are not complemented by indicators related to customers (e.g. timeliness of deliveries, number of complaints...).
- KPI are oriented on the explanation of the past and do not provide information about expected performance in the future. That can be provided by the leading indicators (the number of set business presentations,
  the number of presented price offers, the number of orders, the number of complaints, the plan of promotional actions, the number of product innovations being prepared, etc.) that provide more time to react to the management.
- Too many KPI – this indicates that the company does not have clarity about its goals. For example, at the top management level the using of more than 10 KPI is often contra-productive.
- The employees do not understand how KPI are calculated or what data they are calculated of; how KPI are connected to rewarding or they are not connected at all; why certain KPI are tracked or employees think that other indicators are more important.
- KPI are set from the top and without discussion which lowers their acceptance on the side of employees and it creates the culture they vs. us.
- KPI are not set realistically and they cannot be reached with the resources available. Justness of the set goals should be justified by the management through their comparison with the past (reasonable growth), comparison with other parts of the organization (e.g. with other sales teams) or with the competitors (external benchmarking).
- There are only financial indicators used at the level of management and qualitative and operational KPI are missing, management looks at performance of the own company without putting it into the context of external environment (market, economics, customers, competition, macro environment). In this case for example, savings in costs of purchased material can seem to be positive, but if prices of purchased commodity on

the market dropped significantly, the purchase did not bring savings as high as the market had offered.

## 3. THE FUTURE DIRECTION OF RESEARCH

Nowadays, there is ongoing survey in the field of creation of logistic strategy in industrial companies. Its results will serve for the future research and creation of methodology of making logistic strategy in an industrial company.

As also partial results of the survey show, subsidiaries of multinational corporations have logistics strategies made by their parent companies, respectively the parent companies determine conditions and subsidiaries themselves look for the ways how to meet the conditions. Partial results of the survey are presented at the Fig 7.

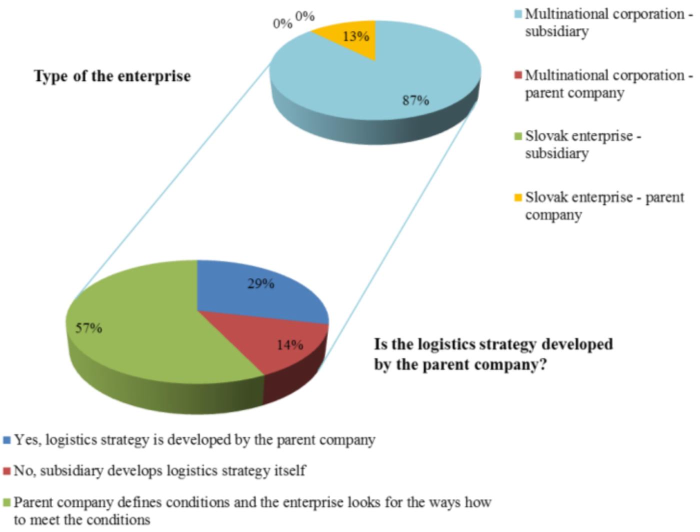


*Fig 7. Partial results of research – types of the enterprises and developing of logistics strategy*

13 % of Slovak parent companies tick the option that logistics strategy is developed by parent company what means they develop this strategy themselves. Slovak companies have a possibility to make the whole strategy themselves which is why this field is more interesting and future research will be focused on the creation of logistics strategy in Slovak industrial enterprises.

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# 4 DIGITAL TECHNOLOGIES AND WAREHOUSES DESIGNING

*Monika Bučková*

## 1. WAREHOUSING

One of the most important parts of company logistics system is warehouse. Its overlap space and time. It's an activity where the physical or other parameters of stored material is not change. Economically, the stored material does not acquire higher value, on the contrary, raises costs, which affect the profitability of products. Therefore is effort of companies to minimize their stocks and thus minimize storage costs of these stocks.

Unequivocal definition of term warehousing, it is not possible, because warehousing contain a large number of processes overlapping with other parts of the company logistics too. According to many authors can be warehousing defined as that part of the company logistics system that provides storage product (raw materials, parts, goods in the production or finished products) in the place of its formation, between the place of its formation and place of their consumption, and provides to management information about their state, conditions and disposition of storage products. [1]

The basic function of warehouse is volume balancing and harmonization of different dimensioned, complicated material flows. The warehouse have the most significant connection with problems of transport, internal logistics, supplying and purchasing. Warehousing and its functioning has a important influence on ensuring a higher level of customer service and for protection of features of the goods. [2]

## 2. WAREHOUSES OF THE FUTURE

Focusing on flexible manner to unstable requirements of final customers and continuing pressure to reduce costs for the implementation of individual customer requirements often can not be achieved without fundamental changes in the management of the entire supply chain, even extensive delivery networks. [3]

Nowadays, everything is variable, the products are different and warehouse operations are often changed. Response to these conditions are innovative solutions that affect every single step during the designing of warehouses, from the initial idea to the complete design of the warehouse, data mining, through processing and subsequent continuous improvement. Meet customer demands imply a continuous development of technologies, software and integration between them. This fact causes rising costs especially labor costs, energy costs and fuel costs and to ensure the development of new technologies. [4]

These costs are mainly increased after thee provide of customer services such as ever faster reaction to customer orders, faster handling of complaints or faster delivery of goods. The company must stay in today's oversaturated market competitive, so the possibilities for delivering supplies to be more interesting, more faster and in many ways even more exclusive in order to retain customers. This creates an increased cost to provide the ability to react immediately on customer's requirements. The sample of reaction could be real-time connection with company website or sell of things / services over the Internet.
The development of technology affects not only the physical designing of warehouse, as well as their technological equipment. Therefore, companies are beginning lean to building a private warehouses independent of external company, building halls with a high proportion of automation and conveyor systems, while increasing the degree of centralization of warehouses. From the perspective of companies is logistics not only a cost item or a separate department that works beyond other processes. [5]

The newest initiative is the development of The Physical Internet, that is the subject of research in Europe, the United States and Canada. Using Internet network, which uses digital information where the goods are handled as a model, which aims is to transfer the same concept to the network of physical goods. As well as on the Internet, will be developed open platforms based on standards and protocols that allowing work with sources and thus reduce logistic costs. The effect of the Physical Internet could be reflected in standardization of handling units, allowing them to be used as a Physical Internet packet, as Internet data packets, supported by new technologies for monitoring goods, such as smart tags. With this approach, it was calculate that total logistics costs can be reduced by 30 %.

Currently, is necessary to fully integrate all processes and departments in the company. For example, the marketing department in preparing special offer must cooperate with logistics, so that customers receive the goods as soon as possible and in sufficient quantity. Trend is already consolidation and centralization of warehouse in large logistics HUBs called as technology HUB and Spoke, where all processes of preparation of goods are literally concentrated under one roof. [6]

It is usually composed of three steps:

The first step is the pickup, specific routes are assigned and regular stops are planned according to a tight schedule. The package will inevitably be send to the hub for consolidation. There is a complex hierarchy of hubs ranging from local hubs servicing a specific market to giant hubs spanning a continent. [7]

At the hub, packages are unloaded and sorted according to the geographical location where they are bound to (Fig. 1). There is a hierarchy of hubs ranging from local (truck deliveries) to national (truck, rail or air) and global (air transportation). Consequently, all the parcels are divided to be loaded in the courier leading to the specified destination. If the parcel is bound locally, then it will remain at the local hub to be sorted. If the parcel is bound to a destination further than the reach of a local hub, it will then sent to another hub that will either consolidate the loads into truck, rail or air depending on the destination. [7]

The last step involves fragmentation into loads that are suitable for delivery that are made by cars trucks.

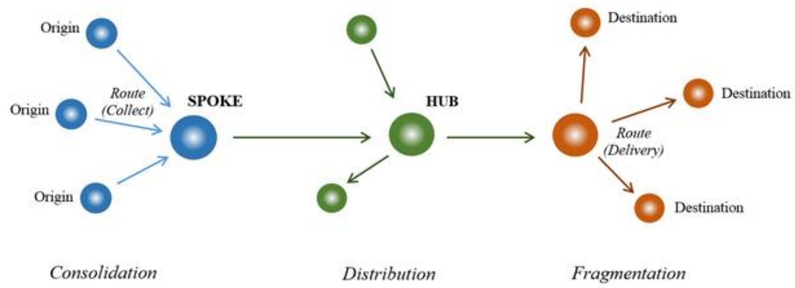


*Fig 1. HUB and Spoke system*

The HUB and Spoke system allows good transport service to outlying regions, supports the development of small and medium businesses in those regions where it is inconvenient to travel with small individual packages. It has a good effect on the demographic composition and is usually supported by the government. [5]

## 2.1. Formation of warehouses of the future

New trends and developments in technology, automation, supplying of goods or digitizing form the concept of warehouses of the future. This term could be imagined as warehouses in a new form, in form when will be eliminated paper form picking operations of them and will be replaced by a system call of goods to an operator, who is entered basic information about the goods and send the goods by conveyor system to place of picking on expedition. To function of this system it is necessary to provide the overall storage system to determine the degree of automation in the warehouse, the method of data mining and sorting. These are the basic points for the creating of internal integration in the warehouse. Well functioning warehouse system is necessary to be integrated with company systems, especially with procesess of sourcing and supply systems and systems of suppliers. [8]

This solution is called. as integrated logistics, which is based on a systematic basis, consisting generally first in connecting of processes and consumption inside company and with external environs of the company. The step when customers inside of company and warehouse are involved into the integrated logistics chain is called internal integration, when there is a comprehensive interconnection of all parts of supply chain. Subsequently leads to connected of company with its suppliers, distribution and commercial articles, up to final customers. [6]

Nowadays companies with technology development provide to their customers much more possibilities than before. Many companies provide integrated logistics connecting by trading logistics, industrial logistics and logistics og services. While the basic services include, for example:

- Creation and improvement of transport plans which ensure the shortest possible delivery times.
- Creation of EDI management, thus, electronic data interchange.
- Track shipments and transport equipment by software or sensors provided by external company.
- Designing multimodal projects.
- Management of returnable packaging, inventory.
- Simplification of customs formalities.

- Preparation of orders and ensuring of goods packaging according to customer requirements.
- Ensure day and night supplies, etc.

All these options that bring new technologies will affect on the way of designing warehouses in the future. The future does not provide aby space for errors in today's economy, and which includes building or re-engineering distribution centers. The reason is that these devices are an crucial part of the supply chain, which require detailed planning process to ensure that they comply return on investment. [9]

### 2.1.1. Development of technologies in warehouses

Companies deal not only with questions about internal integration or integration with suppliers, ekological warehouses, but also by correct use of automation that brings the possibility of reducing costs and progress before competition. It stands before the necessary change in the storage system, which will be by development of new technologies crucial. Rising prices of warehouse space and labor force contributes to the fact that companies are more and more inclined to partial or complete automation of storage processes. Between basic trends of development we could include [10]:

- Automated picking of goods – Concept of a modern automatic picking of goods allows by handling equipment automatically store the goods to pallets, boxes, cartons and crates. Its principle is based on using conveyor systems for transport of goods, robotics for storing goods or Orbiter system for delivery of goods in high rack systems. [12]
- Automated handling equipment – Range of these devices is designed for all types of collection of the goods while they are connected on internal intralogistics solutions. Assortment of automated handling equipment already includes all types of trucks from low lift pallets destined for narrow streets, up to high lift trucks. These trucks are developed to be able to communicate also with each other. By development of technologies also occur to improving the movement of these trucks by 3D scanner and a gyroscope, so that they can avoid the pillars, corners, work equipments, humans and each other. [11]
- Simplified product search by operators – To the forefont it gets Pick by Vision technology, which allows code reading and optical choosing of goods directly from the warehouse. The picker of goods itself wears a small camera that is directly connected to the control system in

the warehouse. In addition to this technology is also used methods Pick by Voice or Pick by Light or scanners to read codes located on the forearm of picker´s hand or finger of picker.

- Using of augmented reality in warehouses – Augmented Reality in warehouses is begins to use in the zone of picking, repair of equipment, safety and quality. While previously used resources of augmented reality such as Google glasses, provide static digital information, in the future will be dedicate to advanced technology systems. These systems are called simulation of combined properties, which allow change the dynamic adaptation of virtual objects or real environment to user. The current research focuses on intelligent lens that can display augmented reality.

The idea is to transformed conventional lenses containing functional system to control and communication circuits, miniature antennas, LED and other optoelectronic components. Hundreds of integrated LED can be used in the future to create the image directly in front of the eye and thus to change the lens on the screen. However, sooner how this becomes a reality, it will be necessary to solve some important problems such as how to ensure connection lenses on the warehouse system and that will not destroy the human eye of picker. [11]

### 2.1.2. Development of technologies in delivery of goods

A key task of the company is to ensure coverage of production by desired material items in required deadline, near minimizing the input value of different units and transport costs. Currently, when material prices rising and an increasingly greater variety of delivery terms of individual components, it is clear that it is not currently possible ordering of input components without conforming of management system and delivery of goods. And therefore are developed autonomous trucks because of anticipated reduction in the number of traffic accidents caused by human factors, reduce the cost of the human factor, energy saving, possibility of rapidly faster delivery etc. A specific benefit of these devices is the ability to pass very long distances, while the driver of truck would have to rest. [12] The machine couldn´t be tired and is not distracted. The basic directions of development of the delivery of goods could be included:

- Shipment transportation for long distances – For transport over long distances companies will begin to use autonomous trucks, the main idea is

to create an autonomous vehicle, which will be controlled primarily by stereoscopic cameras, radars and sensors.
- Shipment transportation for short distances – For this type of transport are begining to use drones, while this kind of transportation is based on the premise that they should deliver the shipment to 30 minutes and handle more routes at short range.

### 2.1.3. Development of technologies for reducing energy costs

Warehouses are frequented places. Goods are always on the move, incoming and outgoing deliveries to be constantly addressed, as well as the individual objects moves from place to place. Many companies integrates packaging and assembly works within a single warehouse, it creates a more complex environment. Companies seek to maximize the return on any efforts made to improve warehouse operations. Therefore they are looking for opportunities to use ecologically focused procedures, which aim to reduce costs while also increasing its efforts in corporate social responsibility. Most measures of cost reduction in storage tends to reduce energy intensity mainly in lighting, heating and cooling. The basic directions of development could be included [10]:

- Devices for creation energy which are independent of power plants – Currently are under testing batteries, which are designed to impose energy from the solar panels throughout the day. Stored energy os then producedrozvodná sieť during the night. These batteries are independent of electrical grid and its perfomance offer the possibility of creating a safety emergency backup.
- Motion sensors – Modern technologies bring with them the possibility of a connection lights and motion sensors. Sensor detects the movement of persons on the basis of broadcasting microwave field. [13] It detects motion also via obstacles such as doors, glass and thin walls. Sensor will shuts down the lights after the time which was set, if sensor detects motion once again the sensor light up the lightingn device. Then when time expire it will remain lighted room in the dark.
- Renewable energy in warehouse – From the reason of fast development of technologies many companies using again potentional renewable energy in their warehouses and distribution centres. They are using wind turbines or solar panels to be completely independent of power plants.

## 3. DIGITAL FACTORY

Nowadays companies can not wait if changes that are realized, will bring the necessary results in the production system. Every wait is a loss and every loss entails costs which must manager in a manufacturing company tries to eliminate. Therefore companies try to identify and eliminate the negative impact of changes on production systems and warehousing at the planning stage. One of the tools that help make such decisions is a computer simulation and solutions of digital factory, which find wide application in companies. [14]

The vision of formation of concept of digital factory focuses primarily on the integration of methods, tools and information. It affects various levels of planning, product testing and the individual steps related to the production process from the first draft to the operational management of the factory. Digital Factory integrates processes:

- The string of product development – testing – optimization – improvement.
- Development and changes in the production process and its optimization.
- The design and improvement of the status of the company.
- Operational planning and production management.

Concept of Digital Factory can also be understood as the individual company, including strategies for mining information, for management and integration processes in the company and later on the global networks. It offers methods and software solutions for improving product and planning of creating new portfolio of products for company, the development of digital products, digital manufacturing, sales, and support for company to give a products to final customers timely and value-added. [13] This concept integrates database for products, processes, accelerated modeling and advanced visualization, simulation and documentation to improve the quality of final product. With digital factory are achieved organizational, technical and economic goals, such as:

- Increase profitability.
- Improving the quality of planning.
- Shortening the time of product launch on market.
- Improving communication in the enterprise.
- The standardization of the planning process.

- Complex knowledge management.

The current digital age provides us with myriad of tools and models for the formation of proposals to increase the speed of meeting with requirements of internal and external customers, process reliability, reducing storage costs and eliminate many other problems in the storage process. [14]

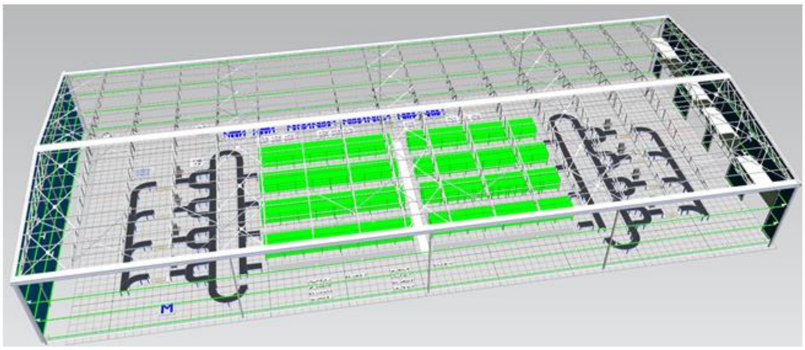

*Fig 2. Sample of 3D model*

Nonetheless it is important that all activities associated with the simulation of existing or planned processes were subject to systematic management, finding a match between objectives and resources of the company. By analyzing and selecting the factors that affect the storage process it is possible to identify problem areas. Pressure to reduce the time between the issuance of individual parts, semi-products from the store causing a greater emphasis on quality of preparation of draft of the warehouse that can detect and eliminate problems before putting the semi-product into the production or shipment of goods to customers already in the planning phase.

Technologies, 3D modeling, digital factory, computer simulation helps to solve the problems not only of production and logistics systems, but also the designing of warehouses. Its allows to transfer problems arising from real warehousing to a virtual environment (Fig 2). Exactly systems making by digital factory helps to fill the gap between CAD systems and ERP systems. [15] With use of digitization is appropriate to start at the first stages of designing, as it facilitates and accelerates the subsequent analysis process of input data. Modern computer technology complemented by software solutions destined for warehouse designing allows the transition from standard outputs such as design technology. drawings in 2D view to a complete 3D model of

warehouse. This model can then be used for the simulation and animation of warehouse operations.
Simulation is one of the best tools for experimenting with proposals to improve the picking of goods for customer. Through analysis and connections to chosen system is can be assessed as for example the number of incoming or outgoing cars (road and freight), picking (eg. speed or the sequence of picking), etc. Other trends that will be required in the development of future warehouse could be [16]:

- Evaluate the effectiveness of storage management.
- Methods of picking or modifications of goods according to the order.
- Planning of creating of stocks.
- Monitoring and evaluation delivery using autonomous handling equipment.
- Evaluation of the handling of material in stock.
- Capacity planning in the warehouse.
- Preparation and evaluation of material flow in the warehouse.
- Impact analysis of automated systems on storage management.
- The impact of automated conveyor systems on picking of goods.
- Assessment of the energy performance storage using simulation models.
- Labor needs.
- Determining how the data will be mining, evaluated and sorted, etc.

Between the main advantages of simulation could be included:

- Is it possible to test and track the behavior of systems that do not exist yet. Think of this, we suggest them and gradually completing.
- In a comparatively short time, we can verify the behavior of the selected system and affect its enough to achieve results acceptable to us.
- We can verify the behavior of the system for a longer period of time in a relatively short time.
- It is possible to compare the behavior of different variants of the system, possibly then choose the most acceptable for us.
- Increased possibilities of spatial arrangement.
- it provides us with the possibility of effective and high quality production of various kinds of products.

Between the main disadvantages of simulation could be included:

- Prep time – Simulation is a method that requires a certain amount of time to mining, process input data, modeling and evaluation experiments.
- Hardware and software demands – Computing and price of simulation software solutions cause increased input costs when introducing simulation in companies.
- Increased demand for workers – Simulation is a cross-cutting areas, therefore the worker performing the simulation must have knowledge of mathematics, statistics, computer science, must understand to simulation software and must have analytical thinking to convert real situation into a computer model. [1]

All from three disadvantages can be eliminate when company use a services of external partner, which could be use for creating a model that can contain parametric configurator to select the model parameters and displaying simulation results.

### 3.1. Computer simulation in warehousing

Tecnomatix® Plant Simulation 12.1 with modules such as Warehousing and Logistics allows to quickly create realistic simulation models of dynamic warehousing and logistics operations.

Modern warehouses works in a dynamic environment of global supply chains. [12] The rational access to designing of warehouses and logistics processes is crucial, because companies must be able to compete in dynamic markets. Storage and logistics module provides functionality to simulate all aspects of warehouse management. The library can be expanded by adding specific subjects and / or different approaches to the control of a specific customer. The interface to the most popular applications, support for analysis and re-use data, such as data from the existing warehouse management system for example. The measurement of performance is presented in a very clear way with the help of reports and dashboards. Storage and logistics process can be visualized with 2D and 3D animation and improved by linking the software with software for displaying static warehouses. [17]

Nowadays, modern computer programs offer many different outputs, which are statistically processed at a high level. For the chosen modeling system that can be individual statistics elements that we used in the simulation model.

These may include:

- Transport systems for example roads (resulting statistics may be percentage of blocking).
- Handling equipment for example forklift or pallet trucks (statistics result can be a percentage of use).
- Workers eg. warehouse staff (resulting statistics can be percentage of use of workers).
- Products, material (resulting statistics can be a number of final products).
- Auxiliary equipment (resulting statistics may be percentage of waiting).
- Generators and liquidators of components (the result of the statistics could be percentage of waiting).
- Storage area (resulting statistics can be a percentage of use).
- Storage facilities (resulting statistics can be percentage of use).

It is also possible to define different areas:

**1. Conceptual design of warehouse**

The main requirements for conceptual design simulation are easy to use and communication. At this stage, there are many options such as changes in space layout and designing store, time windows that are still open and detailed data are available only rarely. The extensive standard library supports the concept of simulation, animation during the process and visualize key performance indicators. Without that there is a conceptual model is difficult to create computer models of complex real system. It is necessary to create a simulation model with current ideas about improvement of system and its motion. [18]

**2. Detailed designing of warehouse**

Conceptual designs can be treated with available data about handling equipment or flows of goods. The library contains a comprehensive set of fully configurable devices and control strategies for accurate simulation. Automatic evaluation experiment provides analysis and optimization of a wide range of scenarios, including different layouts. In addressing the simulation and design of projects we can determine the following parameters:

- Determination of storage capacity - Simulation allows you to test multiple variations of deployment assortment in stock.

- Determining the workload of warehouse and logistics facilities – Simulation will provide accurate distribution of the Fund's facility for work, the casting time, time faults and downtimes.
- Determination of turnover range - Simulation track products from entering the system to its output, which allows you to specify turnaround specified range.
- Testing of the size of the production and transport benefits - Testing the system behaviour and determine the appropriate dosage for the capacity utilization of handling equipment.
- Determining the workload of operators – Determination of the workload of workers in the field of warehousing, logistics and maintenance.
- determine the necessary number of handling equipment – Determination of the number of devices needed to effectively tendance storage and quick response to the demands of production.
- Determining the impact of random phenomena on storage – Inclusion of random phenomena in simulation, for example. the impact of non-delivery of material supplier for storage.
- Selection of the bottlenecks in the warehouse – determine bottlenecks storage and testing of corrective measures to eliminate them. [19]

**3. Determination of the method of data mining**

At this stage, it is necessary to think about how the data was obtained and whether they actually tell us about the real state of the system. If the model is created without data, it is necessary to rely on estimates and opinions of expert staff, who have the most experience with the processes. Data acquisition can take place for example. of process information system (information about production program, production processes, BOMs, etc.) or in the form of physical data collection (imaging, cycle-times, set-up times, etc.). Current technologies allow software applications to interconnect sensors, cameras placed on the device or handling unit making it possible to obtain massive amounts of data. Therefore, a company has to define how they would like to collect data and sort them using algorithms. It must be ensured:

- Securing wireless communications networks.
- Software for monitoring and supervision of logistics vehicles.
- Software to automatic control of logistics elements in system.
- System for remote control handling with units.
- Software for collecting data and information about operations for further processing.

- Software for data processing about processes and following creation of reports and analysis through OEE calculator. [10]

**4. Planning and optimization of existing operations**

Used for example. benchmarking methods is an objective way to optimize storage performance. Simulation models can also be used for operational planning. Different types of quantitative and qualitative data, such as. from previous orders, equipment failure can be dotvorené in the library. Simulation provides a reliable benchmark with clear visualization of operational and performance. From an economic point of view, optimizing warehouse processes is not considered a strategic priority has a major impact on the value of the product, as processes only produce low value-adding activities of the product. The main problem is that in the example. there is no standard storage processes, from which the company can build on. For process improvement in a warehouse or in any area of enterprise can create several frames, which are handled by the basic steps that are cyclically repeated. As an example, it is possible to draw up a general troubleshooting steps for improving project selection process by means of selective steps [17]:

- Understand the needs of the storage process.
- Understand the process of entry and exit of goods.
- Experimenting with new ideas.
- Consideration of the use and introduction of new technologies into the process of storage and the methods used to improve storage processes.
- Determination of the course of the review process and review process, storage, etc.

**5. Creation of simulation model**

Creation of the selected computer simulation model is already means encoded conceptual model of phase 1. In exceptional cases it is possible that a team that solves the problem to decide that the program is not suitable for achieving the objectives. Also, at this stage there is the "control" of the conceptual model, and any inaccuracy in the data instantly detects computer logic. If you find any irregularities, you can be fine-tuned through the manual simulation. This hand simulation consists of using specific values to substitute a simulation program that in every part of the program, the gained values are monitored. [20]

**6. Re-designing of existing processes**
Storage operations must be highly detailed reworked. Plant Simulation module Warehousing and logistics is also a tool for re-designing of existing processes. Reliable models can be developed relatively quickly and alternative scenarios and proposals are announced through clear messages, and 3D animation.

### 3.2. 3D modelovanie a animácia objektov na Katedre priemyselného inžinierstva

Software Tecnomatix® PlantSimulation 12.1 shows the models in 2D or 3D mode or 2D / 3D. The latest version of this software enables you to present a concept created by the system in an entirely virtual, more interactive environment. 3D environment is based on JT format, which is also known as a standard format. This format can be created in the application [11]:

- NX for Manfacturing – Siemens PLM software.
- Solid Edge – Siemens PLM Software.
- AutoDesk Inventor Professional.
- Autocad.
- Microstation.

Objects and their individual elements created in the 3D model can be animated (Fig 3). Each point in the animated objects are displayed by red triangles, which are connected with the lines.

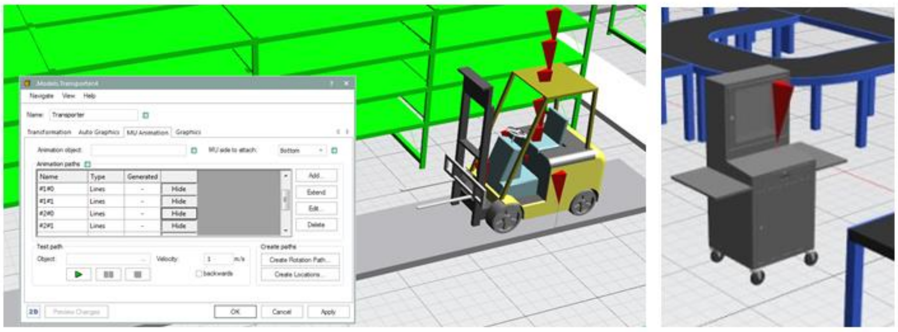

*Fig 3. Animation of objects*

By using these points, it is possible to place the object on the destination with an accuracy of millimeters, also allows rotation with positioning object. New possibilities of this software allows adding and removing these animation points, visualize them and hiding them. Using a tree structure of objects we can dismantle the entire object. [20]

Graphic notation inheritance depends on the graphics whatt we create. It is always necessary to duplicate the entire graphic object, in this program is not supported partial graphical inheritance. This duplication of objects is particularly difficult for the graphics card of the computer on which the task is performed. Long processing graphic data can cause problems when rendering of model. Therefore is developing an option to create your own 3D libraries, create your own special folder where you can save the model, thereby reducing time for duplication of model, searching model and its processing. [20]

### 3.2.1. Model of picking gods

As each project, simulattion project must have a main goal too, the simulation must be specified precisely the main objective of the project. As the computer simulation works witth simulation model created on a computer, it would be time consuming and very costly to capture and understand all the processes that take place in the company. Therefore, before the formation of the model itself it is necessary to determine the relevant processes and relationships that affect the system in achieving goals, which have to be achieved by simulation experiments. Other processes and relationships are neglected. Therefore, the determination of the main goal of simulation project is very important especially in view of the higher mentioned selection og processes. For viewing options and influencing 3D of modeling picking operations I created a simple example of a semi-automated zone picking operations. The purpose of this model is to test the new capabilities of software Tecnomatix Plant Simulation 12.1 with a simple example of picking in a small warehouse (Fig 4).

Monitoring the process of picking the goods in the warehouse is a very important step, because a computer simulation can pointed out when will the system fail by overwhelmed with goods. Then it is necessary to design experiments and to see how the system will react on change, for example the number of workers, changing the shape of conveyors, change in the number of conveyors, governing for the supply of goods, etc. It was necessary to find out how much are workers used in this warehouse, what is their main activity and whit what they spend the most of working time. [21]

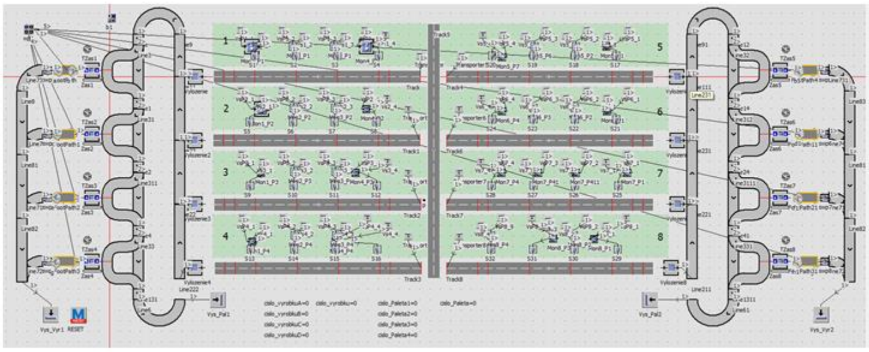

*Fig 4. Simulation model of picking of goods*

The concept of semi-automated picking is designed for the picking of small products – components, parts, cosmetics or pharmaceuticals. It is suitable for distribution warehouses, where are stored medium to fast moving goods.

In this concept it is considered about solutions in which picking of goods coming to picker directly from the warehouse through automated conveyors and materials handling equipment. Product scruteneering area is split into several zones to which assigned to pickers. Products are routed to a defined area where they are stored for example in racks or shelves.

When is the picking of goods in one zone completed, operator by a conveyor directs the product to the next zone. The number of picked goods or empty pallets can be monitored by an counter that can be placed in a 3D view of the object that we want to monitoring.

This simulation model is set move of four product types which are different mixed, and stored in the pallets with number of 10 pieces. Products are placed on pallets, which are imported through handling equipment to the place of picking. To operators htey are further transported by a automated conveyor. Process time is set according to the triangular distribution. Time of picking pallets depend on variables and numbers of pallets which are sent per hour from one warehouse locations.

A priority task of the simulation was to determine when the system begins to fail. I used to experiment executive function 'Experiment Manager', suitable for the realization of simulation studies. Explores the different variants of input values and develop statistical results, following the change of input parameters.

In the example I had two ways of unloading material. The first way of unloading materials - 4 workplaces were serviced by four workers on both sides of the warehouse. The second way to unload materials – 8 offices operated by 8 workers for each side of the warehouse. For each on of this ways it was performed 20 experiments with a gradually increasing number of pallets per hour, leaving from one warehouse location. In the experiments, I looked at the number of pallets, products emanating from sorting offices and the use of operators, respectively, which kind of activities they spent their time at the workplace. [20]

### 3.2.1.1. **The first method of unloading pallets from storage**

Each simulation experiment is carried out in steps as setting the input variables, activate the simulation run and monitoring output readout values. This procedure can be performed manually or automatically by the simulation software module that is responsible for the administration and execution of experiments and which already contains all professional simulation software. For this study I used tools of Plant Simulation software, specifically Experiment Manager. With help of this tool wer could setting input values in experiments faster compared to the experiments made by hand. At the same time, this tool can independently generate output values in the form of clear graphs and tables. Using Experiment Manager can be output of simulation model created in form of Web document (Fig 5). The advantage of this representation is that it is possible to immediately send the results of simulation using various web solutions e.g. e-mail. [21]

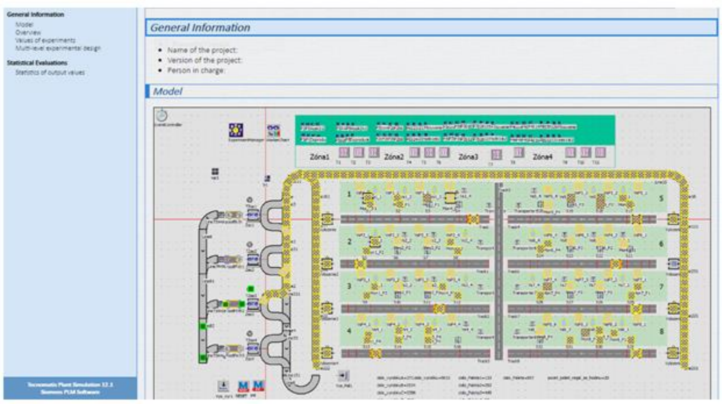


*Fig 5. Sample of Web document for the first set of experiments*

In the first experiments is system connected by one common automated conveyor. The results shows that the system is starting to be overwhelmed at the number of pallets per hour: 7. At that time the system ceases to prosecute the process of sent pallets. In a context of better and more readable representation of results from Experiment Manager, you can simply copy the selected tables to Microsoft Excel, where the tabels can be freely adjusted. [22]

| Experimenty | Pocet paliet za hodinu na 1 regal | Pocet vyrobkov ALL | Pocet vyrobkov A | Pocet vyrobkov B | Pocet vyrobkov C | Pocet vyrobkov D | Pocet paliet | Pocet paliet 1 | Pocet paliet 2 | Pocet paliet 3 | Pocet paliet 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Exp 01 | 1 | 1520 | 630 | 470 | 115 | 305 | 152 | 34 | 40 | 48 | 30 |
| Exp 02 | 2 | 2991 | 1279 | 904 | 197 | 611 | 299 | 67 | 73 | 98 | 61 |
| Exp 03 | 3 | 4429 | 1922 | 1339 | 277 | 891 | 443 | 98 | 105 | 146 | 94 |
| Exp 04 | 4 | 5876 | 2560 | 1772 | 357 | 1187 | 587 | 131 | 137 | 194 | 125 |
| Exp 05 | 5 | 7260 | 3173 | 2187 | 435 | 1465 | 726 | 163 | 168 | 239 | 156 |
| Exp 06 | 6 | 8687 | 3814 | 2613 | 514 | 1746 | 868 | 194 | 199 | 287 | 188 |
| Exp 07 | 7 | 9889 | 4352 | 2973 | 576 | 1988 | 983 | 221 | 225 | 322 | 215 |
| Exp 08 | 8 | 9895 | 4221 | 3007 | 556 | 2111 | 985 | 242 | 238 | 326 | 179 |
| Exp 09 | 9 | 9863 | 4162 | 3013 | 524 | 2164 | 981 | 250 | 248 | 326 | 157 |
| Exp 10 | 10 | 9857 | 4106 | 3042 | 530 | 2179 | 980 | 244 | 248 | 338 | 150 |
| Exp 11 | 11 | 9791 | 4004 | 3089 | 511 | 2187 | 974 | 237 | 256 | 356 | 125 |
| Exp 12 | 12 | 9688 | 3916 | 3046 | 515 | 2211 | 963 | 223 | 258 | 364 | 118 |
| Exp 13 | 13 | 9577 | 3843 | 3021 | 500 | 2213 | 954 | 210 | 264 | 378 | 102 |
| Exp 14 | 14 | 9455 | 3772 | 2990 | 482 | 2211 | 942 | 198 | 268 | 390 | 86 |
| Exp 15 | 15 | 9469 | 3783 | 2966 | 478 | 2242 | 940 | 184 | 266 | 402 | 88 |
| Exp 16 | 16 | 9364 | 3746 | 2899 | 469 | 2250 | 932 | 178 | 266 | 409 | 79 |
| Exp 17 | 17 | 9270 | 3732 | 2814 | 455 | 2269 | 922 | 162 | 266 | 422 | 72 |
| Exp 18 | 18 | 9183 | 3716 | 2736 | 434 | 2297 | 915 | 154 | 263 | 432 | 66 |
| Exp 19 | 19 | 9201 | 3760 | 2690 | 421 | 2330 | 914 | 140 | 267 | 445 | 62 |
| Exp 20 | 20 | 9015 | 3711 | 2534 | 414 | 2356 | 897 | 133 | 252 | 449 | 63 |

*Fig 6. Tabuľka vyhodnotených experimentov*

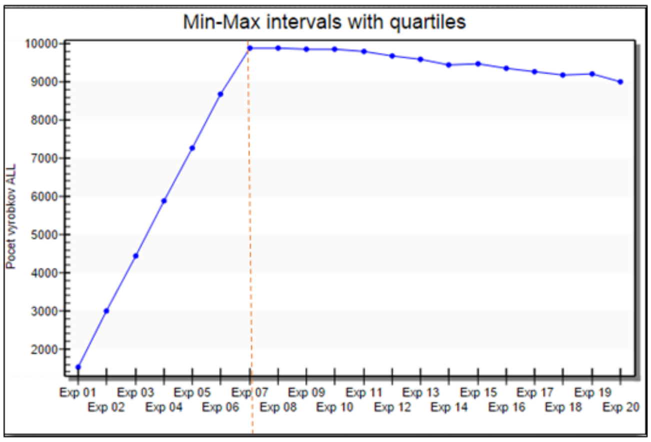


*Fig 7. Graphical evaluation of experiments*

System with this kind of set will reach its peak during the experiment with number 7 (Fig 7), when picker enters 9889 products (Fig 6).

Then it is possible to see on graph the number of unloaded products, which shows that there is no change up to experiment with number 15, when the number of pallets will slowly decline.

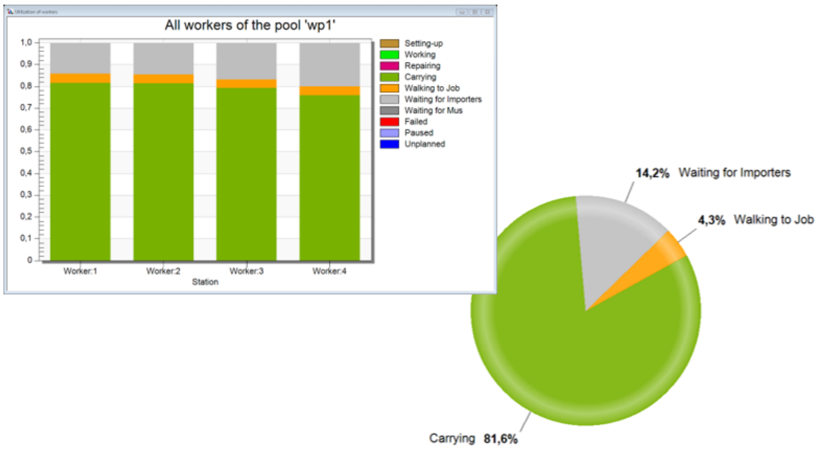


*Fig 8. Grafické zobrazenie využitia pracovníkov*

On th fig. 8 we can see that workers most of their time spent with waiting for the importers of goods, carrying the picking of goods and walking to job.

### 3.2.1.2. **The second method of unloading pallets from storage**

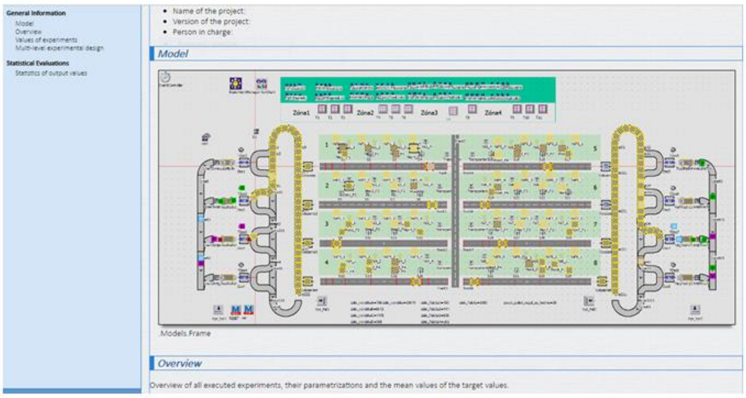


*Fig 9. Sample of Web document for the second set of experiments*

In a second experiment, I set eight workstations, and for every workstation has been assigned one worker and I removed the common conveyor. On Fig 10 is visible when the system already reaches its maximum and begins to be overwhelmed by products, just then it is not fast enough.

| Experimenty | Pocet paliet na regal za hodinu | Pocet vyrobkov ALL | Pocet vyrobkov A | Pocet vyrobkov B | Pocet vyrobkov C | Pocet vyrobkov D | Pocet paliet | Pocet paliet 1 | Pocet paliet 2 | Pocet paliet 3 | Pocet paliet 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Exp 01 | 1 | 1520 | 630 | 470 | 115 | 305 | 152 | 34 | 32 | 56 | 30 |
| Exp 02 | 2 | 3001 | 1283 | 904 | 200 | 614 | 300 | 67 | 57 | 114 | 62 |
| Exp 03 | 3 | 4430 | 1922 | 1340 | 277 | 891 | 443 | 98 | 81 | 170 | 94 |
| Exp 04 | 4 | 5880 | 2560 | 1774 | 357 | 1189 | 588 | 132 | 105 | 226 | 125 |
| Exp 05 | 5 | 7266 | 3175 | 2191 | 435 | 1465 | 726 | 163 | 128 | 279 | 156 |
| Exp 06 | 6 | 8703 | 3818 | 2624 | 515 | 1746 | 869 | 194 | 151 | 336 | 188 |
| Exp 07 | 7 | 10133 | 4464 | 3048 | 590 | 2031 | 1013 | 226 | 175 | 391 | 221 |
| Exp 08 | 8 | 11588 | 5110 | 3485 | 671 | 2322 | 1158 | 258 | 200 | 447 | 253 |
| Exp 09 | 9 | 13009 | 5748 | 3898 | 751 | 2612 | 1300 | 289 | 225 | 500 | 286 |
| Exp 10 | 10 | 14411 | 6370 | 4323 | 826 | 2892 | 1441 | 321 | 248 | 555 | 317 |
| Exp 11 | 11 | 15908 | 7031 | 4776 | 911 | 3190 | 1590 | 355 | 272 | 613 | 350 |
| Exp 12 | 12 | 17333 | 7668 | 5202 | 989 | 3474 | 1732 | 386 | 296 | 668 | 382 |
| Exp 13 | 13 | 18774 | 8307 | 5640 | 1066 | 3761 | 1876 | 419 | 319 | 725 | 413 |
| Exp 14 | 14 | 20189 | 8935 | 6058 | 1148 | 4048 | 2017 | 450 | 344 | 779 | 444 |
| Exp 15 | 15 | 20378 | 8921 | 6123 | 1159 | 4175 | 2033 | 451 | 367 | 791 | 424 |
| Exp 16 | 16 | 20411 | 8764 | 6195 | 1158 | 4294 | 2037 | 453 | 392 | 815 | 377 |
| Exp 17 | 17 | 20591 | 8792 | 6277 | 1159 | 4363 | 2056 | 445 | 410 | 836 | 365 |
| Exp 18 | 18 | 20062 | 8386 | 6116 | 1139 | 4421 | 2003 | 444 | 418 | 825 | 316 |
| Exp 19 | 19 | 19758 | 8049 | 6083 | 1108 | 4518 | 1971 | 449 | 434 | 838 | 250 |
| Exp 20 | 20 | 19049 | 7561 | 6042 | 968 | 4478 | 1900 | 459 | 444 | 836 | 161 |

*Fig 10. Table of evaluation experiments*

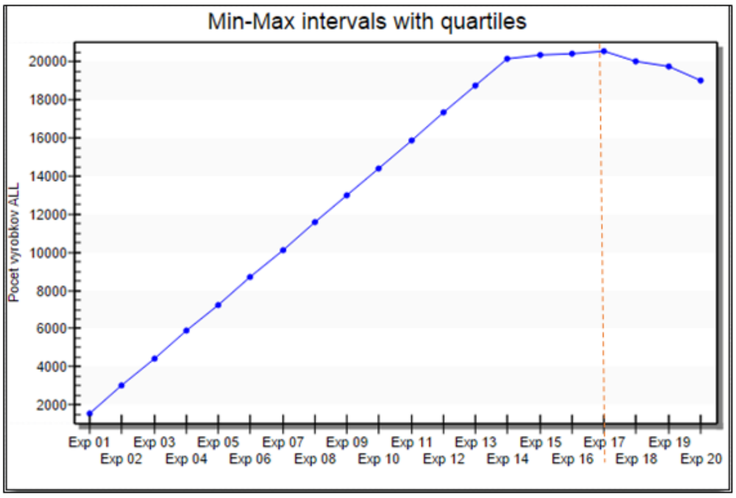


*Fig 11. Graphical evaluation of experiments*

After removing the common conveyor and the addition of 4 workplaces it can be seen that the system ceases to prosecute in the experiment number 17

(Fig 11), which reaches its maximum at 20 591 number of products and number of pallets 2056. What is against to first series of experiments more than doubled. This difference is due by blocking of pallets on one conveyor. After the split of the flow of pallets, this mutual influence is smaller and the system can handle
a larger number of pallets.

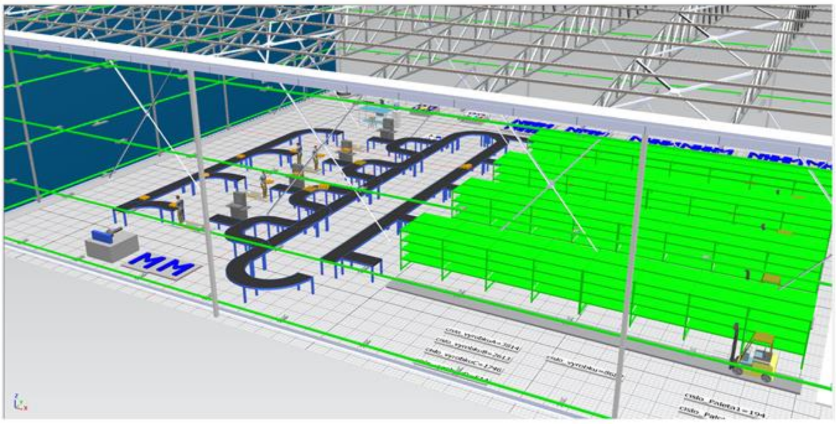

*Fig 12. Sample of 3D simulation model of warehouse*

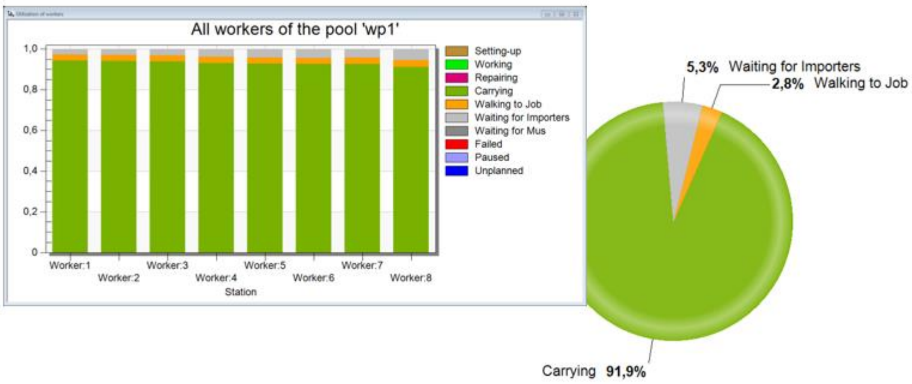


*Fig 13. Graphic representation of use of labor*

On the graph, on picture num. 13 we can see, the use of workers. Workers spent 91.9 percent of their time at work by carrying and analyzing information about the product - which is the maximum workload. Increasing the intensity of incoming pallets not cause a higher system throughput, percentage of portion of waiting pallet is caused by blocking of pallets on the conveyor belt. [23]

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# 5 USING LIDAR SCANNING TO CAPTURE INDUSTRIAL LAYOUTS

*Jiří Polcar, Marek Bureš, Petr Hořejší, Pavel Kopeček, Martin Strapek*

## 1. INTRODUCTION

For industrial enterprises, it is important to have all the data about their production systems. Inconsistencies between the system and its data representation, its processes, topology and other aspects lead in the end to unnecessary costs, delays and errors of all kinds.

In practice, it is, unfortunately, common that the data representation of the production system topology is imperfect or completely missing. Other than that, there is no standard way of drawing, or a standard data format for different hierarchy levels. This brings unnecessary costs in updating or optimizing the production system elements, because it is always necessary to get up-to-date data directly by taking measurements in the production system.

The drawings of layouts of particular workplaces are usually delivered or made time of their deployment. Every supplier can deliver these data in a different format or style, so they are incompatible and thus isolated. During continuous optimization either by production management or by the workers themselves, it is not uncommon that the drawings and other data are not updated as well.

Because of this, we cannot rely on the data acquired during production optimization projects and it is a common habit to get the data ourselves or at least to validate them. The companies are usually missing the appropriate layout drawing software, with AutoCAD being the best case, or even Microsoft Excel as the worst case.

The Digital Factory concept takes advantage of working always with accurate, up-to-date and immediately available data for collaboration with experts from different fields that can even be geographically distributed. For optimization purposes, an accurate 3D model of the production layout brings advantages in better understanding of the situation and can be considered a sandbox for making different variations of optimized solutions. In general, a 3D model provides better knowledge acquisition than a 2D layout drawing.

A common way of acquiring data for drawing the 3D layout is to take traditional measuring tools (one short and one long tape measure, a ruler and a laser rangefinder) and making sketches with the dimensions. Unfortunately, this process is very lengthy and the resulting 3D representation of the layout is very inaccurate: our experience when using common measuring tools) is that we can achieve about 5 cm of inaccuracy or even more. Another possibility would be to take advantage of modern measuring devices, particularly 3D laser scanners.

3D laser scanners are a category of measurement devices that measure the size and geometry of various objects of different sizes. They generally measure the reflection of a laser beam to create a set of points with given coordinates, capturing size and geometry of the scanned object, sometimes including its surface colour by taking shots with an RGB camera.

This chapter deals with the use of terrestrial laser scanners that are intended for scanning large objects such as terrain or buildings. These scanners are deployed usually on a tripod and scan their surroundings. In the following chapters, the use of terrestrial laser scanners is described using three case studies: the collection of data for creating an underlay of industrial layout and for ergonomic analysis.

The advantages of using laser scanners for industrial layout capture are mentioned by Debnar in [1], where he describes the different uses and a very general methodology. According to him, LiDAR point clouds can be used to validate layout models or they can be used as an underlay for making new ones. Gregor states that digitalization of actual factory halls is expensive, but worth the extra costs for the future. [2] The paper dealt with scanner prices at that time, which were much higher than today. Plinta [3] mentions in his paper about the Digital Factory concept, that laser scanning of industrial layouts is often more effective.

The Statoil company in their presentation [4] use very detailed LiDAR point clouds of their oil rigs to improve all processes regarding changes and safety. For example, an oil rig is at a remote location in the sea but engineers do not need to travel to the rig again so often - they just visualize the situation in the point cloud.

The benefits of laser scanned factory halls are described by Lindskog. [5] In his study, the laser scan of a remote hall served as an underlay for a meeting of experts. According to the study, the experts liked this approach because it gave them a good view of the design process they were solving. In his thesis [6], Lindskog deals with using LiDAR data with discrete event simulation in order to enhance the results of the simulation studies.

## 2. CAPTURING LAYOUTS OF PRODUCTION SYSTEMS

The data acquisition process using a LiDAR scanner [7] consists of three steps. The first step is object analysis where we decide if it is even possible to scan the whole object (in our case the factory hall or a workplace), or if it will be necessary to acquire data of some parts of the hall or of the whole hall by a different method. If we conclude that the object can be scanned, we can move on to the next step, which is determining the layout of the scan stations. A scan station is a position where the scanner is deployed to capture its surroundings. A suitable station should have the following parameters:

- Maximum distance between two stations is less than the scanner range. There has to be an overlap with other stations if using visual registration.
- The scanning cannot be interrupted – if the scanner is moved during scanning, it must begin all over again at the same station. Scanning from a single position can take anywhere between a few minutes and several hours. The station should be placed so that it will not interrupt any production processes.
- Movement of employees and transport equipment in the track of the scanner should be minimized. However, production must not be interrupted! Rare movements do not matter. On the other hand if there is too much movement during the scanning process, it may be necessary to re-scan the position.
- Some workplaces can also be scanned only during a break, because the scanner may obstruct the employees’ movement. Also employees may be disturbed by the presence of an unknown device.
- The position is selected so a complete model will be captured while not scanning too many useless positions.

There are two possible ways for scanning objects (applicable not only to factory halls) – scanning with a target and targetless scanning. These two ways differ in the final scan registration.

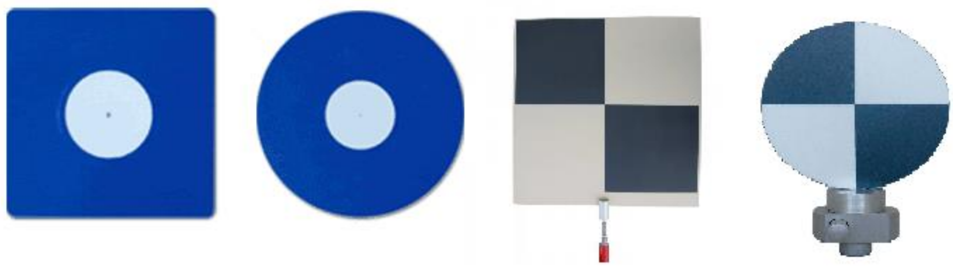

*Fig 1. Examples of various kinds of targets*

When using target scanning, it is necessary to have special targets, which are used for creating geometric references between particular scans. In Fig. 1 we can see several types of targets. These targets must be placed in every scan position and they must follow the following rules:

- There must be a minimum of 4 visible targets shared between at least two stations.
- The target must face the scanner.
- The target needs to be placed firmly to stay at its exact position during the scanning.

Due to the limited number of targets and the high number of scan positions, it might be necessary to move some targets with the scanner to another position. The targets must stay at their precise position, but in real production, there is always a risk of moving a target either intentionally or unintentionally by traffic or workers.

Before or after scanning each position it is also necessary to scan the targets. The scanner must be manually directed into the centre of each target, then the scanner measures the target centre point position and the user has to assign a unique ID to this target.

Scanning big objects (factory halls) requires many scan positions (tens or hundreds of positions) and also a large number of target IDs. These IDs can be very easily confused or mis-selected and thus the system is very error prone. These errors lead to failure of the automatic registration (will be explained later). Fixing these errors also results in an increased layout modelling time. This method itself requires more time spent in the factory during production and our goal is to minimize this time. However, if all IDs are entered correctly, we will save data processing time.

When using targetless scanning, we do not have to use the targets at all. This means we do not have to scan them, which results in less time spent in the factory hall, but the final registration takes slightly more time.

Debnár in [1] suggests creating a plant reference point grid prior to scanning. In his case study, with a hall of 300 × 100 meters and two floors, a total of 800 reference points were used (4 points needed for every scan). Targets could be placed at these reference points, but too many of them would be needed and there could be problems with adding new partial scans in the future – unless these reference points were placed at positions that would certainly stay in their positions.

Once the positions are determined, the last step is the scanning itself. The scanner can be deployed at the first position and can be set up. The settings are: horizontal equilibration, resolution setting, field of scanning setting and colour or colourless scanning. After the necessary settings, the scanning process can start and we have to wait until it is over. The duration of scanning is dependent on the scanner power (if electric sockets are not available for charging batteries) and on the chosen scanning resolution.

We learned the following facts during the data acquisition process in the factory hall:

- The vertical alignment was affected by slight vibrations in the factory hall that could be felt in our feet. These vibrations resulted in us not being able to level the scanner precisely using the internal electronic plummet, with values changing by about +/- 0°5´. The effects on the resulting data are unknown, although subjectively no significant errors could be seen.
- The production was not interrupted during the scanning, although some workers showed interest in the process and took a break to watch it or to talk with us.
- It is not possible to scan all areas. Some areas are too dirty or they are sensitive to electricity, flashes of laser light or their environment values do not meet the requirements of the scanner.
- It is very useful to scan some overviews of the factory hall from elevated areas, for example from stairs or from stable lifters.

- It is also useful to scan the ceiling (for better scan assembling – explained later) Although scanning of the ceiling may seem like a waste of time, our experience tells us that in some cases it has the only overlaps in particular point clouds, which are necessary for targetless registration.

Once the data is acquired, it is processed. The first step of processing is to load the data to the specialized software. This software is normally distributed with the scanner (Leica Cyclone with Leica C5 ScanStation in our case). These software programs have the following functions:

- Downloading the data from the scanner.
- Data checking and cleaning.
- Project management.
- Registration.
- Applying RGB camera photos to colour the points.
- Geometric features fitting (primitives or various pipes and profiles).

The point clouds are stored partially, with each scanning station having at least one point cloud. All of these scans must be checked and cleaned. Scan cleaning is the removal of any unwanted points that interfere with the scan (for example mirrored points scanned through a window or a scanned silhouette of an employee passing by Fig 2). These points are removed using selection tools in the software.

*Fig 2. Interference of passing workers during the laser scanning process. These silhouettes have to be found in the resulting point cloud and deleted manually. If necessary details are obstructed, they must be re-scanned*

Once all the scans are clean, the next step is to assemble them into a single point cloud. This assembly process is called registration. We use two methods for registration – automatic or visual. Automatic registration aligns all the scans based on the scanned targets' positions. This means that this method can be used only when scanning with targets. The second method is visual registration, where the user aligns two scans manually and the software computes the final alignment deviations. This requires overlapping portions of the partial scans, thus in production halls it is very good to scan the ceiling.

## 3. MODELLING LAYOUTS FROM POINT CLOUDS

After complete registration, a point cloud of the whole hall is available for further processing. Strapek presents two possible ways for using scanned data during the layout modelling. [7] Using the CloudSlicer algorithm and visTable software is better for 2D layout modelling and especially analysis. For creating 2D, and mainly 3D layouts, it is more useful to use the method that includes Autodesk software.

### 3.1. 2D Layouts

If we want to use a point cloud in Autodesk software, we have to load it into Autodesk ReCap software first, which is a tool for editing point clouds but mainly for file format transfer. In Autodesk, we can use only point clouds with ReCap. However, we can load almost all standard point cloud formats into ReCap.

It is possible to create a 2D layout in AutoCAD, the quality of which heavily depends on the acquired data quality (scanning resolution). It is possible to load a 3D factory hall point cloud directly into AutoCAD and then edit it with the selection tools. The best way for creating a 2D layout is to remove the ceiling and a very thin surface of the floor. Then only the walls and objects within
the hall will remain, which are the objects that are necessary for creating a 2D layout. Then the top view of this edited model represents a 2D layout. In this layout, we can measure all the dimensions. However, there are no analysing tools in AutoCAD for layout analysis. Some of these tools are included in the Factory Design Utilities add-on for Autodesk software.

If the company already has CAD format layout, we can enhance this layout with the point cloud model and verify whether the CAD layout is up-to-date. There are many companies which use their own CAD layout, however, this layout may not have been updated for a long time, and the real status of the factory hall does not fit this layout.

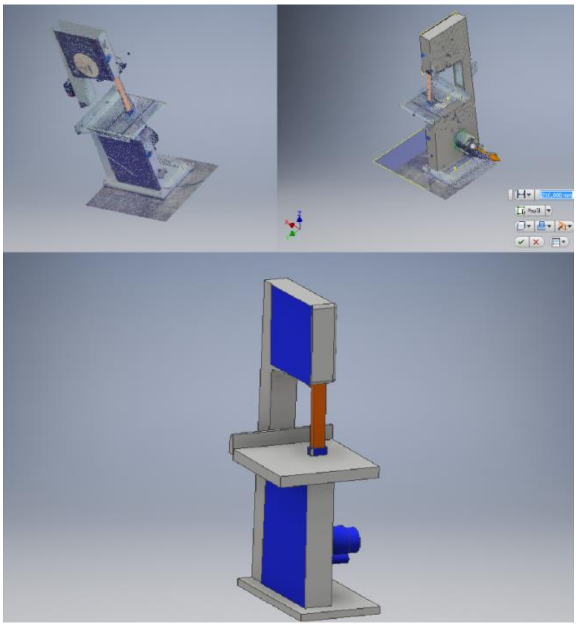

*Fig 3. Reconstruction of a single model from a point cloud. Top left is the input point cloud, with an example of the modelling during the process at top right. The lower image shows the final model*

### 3.2. 3D Visualizations

The RCP format of the point cloud can also be loaded in to Inventor software. In Inventor, we can use this model as a 3D visualization of the factory hall. We can remove any part of the point cloud or we can load newly created models into it so we can visualize the planned changes in the factory hall. We can also use this edited model in Navisworks software for a flythrough or for clash detection analysis. In the 3Ds MAX design the model can be used for creating animations or simulations.

These point cloud models can only be used within the Autodesk software suite. If we want to use them for example for a scanned model of a machine in other software (visTable for 3D visualization or Tecnomatix Jack ergonomic software), these models cannot be uploaded. However, we can load models that were created with the use of point cloud. If we have a quality point cloud of a machine, we can use it as an underlay for modelling. Inventor can reconstruct surfaces from the point cloud. Then it is possible to create a sketch on these surfaces by tracing the edges of the scanned model followed by extraction and other standard modelling tools in Inventor. We can see an example of modelling in Fig. 3. The model created this way was created more quickly than by standard modelling (based on drawings, dimensions and photos of the real object) and deviations between the dimensions of the real object and the created model were +/- 2cm. This deviation is acceptable for layout modelling but not for creating very accurate models.

### 3.2. Adjustable Layouts

The methods listed above are used mainly for layout visualization. For creating a layout which can be optimized, we have to create this model using a different method. The main concept of this method is to divide the complete hall point cloud into elemental parts. When using Autodesk software, we can create these elemental parts in ReCap. The level of detail depends on our needs. We can divide the layout into individual workplaces, machines or objects. In Fig. 4 we can see an example of a separated machine. We can create a library of models, which can be used not only in the current project but also in future projects.

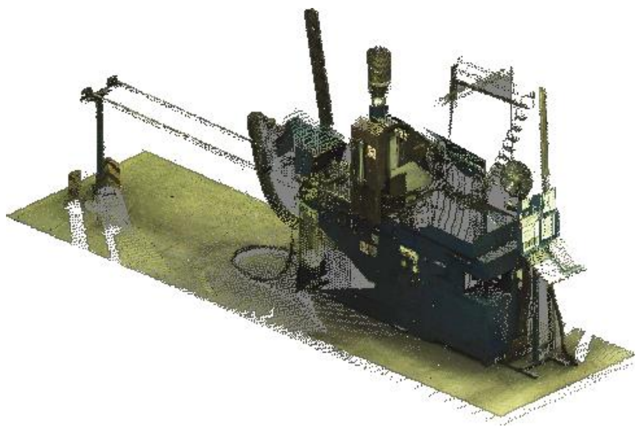

*Fig 4. Example of a machine captured by LiDAR scanning and separated from the rest of the point cloud*

After creating a collection of models, we can load them into suitable software (AutoCAD, Inventor, ...) and assemble a complete layout. An undivided model can be used as the underlay for layout assembly. After layout assembly, we can start implementing the planned changes. When using Factory Design Utilities in AutoCAD, we can also start analysing variants. Factory Design Utilities includes tools like process duration, material flow length, process costs and workplaces workload. Material flow analysis in AutoCAD with Factory Design Utilities is shown in Fig 5. Then we can visualize these changes in 3D via Inventor or Navisworks.


*Fig 5. Material flow analysis in AutoCAD with Factory Design Utilities. Point cloud is used as an underlay*

The method is almost the same for creating an adjustable layout with the use of CloudSlicer and visTable. After creating an output image from CloudSlicer, we divide this picture into elemental parts (workplaces, machines, objects). For dividing, any graphic editor can be used. We create a library of models (pictures in this case) and then these models are loaded into visTable, where the complete layout is assembled. In Fig 6, we can see an example of material flow visualization in visTable. VisTable offers better analysis visualization and it contains more analytical tools than AutoCAD Factory Design Utilities.

*Fig 6. Material flow visualization in visTable software*

### 3.4. Documentation Verification

If layout documentation exists, it is possible to use the scans for updating or verifying it. Usually, a scanned building in reality has about 5 cm error if compared to the building construction documentation, but these errors are usually irrelevant. More important are errors that are caused by modification of the hall equipment and documentation which is either incorrectly updated or not updated at all, such as can be seen in Fig 7. The position of the table is drawn completely wrong – the table is actually somewhere else and its dimensions are totally different.

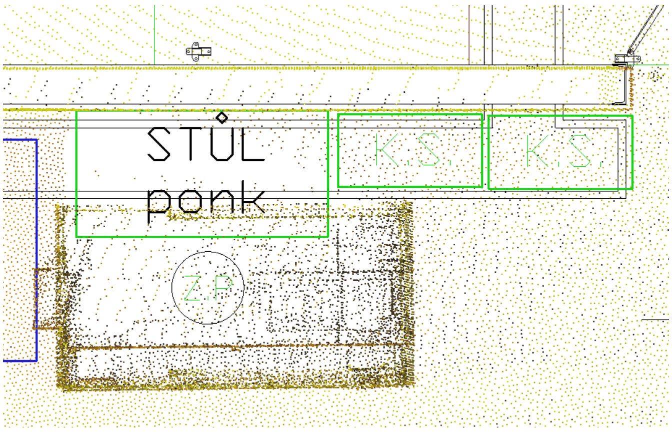


*Fig 7. Validation of a 2D layout with a point cloud overlay. Note errors in the walls and a misplaced and incorrectly sized worktable*

## 4. SIMPLIFYING POINT CLOUDS

A raw point cloud is only rarely usable, because of computing power constraints and because most modelling software cannot handle such large data sets or are not able to import point clouds at all. All point clouds need to be cleaned of interference caused by passing workers, reflections on glossy surfaces and other disturbances. Other than that, it is usually a good thing to use only the part of the point cloud that is relevant to solving the actual problem and downsample it and eventually convert it to a mesh and reduce its triangle count. Then, most CAD modelling software can handle such point clouds. This proved to be a very good approach for parts reconstruction or for ergonomic analysis.

However, this is not very suitable when capturing an industrial layout. Some software for layout modelling is not compatible with point clouds, and usually larger sections of point clouds are required to work with. Downsampling such big point clouds will lead to having the density too low and thus not being able to understand their context.

For the following case study, we scanned the interior of our Regional Technological Institute in 2014 from 26 stations, when the hall was still without equipment. In 2016, the hall was fully equipped and we supplied the old scan with a new one consisting of 6 stations. The overall scan boundary box size is 22×40×6 meters.

*Tab. 1 Counts of points in various sections of the RTI production hall. The hall was first scanned empty and the scan was supplemented by a new scan after the hall was equipped*

| Section | Points count | Points count ratio [%] | Points after downsampling |
|---|---|---|---|
| Actual layout | 18,703,906 | 21.98 | 854,937 |
| Walls | 13,400,308 | 15.75 | 232,903 |
| Floor | 18,542,589 | 21.79 | 210,050 |
| Ceiling | 34,454,332 | 40.49 | (deleted) |
| Total | 85,101,135 | 100 | 1,297,890 |

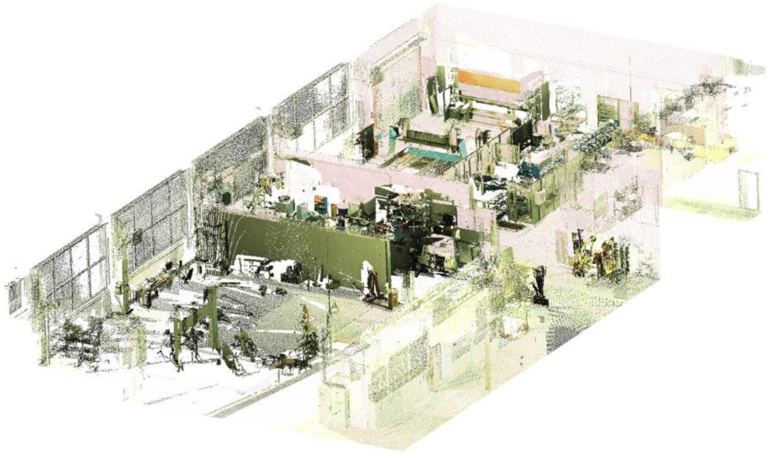

*Fig 8. Selectively downsampled scan of the RTI production hall*

Still, the decimation of the point cloud is a necessary step. In a reference scan of our research institute, only about 22 % of the total 85 million points in the raw scanned point cloud represent the actual scope of our scanning – the machine layout. See Tab 1 for details. The ceiling with crane, lights and other installations could be cut off totally, reducing the amount significantly. The floor and walls have together 37 % of the points, but for alignment and context reasons, it proved necessary to keep them, but they can be downsampled much more (in this example one point per 0.05 meters) than the actual layout (0.02 m point spacing) to keep the point cloud eligible. The resulting 1.3 million points are enough to understand the context of the points, but still small enough for a few programs to work with it. This means that selective downsampling of the point cloud is a much better approach than downsampling the whole cloud. The resulting point cloud can be seen in Fig 8.

The number of points for the ceiling is always quite high, because a large portion of the ceiling is scanned from most scan positions. When scanning the whole layout directly in the finished hall (without taking a scan of the empty hall), the ratio of points in the layout and the rest (walls and floor) is also better, because the layout actually obstructs the walls and floor. See the next case study.

In this case study, a real production hall with welding and grinding machines was scanned during worktime from 25 stations. The dimensions of the hall are 37.5×130×11 meters. The selective downsampling was made with same values (point spacing of 0.02 for layout and 0.05 for walls and floor, with the ceiling deleted). See the resulting downsampled layout in Fig 9 and the overview of the point count in Tab 2.

Still, there are tools that do not manage to work effectively even with the decimated point clouds, or they are not compatible with them at all. In such cases, when preparing 2D or 3D models of the layout, the point cloud can be orthographically projected to bitmap slices.

We use our own software program called CloudSlicer written in C++. The input file with the point cloud in ASCII format is first translated to a proprietary binary format as a step of pre-processing, because reading points in binary format is much faster than parsing the values stored in a text file.

This file is then subjected to the next step, where three direction vectors are defined. These vectors define the directions of the projection to a raster image. Vectors X and Y correspond to the horizontal and vertical axes of the resulting image; vector N is the direction of projection. The last inputs are two floating point values representing near and far culling distances. These values define a transformation function.

Now, the algorithm can load the point cloud points one by one. They are arguments of the transformation function in the transformation class. If they fit into the bitmap raster, their colours are blended - usually averaging the colours of points projected to a single bitmap pixel. When all of the points pass the transformation algorithm, the bitmap can be exported as a BMP file. This image can then be converted to any image format and used as an underlay in almost all modelling or layout drawing software tools. See an example of such raster image slice in Fig.10.

*Tab 2. Counts of points in various sections of the RTI production hall. The hall was first scanned empty and the scan was supplemented by the new scan after the hall was equipped*

| Section | Points count | Points count ratio [%] | Points after downsampling |
|---|---|---|---|
| Actual layout | 23,235,765 | 27.68 | 5,040,228 |
| Walls | 3,698,929 | 4.41 | 363,711 |
| Floor | 15,040,581 | 17.92 | 690,210 |
| Ceiling | 41,967,126 | 49.96 | (deleted) |
| Total | 83,942,401 | 100 | 6,094,209 |

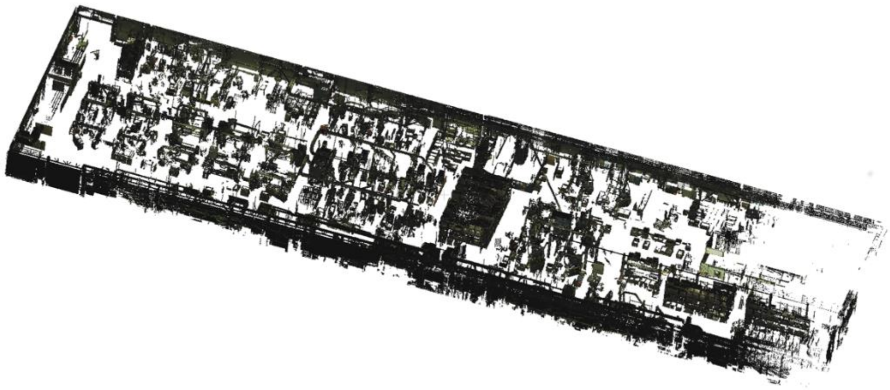

*Fig 9. Selectively downsampled scan of a production hall with welding and grinding machines. The scan was conducted during the regular operation of the production system*

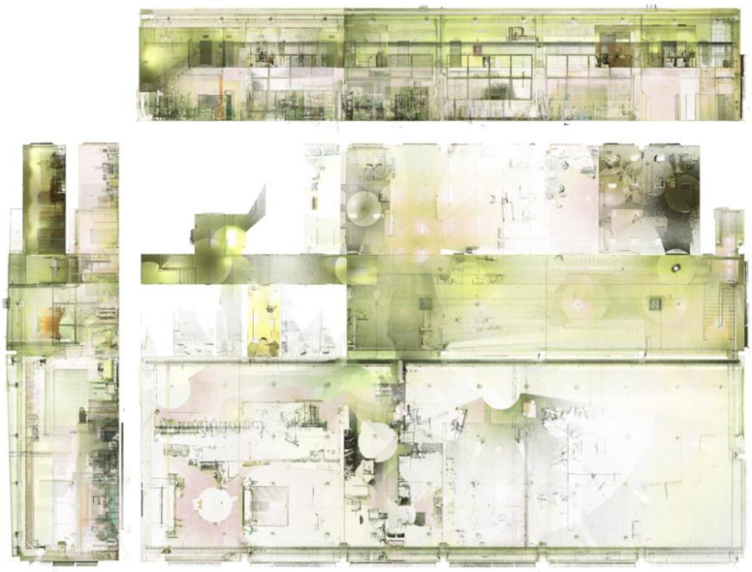

*Fig 10. Parallel projection of the RTI production hall layout in three views*

## 5. 3D SCANNING FOR ERGONOMIC ANALYSIS

Ergonomics, as well as other sciences, is influenced by a massive utilization of information and communication technologies. In ergonomics, one of the most common computer applications is the creation of digital human models (DHM) that are used to test different scenarios in a virtual environment. Digital human representations in various forms are increasingly being incorporated into the computer-aided design of human-machine systems, such as driver-vehicle systems or manufacturing workstations.

DHM-tools have been introduced in industry to facilitate a faster and more cost efficient design process as well as to evaluate existing workplaces. Virtual technology allows ergonomists and engineers to perform virtual builds, and the rapid adoption of virtual tools creates an opportunity to integrate considerations of ergonomics into early design stages. [8]

If we focus on the case of existing workplace optimization, we need to digitize the workplace or create a virtual environment of a current workplace. Usually the evaluation process can be divided into four phases, as presented in. [9]

**1. Collection of workplace information** – The first step is always to collect all the necessary workplace information (such as workplace dimensions, worker and process data) in order to create the most accurate virtual environment of the real workplace, on which analyses and experiments will be performed. It is necessary to establish a complete work environment, including the facilities, machines, equipment, and tools. In this phase we have two options for obtaining the required dimensions of the workplace. The traditional and most commonly used way is to measure the workplace dimensions directly (e.g. by measuring tape and camera) or with modern tools such as 3D scanners.

**2. Construction of the virtual environment** – The next step involves construction of the digital workplace or the environment that is being evaluated and also importing and setting up the DHM. Depending on how workplace dimensions were obtained in the preceding phase, we have to either draw the 3D models in graphical software or create a 3D model from the point cloud obtained with the scanner. Individual models are subsequently assembled to create a whole virtual environment. Finally, the DHM is inserted and its properties such as population group, sex, height and weight are set to ensure that the analyses will be performed for specific workers.

**3. Ergonomic evaluation** – The third step involves task simulation and evaluation of these tasks with ergonomic analyses and interpretation of the results. This part is always different. It depends on the issues we need to solve.

**4. Improvement and re-evaluation** – The final step involves suggestions for improvement and their re-evaluation. Re-evaluation is very important to be sure that the proposed changes have the required effects.

In the experiment described in [10] we focused on the first two phases in detail. We analysed two industrial workplaces. Each workplace was analysed by a different engineer who was highly skilled in the use of 3D modelling software and had average skill with the DHM software. They were assigned to perform the first phase in the standard way – measure the dimensions and create a 3D model in graphics software (Catia V5, Inventor). Tecnomatix Jack was selected to create the virtual environment and subsequent ergonomic analyses. During the whole process of ergonomic evaluation, the engineers were assigned to fill the timesheet for their progress and to divide it into the four phases mentioned earlier. At the same time, the authors of the paper performed the 3D scanning of selected workplaces, extracted the model from a point cloud using CloudCompare software and created the virtual environment.

Both workplaces were quite similar regarding the workplace complexity and utilization. They were composed of several components such as a working table, rack, packaging (boxes) and a chair. The 3D model and the model from 3D scanning of workplace 1 can be seen in Fig. 11.

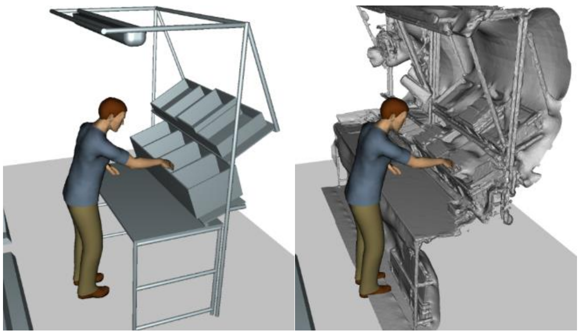

*Fig 11. Visualization of the virtual environment created by 3D modelling (left) and 3D scanning after applying a point cloud surface reconstruction algorithm (right)*

The numbers of hours that engineers spent analysing each workplace are noted in Tab. 3. The duration was recorded to the nearest 0.25 hour. In both cases, all phases were completed within 12 hours. For comparison with 3D scanning, the first and second phase are important. These phases last 5 hours for workplace 1 and 5.5 hours for workplace 2. In the first phase the engineer obtained the basic information about the process (work instructions, time duration of the operations, data about the workers, video of the operation) and about the workplace itself (workplace photos and measurement of dimensions). During the second phase the engineers drew the individual parts of the workplace (table, rack, chair, boxes, etc.). The last activity in this phase was the compilation of the whole workplace and importing to Tecnomatix Jack.

Scans of both workplaces were then performed. Scanning consisted of the first and second phases. During the first phase only data about the process were obtained because these data (dimensions and photos) were obtained by the scanner. Additionally, the data about the process were gathered during the automatic scanning by the scanner. Thus the scanning in the first phase was done in 45 minutes (workplace 1) and 30 minutes (workplace 2), see Tab 3. The scanning of each workplace was performed from 3 positions. The second phase was done almost automatically, because the model of the workplace was extracted from the scanned point cloud using the Screened Poisson Surface Reconstruction algorithm [11] in CloudCompare. Only the last activity of importing the model to the Tecnomatix Jack was the same as in the previous case. The duration of this phase was 45 minutes for both workplaces.

*Tab. 3 Comparison of time spent preparing the 3D data for ergonomic analysis*

| Phases | Workplace no. | | | |
|---|---|---|---|---|
| | 1 (model) | 2 (model) | 1 (scan) | 2 (scan) |
| 1. Collection of workplace information [h] | 2 | 2 | 0.75 | 0.5 |
| 2. Construction of virtual environment [h] | 3 | 3.5 | 0.75 | 0.75 |
| 3. Ergonomic evaluation [h] | 3 | 3.5 | 3 | 3.5 |
| 4. Improvement and re-evaluation [h] | 4 | 3 | 4 | 3 |
| Total [h] | **12** | **12** | **8.5** | **7.75** |

As can be seen from the previous data, the use of a 3D scanning device for obtaining a 3D representation of a workplace in order to make an ergonomic analysis proved to be a very useful method. The speed of data acquisition and processing was much higher (up to four times faster) when using the 3D scanner than while measuring the workplace using traditional tools and making the model in CAD software. While comparing the traditionally made model with the scan of the workplace, the differences ranged from 3 to 5 cm. The question is, whether errors occurred during scanning because of vibration or the soft floor, or whether it occurred during measuring (or both). However, such small differences are not relevant to the results of ergonomics analysis, be it RULA, NIOSH or any other analysis. Usually the positioning of the digital human model in the virtual environment brings its own deviation.

## 6. DISCUSSION

Use of terrestrial laser scan stations proved to be very useful as a tool for capturing industrial layouts, although the devices are still very expensive and require qualified and responsible workers to operate them. Most companies are not big enough to be able to afford the advantages of owning one, including processing software licences and employing the operators. We suppose that the majority of laser scanning projects involving industrial layouts will outsource them, which is also quite expensive. We estimate that the costs of outsourcing are almost equal to the costs of commonly used measuring tools and measurement methods.

However, the benefits are much faster data acquisition (in the case of ergonomic analysis up to four times faster), a much higher level of safety (there are no people moving between the machines to take the measurements), and almost no interruption of the production. We believe that laser scanning would be the number one option for general layout capturing if the devices were not so expensive.

Another aspect to consider is the type of production. For example, it may be hard to scan robotic welding lines as the robots are moving all the time, but it should be sufficient to scan their bases and use models of existing robots. Moving objects can be a problem when scanning, although the scans should capture the silhouettes of moving objects, which should be efficient for capturing trajectories. Last but not least, the laser light energy has to be taken into consideration. The flashes of the laser beam could tamper with various sensors. In our experience, some workplaces are very narrow and do not allow convenient deployment of the scanning station without interrupting the production flows. If only a few workplaces are present, it is possible to cover them during workers' breaks. If not, then the scanning could be conducted after the shift, although it might bring some expense and inconvenience for the customer (such as lighting, security issues, etc.).

It is also necessary to consider what the target of the scanning is. If layout models already exist, partial scans are sufficient to place the 3D models. When it is necessary to make models of the objects as well, the scanning will take much longer because it is required to have them scanned from all directions.

It is also necessary to consider target vs. targetless registration. The target scanning was a source of errors and failed registration when misselected. On the other hand, targetless registration can be time consuming, because it involves manual alignment of particular point clouds - although the manual part of the process does not have to be precise, the actual constraint is computed afterwards thanks to fine algorithmic alignment. The other thing we found inconvenient with target registration was the requirement of 4 constraints between two scans, which was not always easily achievable. In addition, in conditions of real production, we believe the targets can be moved both intentionally and accidentally by passing workers or vehicles.

The accuracy of laser scanning exceeds the accuracy of common measuring tools. For ergonomic analysis and modelling industrial layouts for discrete event simulation and material flows, an accuracy of 10 mm is quite sufficient. By using the laser scanner, we achieve this kind of accuracy.

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# GENETIC ALGORITHM FOR FACILITY LAYOUT PROBLEM

*Viktor Hančinský*

## 1. INTRODUCTION

Within the design of production layout, the planners are often confronted with complex, sometimes conflicting demands and a number of restrictive conditions, which encourages their efforts to develop new, progressive approaches to the development of production layouts. The purpose of the innovative approaches in this field is to provide users with better, elaborated designs in less time, while they are able to implement various restrictive conditions and company priorities to the design. [1]

The trend of todays advanced times is evolutionary algorithms that use mechanisms inspired by biological evolution, to evolve solution. These algorithms are heuristic in nature and show good results for complex optimization problems.

The combination of these two technical fields offers the opportunity to exploit the available potential of evolutionary algorithms for the development of production layout, so that quality solutions within a reasonable time can be achieved.

## 2. GENETIC ALGORITHMS

Genetic algorithms are based on the Darwinian principle of natural evolution that was described in his book On the Origin of Species by Means of Natural Selection, or the Preservation of Favored Races in the Struggle for Life (1859). This publication brought a revolution of the perception of life on Earth. Together with other disciples they gradually formulated the laws of classical genetics and the basic principles of reproduction. In the twentieth century these principles expanded into other, than biological fields.

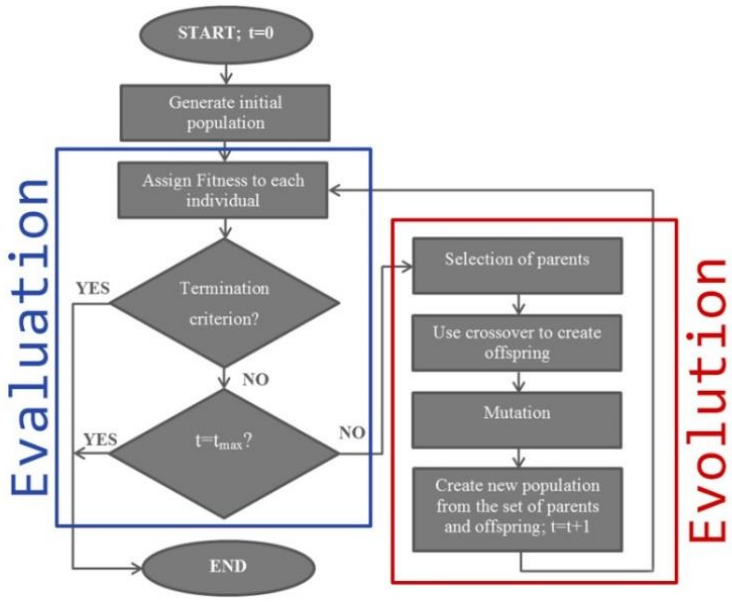



*Fig 1. Basic genetic algorithm*

In the seventies of the twentieth century, genetic algorithm was proposed by J. H. Holland as an abstraction of appropriate genetic processes. A decade later, genetic algorithms became one of major rapidly developing fields of informatics and artificial intelligence. Fig 1 shows the basic procedure of genetic algorithm, which was divided into three main sections – initialization, evaluation and evolution. [2]

### 2.1. Beginning and evaluation steps

Before running the algorithm, several values must be set, such as probabilities for crossover and mutation, maximum number of generations, number of individuals in a population, selection criteria and so on. After generating the initial population, which can be created randomly, or based on historical/empirical data, the evaluation section takes place. The first step is to evaluate each individual in relation to the solved problem. Within genetic algorithms, we call the function that evaluates individuals as fitness function. Basic principle of genetic algorithm is that individuals with better fitness must be unconditionally preferred in selection to next generation. However, with certain probability, it is possible for every solution to be selected. This ensures the diversity of the population. [3]

The next steps after determining the fitness of all individuals in current population are two decision blocks, where the first evaluates, if the termination criterion is met (e.g. cost is bellow specified value) and the second checks, if the maximum number of generations is not exceeded. If none of the above applies, the evolution section takes place.

## 2.2. Selection

Within the evolution, the algorithm must first select the parents. As we mentioned, higher fitness means higher probability of individual being chosen. Several methods for choosing parents are known, we particularly can mention these:

**Roulette mechanism (fitness-proportionate selection)** – in roulette mechanism, all individuals have a chance of being selected at any given point. The probability that a given individual will be selected is proportional to its fitness value. The probability of selecting an individual j with fitness f out of population of i individuals is defined by following formula:

$$p_j = \frac{f_j}{\sum_1^i f} * 100[\%] \qquad (1)$$

After studying various modifications of this mechanism, J.E.Baker designed an improvement – instead of the cycle of k-fold use of roulette and gradual selection of k-individuals, roulette mechanism will be carried out only once and all k-individuals will be selected at once. Mechanism does not work with only one roulette ball, but k-balls, which are equally spaced around the circumference of roulette. This method can be found in literature as **stochastic universal sampling**.

**Roulette mechanism (rank selection)** – to suppress the effect of above-average individuals (reducing the selection pressure) a modified version was designed, in which individuals are ranked in ascending order according to their fitness value. This type of selection offers a better chance of maintaining diversity of the population, but can also lead to slower convergence, because the difference between the individuals is not so considerable.

| - | Individual 1 | Individual 2 | Individual 3 | Individual 4 |
|---|---|---|---|---|
| Fitness | 25 | 5 | 3 | 10 |
| $P_{fps}$ | 58% | 12% | 7% | 23% |
| Rank | 1 | 3 | 4 | 2 |
| $P_{rs}$ | 40% | 20% | 10% | 30% |

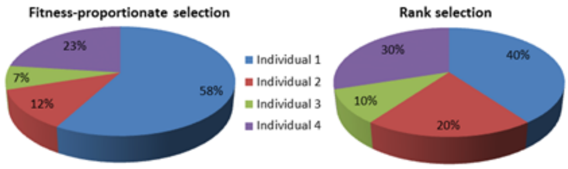



*Fig 2. Selection probability distribution of individuals by roulette mechanism*

**Elitism** – this method avoids losing so far the best solution found by copying this solution to the new generation before applying genetic operators. The rest of the selection continues by one of the other methods.

**Steady-State Selection** – the main purpose of this method is the survival of a large portion of individuals to the next generation. A specified number of the best and worst chromosomes are selected. The best chromosomes will then reproduce and their offspring replaces the weakest individuals. The remaining individuals are left unchanged. [4]

**Tournament mechanism** – for each iteration, the mechanism chooses k-individuals (k-determines tournament size) and then selects the best of these individuals and moves it to the next generation. This process is repeated i-times, where i is the size of the population.

To find the right balance between the selection of the finest individuals and the search of solution space (finding the right selection pressure) is one of the key aspects of effective search for a solution. Higher selection pressure leads to faster convergence, but increases the probability that the algorithm gets stuck in local minima. On the contrary, lower pressure prolongs the time needed to find a solution.

## 2.3. Reproduction

In genetic algorithms, crossover is a genetic operator, which is responsible for mutual exchange of parts of chromosomes.

In general, we can speak of a *j*-point crossover, where $n>j\geq1$ ($n$ = chromosome length). *J*–crossover points are generated, which divide the individual into j+1 strings, which are then exchanged between individuals. After further generalization we can speak of uniform crossover. During the creation of the first descendant, for every gene there will be a decision with probability $p$=0,5;

from which parent it will inherit corresponding allele. The second descendant then inherits alleles from the second parent. [5]

In case of representation of possible solution by real numbers, we can mention another types of crossover such as arithmetic (descendant allele is the arithmetic average of parental alleles) or geometric (descendant allele is the square root of the sum of the squares of parental alleles).

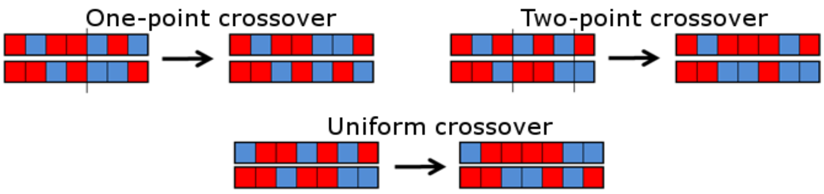



*Fig 3. Types of crossover*

## 2.4. Mutation

Mutation is a genetic operator used to maintain genetic diversity of the population. Within mutation, one or more alleles in the chromosome are altered from their initial state. The main goal of mutation is to prevent algorithm from being stuck in local extreme by preventing excessive similarity of individuals. It is also important to determine the mutation rate within the genetic algorithm. If the probability is set too high, the algorithm can turn into a random search.

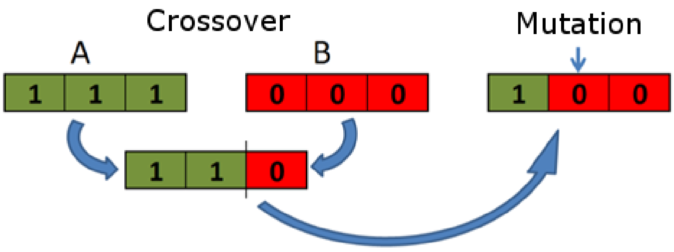



*Fig 4. Genetic operators – crossover and mutation*

### 2.5. Summary

The main advantages of genetic algorithms include:

- They do not require any special knowledge about target function, they are universal.
- Genetic algorithms have very good results with problems with a large set of possible solutions.
- Versatility for a variety of optimization problems.
- They work with a population of possible solutions, thus it is less probable for the algorithm to end at a local optimum.

Disadvantages include:

- They do not find optimal, but feasible solution.
- The implementation of the algorithm, the representation of solutions and the formulation of evaluation function can be difficult.
- If there is a specialized algorithm for a particular problem, which uses some knowledge about the problem, it usually surpasses the genetic algorithm both in speed and quality of the solution. [6]

## 3. USAGE IN INDUSTRY

Initially, the genetic algorithms were used for experiments and simpler variants of problems (for example knapsack problem). After the verification of applicability of genetic algorithms and the increase of computing power, over time they were used in more complex tasks.

Out of many application fields we can mention the following examples:

- Design of products, their components or materials.
- Robotics.
- Logistics.
- Job scheduling.
- Facility layout design and optimization.
- Balancing manufacturing and assembly lines.
- Machining.
- Data mining. [7]

Following lines show real applications of genetic algorithms to various problems in industrial practice.

Genetic algorithms found their use in design of racing and also regular vehicles. The struggle to create faster, lighter, safer, and environmentally cleaner and fuel efficient vehicles can be greatly accelerated by computer modeling and simulation, which use this kind of algorithm. With suitable application, they can replace time-consuming testing in wind tunnels, or laboratory experimentation with polymers. In paper Optimizing the performance of a Formula One car using a Genetic Algorithm [8] is described the use of a genetic algorithm to optimize 66 setup parameters (i.e. camber settings, ride height, toe in settings, radiator size, tire pressure, gear ratios) for a simulation of a Formula One car and performance improvements are demonstrated.

Another fast developing application of genetic algorithms is the maximization of use of the potential of whole variety of materials. The main aim is to optimize structural and functional design of buildings, facilities, plants, machines and equipment. Among these kinds of applications, we can find design of heat exchangers, antennas, turbines, or robot effectors.

In logistics, they have found use, for example, in the traveling salesman problem. With the use of genetic algorithms, we are able to plan the most efficient route, correct timing to avoid rush hours, and maximize the use of transport vehicles, which can be very useful for freight companies.

Out of many other fields in which genetic algorithms have found their use we can mention, for example, robotics, encryption, criminalistics, computer games, finance or marketing.

In fields of industrial engineering we can also find many potential areas for application of genetic algorithms. The first area in which it is possible to use genetic algorithms is production scheduling. In dissertation thesis Production scheduling with the support of simulation and evolutionary methods [9] a modular system methodology for job shop scheduling with the support of simulation and evolutionary methods was proposed. In this methodology scheduling is defined as a sequence of steps, which are divided into three main parts:

1. Generation part – Generation of raw schedule using priority rules.

2. Evaluation part – Evaluation of the schedule using a simulation model.
3. Optimization module part – Schedule optimization using genetic algorithms. [9]

The optimization module part tries to find an optimal schedule according to defined criteria, which are expressed in fitness function. Input data and results are displayed in MS Excel environment, wherein communication between Excel and simulation software runs through ActiveX interface. Optimization module itself is a part of the Plant Simulation software, developed by Siemens. In this software both the simulation and the optimization take place.

In addition to production scheduling, with simulation software along with evolutionary methods it is possible to optimize the production system. In thesis Simulation of the production system with the use of evolutionary methods [6] a concept of simulation-optimization system with genetic algorithm has been designed and verified. Application named GAsfos2 is presented, which cooperates with the simulation software Witness to optimize production system. Application is programmed in Visual Basic 6.0 and uses the core created with GAlib library. This library, which includes tools for using genetic algorithms, is programmed in C++ and is available for free for academic purposes. The application consists of:

1. GAsfoS2 – user interface.
2. GAworker – core, which uses genetic algorithms.
3. Valuator – used for communication between Witness and GAworker core, using OLE interface.

The application works as follows: When the GAsfos2 starts, through application it also starts Witness software with selected simulation model. The size of population, number of generations, simulation time and other factors affecting the course of optimization can be adjusted. After starting the optimization, GAworker creates the zeroth generation, which is recorded to the communication and evaluation interface – Valuator. Subsequently, the model is set in Witness and the simulation is launched. After its completion, the model is evaluated and GAworker creates a new population, using roulette mechanism. After every generation, the results are recorded into Valuator. Process runs until one of the termination conditions are met – the maximum number of generations, or achieve desired values. Fig 5 shows the working principle of GAsfos2.

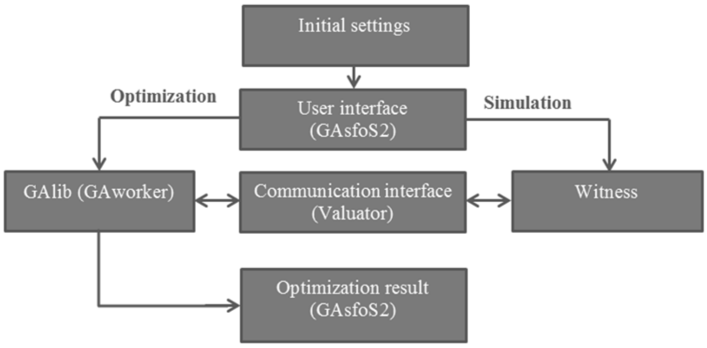
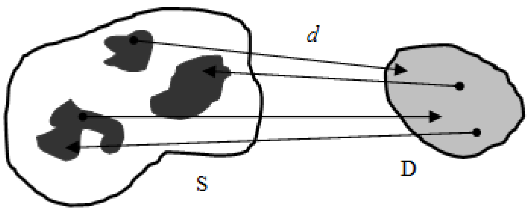



*Fig 5. Working principle of GAsfoS2 [10]*

Problem closely linked to production scheduling is Assembly Line Balancing Problem. We can talk about General Assembly Line Balancing Problem (GALBP) in the case that not only precedence constraints but also other attributes and limitations are taken into account. A common feature of most line balancing problems is that one predefined precedence graph represents all possible precedence constraints between the operations. However, in real industry problems, there may be some parts of the manufacturing process replaced with alternatives, so there may be more variants of manufacturing process procedures. This is possible in many cases either assembly or disassembly of products for which there are multiple variations of production. So there is large space with possible solutions to the problem and it is needed to have effective tool for finding solution close to the optimum.




$$d : D \rightarrow F(c_1,\ldots,c_m)$$

*Fig 6. Transformation d between spaces S and D [3]*

In the genetic algorithm for solving line balancing problem it is needed to use technology of decoder. Its use leads to the fact that the chromosome is not seen as a coded solution, but rather as information, which makes it possible to construct a feasible solution. Chromosome represents a sequence of operations, which will be assigned to workstations. So instead of searching space S and its subsets it is possible by using an appropriate representation to create a completely different searching space D. So decoder d serves as a transition between individuals of space S and their images in the set of feasible solutions $F(c_1,...,c_m) \subseteq S$ .

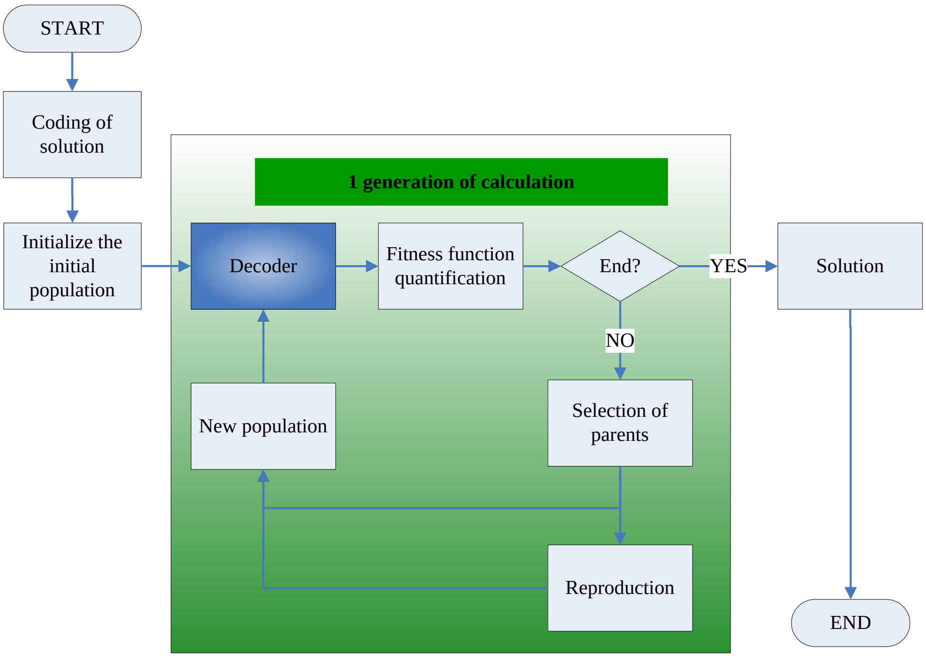



*Fig 7. Application of GA in line balancing problem [8]*

Another area of application of genetic algorithms is the design or optimization of various layout solutions. In subsequent chapters, we will focus on facility layouts, where genetic algorithm is used for machinery and workplace placement.

## 4. GALP – GENETIC ALGORITHM LAYOUT PLANNER

In general, we can define the facility layout problem as the search for the best arrangement of physical objects, which ensures the most effective operation of these facilities. Within solved dissertation thesis, an extensive study was dedicated in this field, and a solution for integrating genetic algorithm into production system design is presented.

### 4.1. Demands on the application

For setting the most feasible parameters, as well as the overall representation of the solution it is necessary to summarize the demands, which should be met within the solution. These were specified as following:

- Interconnection possibility – within our solution, we set as one of the main demands the possibility to connect our solution with software for developing 3D layouts. Also, solution will be integrated in the digital factory concept where it will fit in with previous and following activities of production system design. [11]
- Possibility of problem specification – Because of diversity of production systems and their possible requirements, it is important within created algorithm to implement the possibility of setting parameters for the specification of the search for solutions in order to achieve better results. Using the user interface it should be able to enter:
    - Facility dimensions.
    - Existing restrictions within facility - columns, aisles, machines,
    - Machine dimensions.
    - Specification of machines that will not be placed using developed algorithm, but will be permanently placed by user.
    - Choice of fitness function, or the weight of various functions of which will be the resulting value of fitness calculated. [12]
- Output and its visualization – within a running program it is necessary to provide user with a brief, but clear information about the status of solution. After the termination of algorithm, it is also needed to visualize the reached solution.
- Utilization of genetic algorithms – The core solution will use selection, recombination, mutation and the other operators of genetic algorithm for finding a feasible solution.
- Discretization – For metaheuristic optimization method, suboptimal solution is normally sufficient as a compromise considering the time of calculation. Created genetic algorithm, as genetic algorithms in general, are highly inefficient when working in a continuous space [12] so we decided to discretize the space on the base unit - one meter. Each machine,

aisle, or restriction in the facility that is to be included in the solution therefore must cover an area of at least one square meter. Dimensions therefore have to be rounded to integers. Exact dimensions are taken into account only when working in CAD system.

- Clarity and simplicity of the user interface - entering input data as well as specification of the desired solutions should be clearly arranged, grouped under various sections and easy to use.

### 4.2. Algorithm for plant layout design utilizing genetic algorithms

Within the practical part of dissertation thesis, an application based on the proposed algorithm was programmed using software solutions available on the Department of Industrial Engineering at University of Zilina – Matlab, where the genetic algorithm core was programmed and FactoryCAD / FactoryFLOW pack developed by the company Tecnomatix, which was developed for the 3D production system design and also for static evaluation of these systems. We can also export this data in a SDX format (Simulation Data Exchange). The control is made through a user interface created in MS Excel. Main scheme of plant layout development utilizing genetic algorithm can be seen in Fig 8. Connection diagram of the proposed solution in general, and also in a processed version is in Fig 9 and Fig 10.

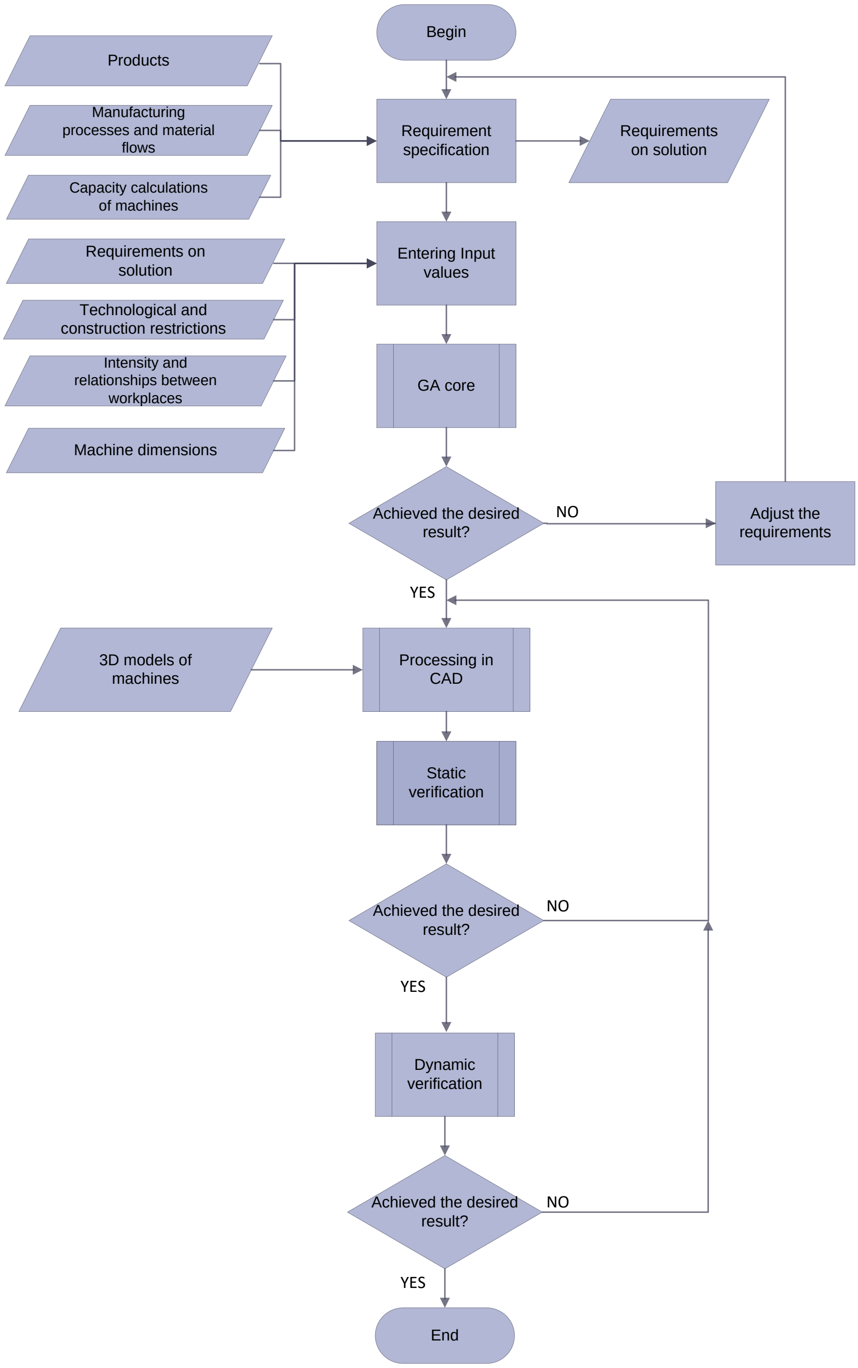



*Fig 8. Algorithm of plant layout development utilizing GA*

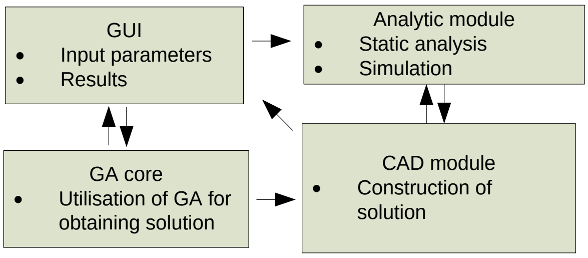



*Fig 9. Interconnection of proposed solution modules*

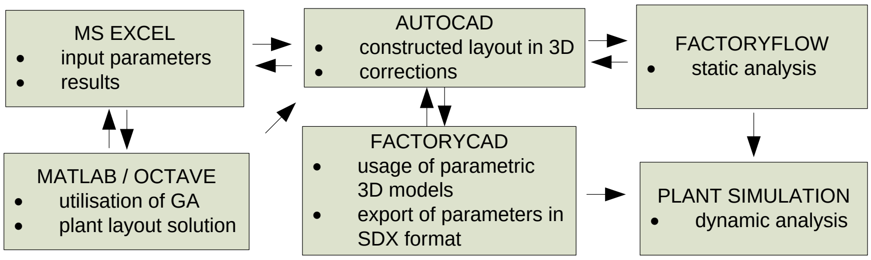



*Fig 10. Interconnection of processed solution modules [12]*

In the following chapters we will further specify and describe individual steps of plant layout design with the utilization of genetic algorithms.

### 4.3. Specification of solution requirements and entering input values

This step is necessary to define the essential requirements for the proposed production layout. These requirements are based on previous steps of Plant layout algorithm developed by Furmann in his dissertation [13]. It is necessary to specify parameters such as:

- Number of placed workplaces, machines and equipment.
- Relationships and intensities between individual machines and workplaces.
- Coeficient values for A,E,I,O,U,X codes used for relationship assessment (optional – only if relationship fitness function will be used).
- Ratio between distance-intensity fitness and relationship fitness.
- Specification of entry and exit points of the production system (optional).
- Specification of individual machines and workplaces – names, dimensions (optional).

- Specification of facility dimensions and any eventual construction restrictions such as walls, columns or aisles (optional).

It is also necessary to define the parameters of the genetic algorithm as:

- The maximum number of generations (iterations).
- The number of individuals (solutions) in generation.
- Types of selection, crossover, mutation and their probabilities.
- The maximum allowable value of fitness function (optional).
- The maximum time of solution (optional).
- The maximum number of generations without improved solution (optional).

After determining the input values, they need to be entered via the developed user interface. A demonstration can be found at Fig 11.

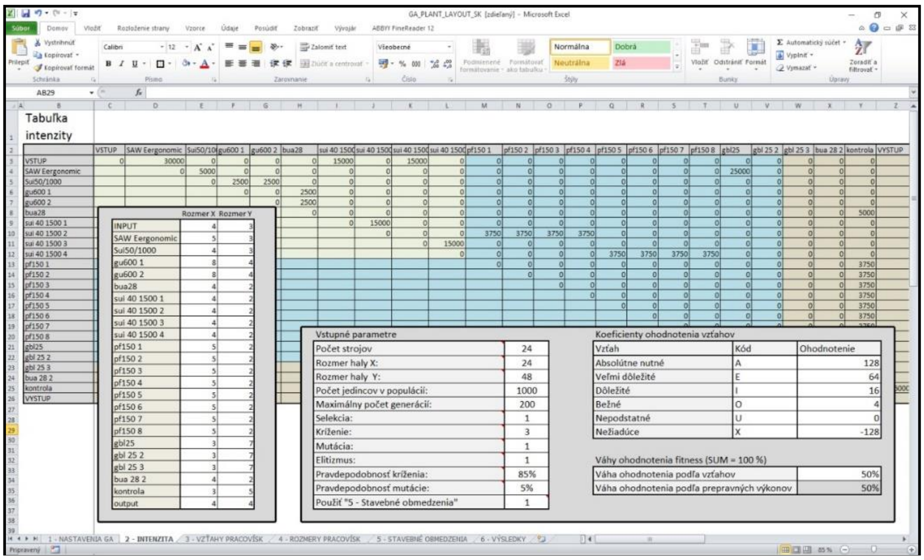



*Fig 11. Entering input variables*

### 4.4. Solution core - utilizing genetic algorithms

After entering all input information, which is essential for the successful run of the algorithm, it comes to the actual solution using genetic algorithm, where the process can be seen in Fig 12.

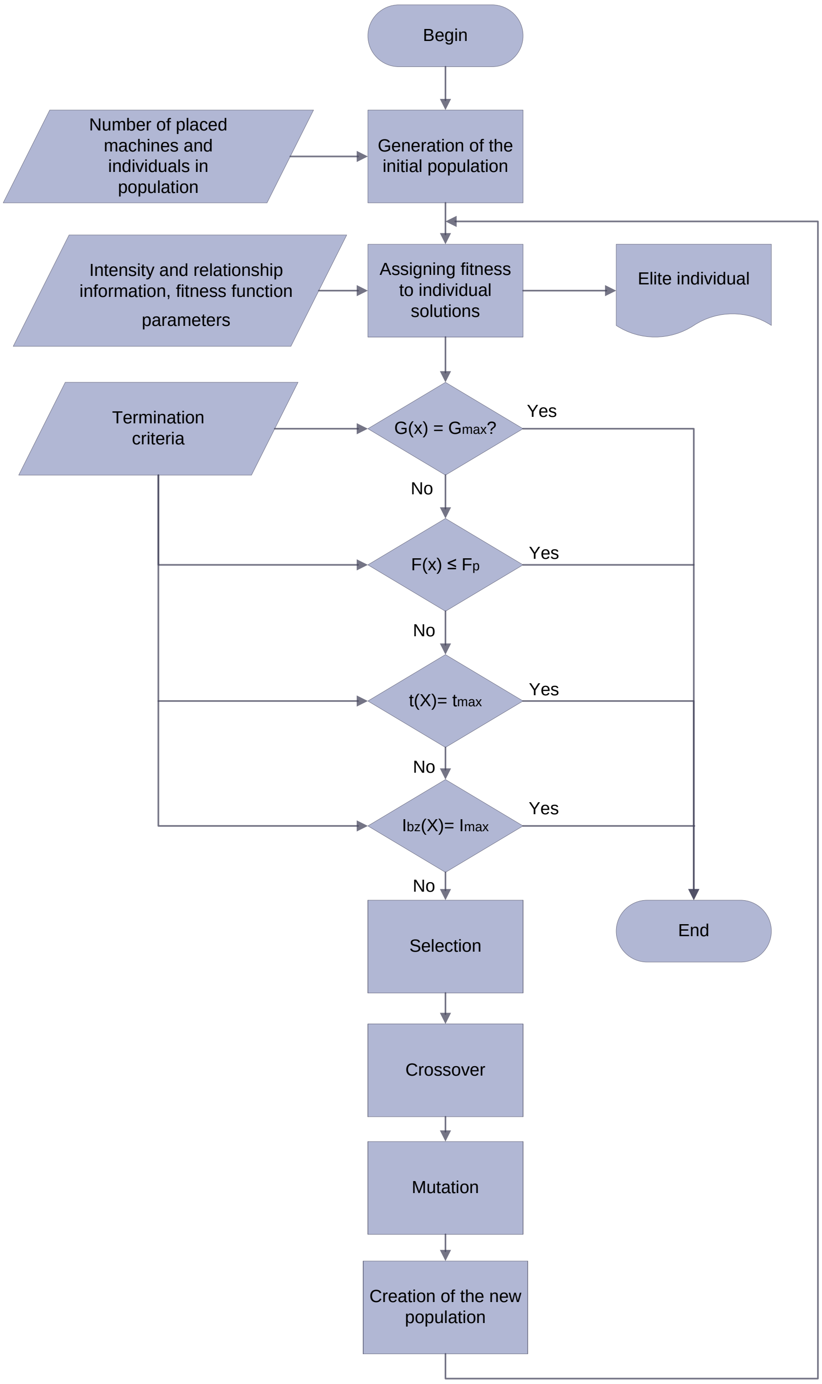



*Fig 12. Developed genetic algorithm*

### 4.4.1. Generation of the initial population

The first step is to create an initial population, which is a set of solutions that will be further evolved. In our solution, every individual is composed of genes in the number count value equal to the number of placed machines. These can take the values from 1 to n, where n is the number of machines that are being placed. The order of individual genes is corresponding to the order in which the machines will be placed into the layout. The starting solution is formed by random generation. One additional gene is reserved for determining the patter in which the machines will be placed. The overall size of the matrix corresponding to the population in a single generation is thus:

**Number of individuals in population * (number of placed machines + 1)**

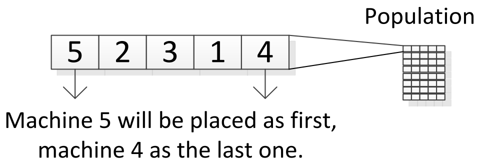



*Fig 13. Demonstration of order and ID interpretation*

### 4.4.2. Evaluation of individuals by fitness function

Following the creation of the population it is necessary to evaluate it by the fitness function that consists of two weighting components – evaluation according to the intensity and distance ($f_{ID}$) and by relationships and distance ($f_V$). The formula for the calculation of the components is as follows:
Calculation of $f_{ID}$:

$$f_{ID} = \sum_{i,j=1}^{i,j=n} D_{ij} * I_{ij} \quad (1)$$

n – the number of placed workplaces
D – rectilinear distance between workplaces i-j

$$(D_{ij} = |x_i - x_j| + |y_i - y_j|) \quad (2)$$

I – intensity between workplaces i-j

Note: The rectilinear distance was chosen for evaluating distances that are closer to possible real state, than the Euclidian distance. Calculation of $f_v$:

$$f_V = \sum_{i,j=1}^{i,j=n} V_{ij} * D_{ij} \quad \text{for } V_{ij} \geq 0 \tag{3}$$

$$f_V = \sum_{i,j=1}^{i,j=n} \frac{V_{ij}^2}{D_{ij}} \quad \text{for } V_{ij} < 0 \tag{4}$$

n – the number of placed workplaces
D – rectilinear distance between workplaces i-j

$$(D_{ij} = |x_i - x_j| + |y_i - y_j|) \tag{5}$$

V – coefficient value of relationship between workplaces i-j (AEIOUX)

The resulting value of the fitness function is defined as [5]:

$$min: f = \alpha * f_{ID} + (1 - \alpha) * f_V \tag{6}$$

α – ratio coefficient between $f_{ID}$ and $f_V$ ($\alpha \in <0;1>$)

In order to gain a rectilinear distance between the individual workplaces within solution, it needs to be constructed. Within the evaluation was thus created a module that constructs the coded solution. Also, corrective measures that prevent workplace overlapping or exceeding layout dimensions were incorporated. In addition to the length and width, we have decided to have the possibility to check the available height in the facility. The machine that will be placed into the layout will be therefore placed on position, where it will be guaranteed that in this place it is actually possible to place the machine in question.

After evaluation of all individuals by the fitness function, the best solution in generation is identified and saved – the elite individual, its achieved fitness value and the mean fitness of the population. This data can be displayed while running the algorithm for each generation, for monitoring the development of solutions. After the end of run, it is also possible to chart the development of elite and average value of fitness. The whole process of construction and evaluation of solution can be seen in the following figure.

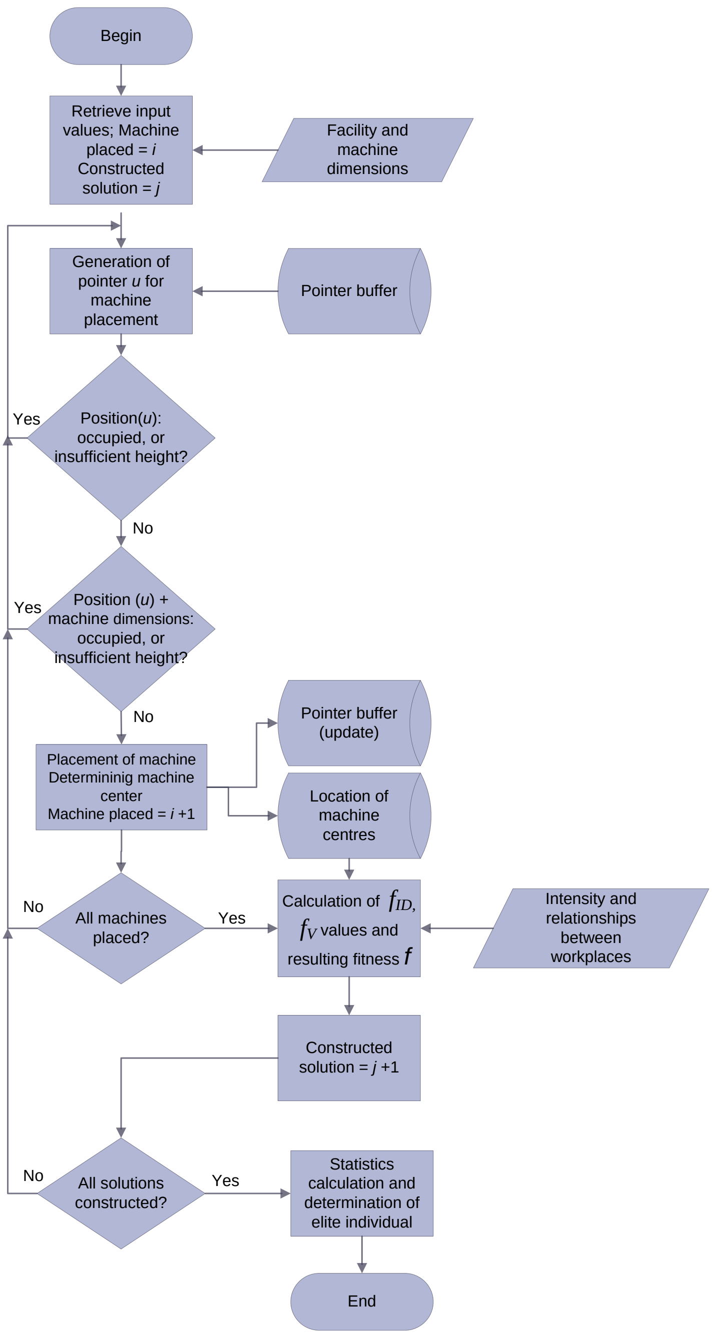



*Fig 14. Process of construction and evaluation of solution*

### 4.4.3. Decision blocks

In this step it is necessary to make comparison of specified conditions for termination of the algorithm with the current solution status in four decision blocks.

The first condition is to achieve the maximum number of generations (iterations) – $G_{max}$.

The second condition is the achievement, or exceeding the maximum allowable fitness value – $f_p$. The third condition is to achieve maximum specified solution time – $t_{max}$.

The last condition is exceeding a defined number of iterations ($I_{max}$) without the improvement of reached solution. This condition has been incorporated into the design in order to prevent long calculation time, if maximum allowable fitness value $f_p$ was not specified (or it is not reachable) and there is no further improvement in the value of the fitness function, creating a presumption that extreme in the set solutions was found.

### 4.4.4. Selection

In the case, that neither of the termination criteria has been met, the algorithm continues with selection of individuals to be crossed with each other and subsequently mutated. For developed solution we chose a roulette-wheel mechanism with fitness-proportionate selection. This method was chosen on the basis of good search capabilities of a comprehensive set of solutions for the latter parent recombination and also for its calculation speed. To avoid premature convergence we have also incorporated remapping the suitability of individuals using sigma scaling. With sigma scaling the average expected number of offspring generated from individual *i* in generation *g* is given by:

$$p_{(i,g)} = \begin{cases} 1 + \frac{f_{(i,g)} - \bar{f}_{(g)}}{k_{\check{s}} * \sigma_{(g)}} & pre\ \sigma_{(g)} \neq 1 \\ 1 & pre\ \sigma_{(g)} = 0 \end{cases} \qquad (7)$$

$f_{(i,g)}$ – fitness of *i*-th individual in generation *g*
$f_{(g)}$ – average fitness of population in generation *g*
$k_{\check{s}}$ – sigma scaling coefficient
$\sigma_{(g)}$ – standard deviation of the population in generation *g*

For sigma scaling factor $k_š$ =1, the individual evaluated with suitability of one standard deviation closer to the desired extreme than the average suitability of the population, will produce two offspring for the next population on average. The higher the $k_š$ value, the lower the selection pressure.

After remapping it is possible to choose parents with either classic roulette mechanism (generating random numbers) or using stochastic universal sampling (uniformly spaced indicators are generated, which will determine parents in a single iteration).

Pseudocodes for both methods are as follows:

**Roulette wheel mechanism:**

1. Generate random number on interval <0;1>.
2. Get parent.
3. Achieved desired number of parents?
4. False – go to step 1. True – continue with the next step of algorithm.

**Stochastic universal sampling:**

1. Generate random number – the first pointer $U_1$ – start at interval <0;F/n>.
2. Generate the rest of pointers based on the following formula: $U_1$+ i*( F/n) where i = = [0..(n-1)].

*F* – sum of fitness of each individual in population
*n* – desired number of individuals

The difference can be seen on the following picture.

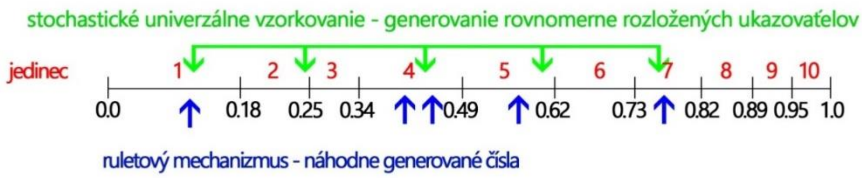



*Fig 15. Difference – roulette wheel selection and stochastic universal sampling*

After selection, the pairing will take place where individuals are randomly assigned as Parent 1 and Parent 2, which should create Offspring 1 and Offspring 2.

### 4.4.5. Crossover

After selecting individuals, their mutual recombination takes place. As part of the proposal, single point and uniform crossover, which are common in genetic algorithms, were initially programmed. However, this variant often produced degenerated solutions, with duplicated machines, or machines that have not been incorporated into the solution (Fig 16) and it was necessary to carry out corrective measures.

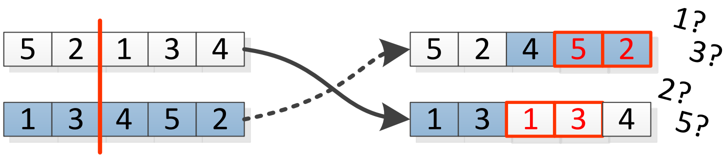



*Fig 16. Degeneration of solutions*

For more efficient crossover process, we therefore incorporated partially matched crossover (PMX) designed for similar types of coded individuals. This type of crossover has implemented measures to ensure that within the solution, each encoded machine occurs just once within its steps.

Partially paired crossover procedure is as follows:

1. Generate two random points defining the genes that the parents will exchange.
2. Pair the values of genes that have been exchanged.
3. Fill in the parent values to genes, in which there is no conflict.
4. Use paired values for the conflicted genes.

Example of partially matched crossover can be seen in Fig 17.

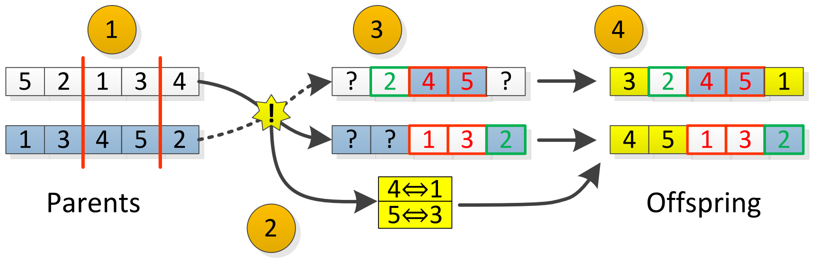



*Fig 17. Partially matched crossover*

### 4.4.6. Mutation

After crossover comes the mutation. However, in this type of solution encryption, traditional mutation, that is the change of random gene value is not an option, as this would automatically require the corrective measures to remove duplicates or machines not included. We therefore chose mutation by inversion or exchange. Since inversion is a fairly big change in the solution, we divided the probability of exchange or inversion to 80:20. The principle is shown in Fig 18.

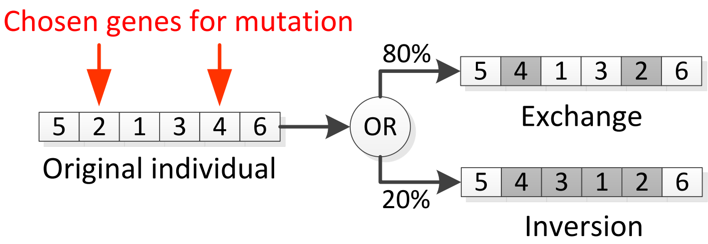



*Fig 18. Principle of mutation in the proposed solution*

### 4.4.7. Creation of a new population

Following the actions of genetic operators are parents replaced by the offspring. In the case of using elitism, where we saved the best solution after subjection to fitness function, this individual will replace the descendant with the worst fitness value. After this step, the algorithm returns to evaluation, to assess new individuals through fitness function. The algorithm is repeated in cycles until it has fulfilled one of the termination criteria.

### 4.4.8. Decision block – achievement of desired solution

After termination of the genetic algorithm, outputs are generated in the user interface outputs: block layout, the reached value of fitness with the information, when has it been reached and a chart showing the evolution of the average and elite values of fitness in the population.

Then it is up to the user to assess, whether the requirements have been fulfilled. If the solution is unsatisfying, it is necessary to further specify requirements. When the requirements are met, the algorithm continues by processing in the CAD system.

### 4.4.9. CAD system processing

After obtaining solution, GALP automatically generates a script that transfers the entire solution into the AutoCAD environment. Using Siemens Tecnomatix FactoryCAD, 2D objects with rounded dimension are replaced with 3D models of machinery and equipment with their exact dimensions. The proposal is additionally modified this way, to better correspond to the real possible state of the production system.

In addition to machine models, the user can also use an extensive library to design warehouses, offices, workplaces or the building itself.

### 4.4.10. Static verification of solution

This step focuses primarily on the design verification using static analysis such as a D-I diagram, Sankey diagram, aisle congestion analysis or capacity calculation. In the developed solution, we utilize FactoryFLOW module from Siemens Tecnomatix for these purposes.

Within the analysis it is necessary to define individual products, their bill of materials, production volumes, activity points (machines, warehouses, and other workplaces through which the product passes) and shipping and handling information. The purpose is to examine the factors affecting the quality of the proposal, which are not taken into account by the genetic algorithm, such as planned transport network, intersecting material flows, insufficient number of transport equipment, or aisle congestion.

After processing of outputs, it is necessary to decide whether the proposal is acceptable. If the static analysis revealed deficiencies, the algorithm returns to AutoCAD, to allow correction of observed proposal deficiencies. If the proposed solution is acceptable the algorithm proceeds to the next step.

### 4.4.11. Dynamic verification of solution

The last step is the dynamic verification. Here, the aim is to back the results of the static analysis by simulation of the proposed production system, examining the impact of random or dynamically changing factors, such as machine failures, changes in production volumes, delayed delivery of materials, storage capacity, and more. The aim is that the proposed solution will be flexible enough to adapt in rapidly changing circumstances. Within the developed solution, we propose the use of software Plant Simulation. Tools FactoryCAD and FactoryFLOW, mentioned in the previous chapters allow using SDX format to export parameters of the production system to the other tools of Tecnomatix portfolio – which Plant Simulation is a part of.

SDX file consists of a header, which contains details of used units, information on shifts and the simulation run. After the header, all objects and attributes used in the drawing are defined – such as parts, machines, buffers, or transport network. Depending on the object type, individual instances are described by various attributes that are required to set up simulation runs (e.g. cycle time, setup time, the mean time to failure, cost data, etc.). Plant Simulation software can import this data, eliminating the need for multiple filling of input data. Subsequently, additional parameters are entered, which SDX does not contain – for example, warm up period, and simulation time. After the simulation run, it is necessary to interpret the results and assess whether the objectives have been reached.

### 4.4.12. Tie up with following activities

After the simulation, the process of variant layout design is completed by finding the (sub) optimal solution, which was constructed in CAD system and verified by specialized software tools. Thus, production layout design algorithm utilizing genetic algorithms ends. The next step in production system design is the detailed design which is not the subject of this work.

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# 7 THE IMPLEMENTATION OF INTELIGENT ROBOTS TO HOLONIC PRODUCTION SYSTEMS

*Peter Marčan*

## 1. BASIC CHARACTERISTICS OF HOLONIC APPROACH

In the industry nowadays we can see the turnover that leads to the systems that can be easily and in an effective way adapted in order to cover the customer needs. This kind of systems should be adaptive, reconfigurable and resistant to failures. The future of manufacturing systems should lead to a production of products based on customers' needs. Based on the above mentioned, we can ponder over the differences between the approach mentioned above and mass production in which we cannot speak about prompt reaction to the market´s needs.

These new advanced technology should include at least these following attributes:

- Distributed control to achieve resistance to failures.
- Flexibility and reconfigurability to achieve prompt changes in production when on demand.
- Modularity.

Reconfigurability is very important factor in the case of unpredictable events such as broken machines or some small failures but we can also rely on this attribute during development of new machine integrated to existing production line. [1]

### 1.1. Terminology

The term holon was originally developed by philosopher Arthur Koestler. The word was released in Arthur´s book called the ghost in the Machine in 1967. Koestler set the basic principles in order to explain self-configurability of social and biological systems in which the holon is considered to be the main structural element. The term holon is derived from a combination of a Greek word holos, which means whole, and a Greek suffix on, meaning particle or part, as in proton or neutron. From the main point of view it reflect a tendency of holons to act autonomous even though they might collaborate, communicate with another autonomous systems. [2]

A good example is human body which consists of organs that are made of cells that might be further derived etc. Also humans are usually part of a family and society. No element can be sufficiently understood without thinking of the other elements.

Association of HMS proposed some following key words:

- Holon: Holon is an autonomous and cooperative unit used for transporting, storing and confirming information about a physical object. The Holon might include another minor holons but might be a part of superior holons either. For instance the production unit can be considered to be the holon.
- Autonomy: The capability of the units to create, execute and control its own actions.
- Cooperation: All holons create an actions whereby a cooperation, a communication is executed.
- Holarchy: A group of the holons created in order to achieve a specified aims. Holarchy specifies the basic rules about the suitable way of cooperation.
- Holonic manufacturing systems: include activities from automation such as orders acquired from a customers through order processing, their realization to marketing. [3]

Holons and holarchy built from holons might act independently. It follows that holons have a certain extent of intelligence and might solve their problems from their level without asking higher level (master holons) for helping them. Using of this attribute contribute to stabile and never-failing systems. [4]

Holons also might receive instructions and be supervised by holon from higher level (by master holon).

**HMS description and architecture**

Holonic manufacturing system is based exactly on the concept of the Holonic system defined by Arthur Koestler as mentioned above in the article. Koestler points out the autonomy that shows us up to how much the system is an

intelligent , how the system knows to react against to failures and solve all the problems itself without asking master holon.
Control systems of production processes are composed from software as well as physical modules. Holon in Holonic manufacturing system is created just by those modules connected via communication module. All holons might communicate in this way to each other. The number and the kind of the software modules or connection of physical modules might create a variety kind of HMS architecture.

One of the basic architectures is thought to be the architecture described by Christensen in 1994. We can see the fig.1-1, where the information processing and physical inputs/outputs processing are shown. [5]

- Block of physical processing is derived in the following way.
- Sector of a physical (inputs/outputs) processing that controls a process of a production.
- Sector of a control unit (PLC, CNC, …) that is used to process a concrete data according to predetermined algorithms.
- Block of information processing that consists of the following sectors.
- Kernel of holon, that is responsible for the whole performance and autonomy of the holon.
- Interface holon-holon.

Interface human-machine (human-holon) created in order to provide input/output parameters entry, instructions entry and to inform attendants about details from a production.

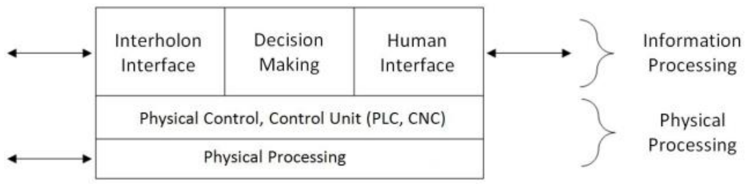


*Fig 1. The basic architecture described by Christensen in 1994*

Type of architecture used for holon's (agent) creation might be organized as following:

- Deliberative architecture (typical approach) – Think, subsequently act.
- Reactive architecture (alternative approach) – Do not think, just act.

- Hybrid architecture – Autonomously and simultaneously thinks and etc.
- Behavior-based architecture – Think the way out how act in the environment.

Holons in deliberative architecture usually operate with effective way of generation of strategic plans and actions. This approach is used only if it contains of all important data from environment. The next important factor in designing such holon is to take to account more time counted from action´s creation to reaction´s execution.

Holons in reactive architecture operate with the principle of action-reaction, so the operation looks like instinctive way of thinking. Holon still observes the environment, and if the action occurs, agent will be able to react by following the predefined algorithms.

Both above mentioned architectures have some advantages and disadvantages. Simply written, hybrid architecture is composited from reactive and deliberative architecture´s advantages.

Agent-based system is defined as a set of agents, which are designed to communicate to each other. The agents are considered to achieve some usually predefined goals. The creating of intelligent modular systems is created exactly by this way of thinking. This method is applied in various fields including industry.

In a holonic approach, an agent is a part of a holon that bears all the meaningful attributes of the holon (autonomy, cooperation…). Autonomous agent is able to sense environments during execution of its own activities. We have to mention, that all holons have its limitations. It means holon is able to act only among the limits of its sensors (scanner, camera…) and actuators (engines, arms…). Under an interaction of the agent with an environment we might understand receiving signals from the sensors or sending signals to the actuators, direct or indirect communication of agents to each other. It is all about changing the messages which are important to make agents intelligent. [6]

## 2. STANDARD TOOLS FOR HOLONIC APPLICATIONS

There are several tools for creation, configuration and programming of control system for holonic systems (4DIAC, FBDK). Most of them are based on standard IEC 61499 – Function blocks, which is often used to describe the holons and agent based technologies.

Basic building cell in holonic applications are function blocks. Function block is perceived as an abstract which is considered to represent a particular part of the system.

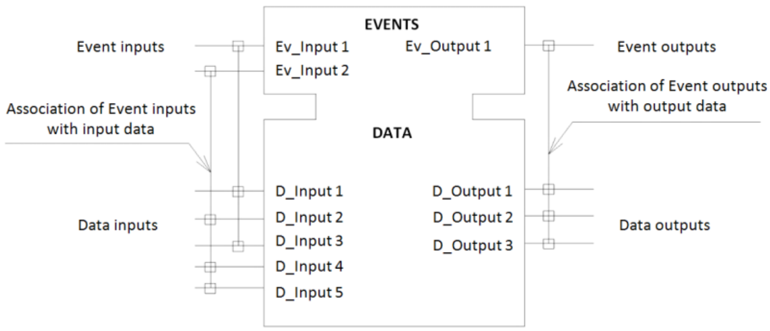


*Fig 2. Describing of the function block*

On the Fig 2, Inputs are lumped on the left side. On the other side (right) we can see the outputs. The upper part of the block is called head and the location of the data (lower part) is known under the name body of the function block.

Moreover, according to the standard IEC61499, definition of the function block determines an association of the events and the data fall within events cognizance. Following the sentence above, we can take a look on the Fig 2 where the mentioned association is represented by vertical lines from events to outputs. It means that particular data fell within event cognizance are actualized only just in the case of occurrence of the concrete event. [7]

We use this standard as starting point of our application. During the development of our experimental application we have used this standard just as guideline. We didn't implement all features. We also didn't use any of upper mentioned tools with implemented IEC 61499.

## 3. NEW APPROACH IN DESIGNING ROBOTIC WORKSTATION

Nowadays, industrial robot´s producers and developers do a research in the field of robot-human cooperation, in which the injury of the personnel is completely excluded. In fact, cooperation human - robot offers complementary features to improve commonly performed tasks. The robot is designed to perform tasks for people considered to be debilitating or dangerous. However, a person is capable of performing the tasks which can´t be simply executed by the robot. There are mostly the tasks requiring a certain level of skills and intelligence. Merging of the attributes, mentioned above, contributes to advantages. One of the most important advantages is achievement of the continuous production even in the case of personnel´s presence in the robot´s defined safety area. [5]

Robots called co-worker fall into the group of new robots. All over the world we can find many producers and developers to be concerned with the co-worker designed for industry. In general, it is a double-arm robot mounted on a static torsion or on a mobile chassis. Usually, industrial co-workers tend to be equipped with HMI (human-machine interface) system in the form of co-worker head intended for basic communication with personnel. The additional equipment of these robot can include image recognition, face recognition, guidance system, handling systems, and so on. These technologies offer, in addition to the above mentioned direct cooperation with the person, operator detection and subsequent modification of production processes according to predefined requirements of the operator. In the case of any changes in the production, the robot might be simply programmed and configured by using gestures of the personnel. Merging of the mentioned technical attributes of
the co-workers contributes to huge potential to utilization of these robots in the industry. Today, however, their actual industrial applications are very rare in the world. This uncertainty is mainly based on their unexplored potential and from the absence of any methodology that would define their applicability, established principles and approaches of implementation and methodology that would be guidance for future technical standards. [8]

## 3.1. Comparison of the current state of robotics with a new approach

*Fig 3. View of industrial robots with co-worker on the left side*

The demonstration of the both above mention approaches is depicted on the Fig 3. The new one is on the left side in comparison with the actual commonly used approach of designing industrial robotic workstations on the right side.

### 3.1.1. Advantages and Disadvantages

The brief characteristic of the robots and their advantages and disadvantages are following:

The robots commonly used in an industry (Fig 3 – right side):

- + Strong and solid construction of such robots.
- + High speed – up to 5 m/s.
- + High accuracy/repeatability – up to 0.02 mm.
- - Higher costs. We have to take to account above mentioned safety systems, solid constructions of robot workstations and so on.
- - Lower flexibility of such robot workstations. [9]

Industrial robotic co-worker:

- + One of the most valuable advantages is the possibility of job execution even if the person is in the robot´s safety area. It means that there is no need to take to account the safety systems such are the barriers, light curtains, scanners and so on.

- \+ The co-workers are designed to help human in terms of direct cooperation.
- \- Lower speed, repeatability and accuracy.

Disadvantages of the co-workers are especially because of their construction created in consideration to assure the safety of personnel.

### 3.1.2. Programing and Designing Robot Workstations

The next and simultaneously one of the biggest differences might be seen in programming and designing of these robot workstations.

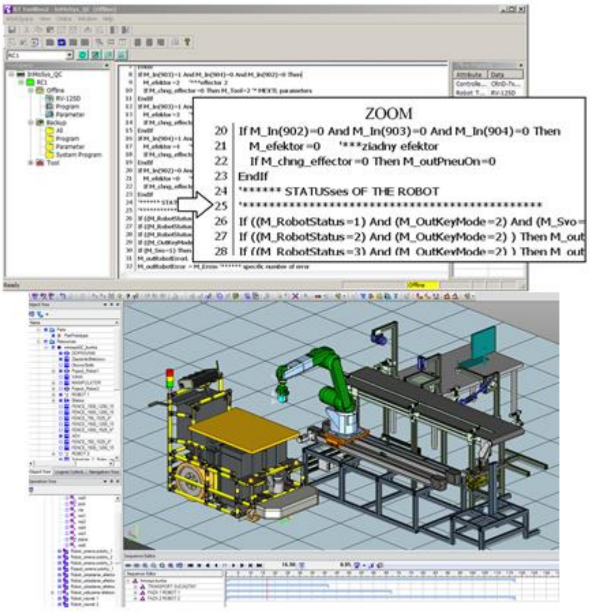


*Fig 4. Screen shoot of the robot programming and simulation*

The typical approach of programming industrial robots is depicted on the Fig 4. The programmer has two choices. One of them is programming the robots by writing the codes exactly as it is shown on the Fig 4. The positions of robots have to be taught by programmer directly in the workstation. The second one (Fig 4) is using programs that support 3D modeling. In this case, designer might create virtual workstation, implement 3D model of robot and then create a simulation. This is one of the approaches where the authors can simulate all the processes and thus avoid of robot collision and so on. After the simulation is created, designer can proceed to virtual commissioning. This process involves replicating the behavior of hardware with a software environment. In another words, designer of robotic workstation might use real hardware of PLC connected with virtual robot and thus simulate the process. After the simulation is considered to be finished, programmer might download the program and movements to robot and make corrections between the real and virtual workstation [10].

Programming and teaching industrial robotic co-workers is much easier. Mostly it is just showing robot what is needed to be done. For example personnel in the factory need to help by simply job pick and place. In this case operator just might show robot, where the source is and where is a destination of the components that needed to be transported .

As we can see on the Fig 5, we can also implement 3D model of the co-worker to virtual digital factory. This implementation and simulation helps designer to create appropriate workstation for robot-human cooperation. [10]

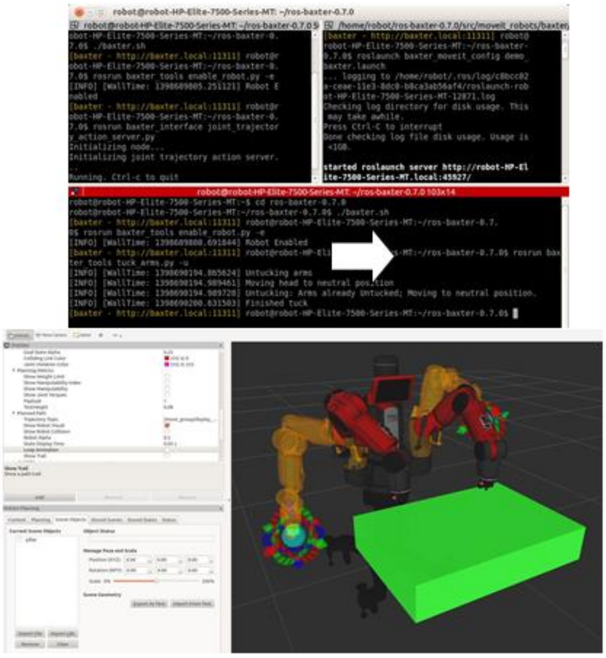

*Fig 5. Software used for robotic co-workers simulation*

### 3.2. The main safety function of robotic co-workers

The laboratory ZIMS has one of robotic co-workers called Baxter. Unlike typical industrial robots that operate behind safeguarding fences, the collaborative robot from company called Rethink Robotics, is designed to work effectively directly alongside people. Those co-workers combine numbers of unique technologies designed to allow deployment without some of the traditional safeguarding described in OSHA, ANSI, ISO or other safety standards. These robotic co-workers are designed for physical interaction between a worker and the robot, avoiding accidental contact and minimizing forces and slowing/stopping during human contact. The examples of the safety functions are listed below:

- Software control. Robotic co-workers are designed to slow or stop the motion in the case of unpredicted collisions.
- Multiple redundant systems: Robotic co-workers have a wide range of innovative sensors to achieve the highest possible safety.
- Lightweight: construction of conventional industrial robots are made from heavy material, that is used to satisfy the stiffness and subsequently the positioning accuracy. The additional advantage of such materials (metal) is the robustness in the case of unpredicted collisions, nevertheless the collisions of robots with machine operators are strictly prohibited. Under the previous text, the construction of robotic co-worker is designed from
  a lightweight materials to ensure safety.
- Dynamic braking: Robotic co-workers in the event of loss of power or pressing the emergency stop smoothly and slowly move to the starting position.
- Diverse motor enabling system: Two separate signals are maintained to keep motion enabled.
- Human awareness: The robots are equipped with a sonar system for detecting people in 360 degrees. The system signals the awareness of detected object or people.

In the following section we are going to describe some additional technical specifications, that might be understood as something different from the conventional industrial robots.

- Those robots use different kind of actuators. In the case of robotic co-worker Baxter, it is SEAS- series elastic actuators. Springs at all joint provide passive compliance to minimize the force of any contact or impact.
- Fully back-drivable joint: Joints of the robot are back-drivable and might be easily rotated by the operator, even when the robot is powered off.
- Velocity: Robotic co-workers operates at human equivalent speed, which makes it easier for nearby people to avoid any contact with the co-worker.

The main goal of designers of co-workers is the safety of people. Moreover it is very important to take into account the protection of property against destruction. From that reason, hardware and software safety functions are implemented. Examples are as follows:

- Overheating sensors: Temperature are monitored and if overheating is detected, the robotic co-worker will shut down.
- Automatic braking: Robot´s braking system automatically prevents uncontrolled movement.
- Emergency stop button: If the signals from emergency stop function is detected, the power to actuators will be removed and the brakes will be applied. [11]

## 4. TECHNICAL SPECIFICATION TS 15066

The scope of ISO/TS 15066 is Occupational safety requirements for collaborative robots and their work places. The standard title indicates the new concept of Occupational Safety that should be a tool at disposal of workcell designer. It takes into account all parts of an industrial robot as an end-effector and other equipment necessary for performance of the work tasks, supplements or specifies the requirements for collaborative robot operation of EN-ISO10218. As other standards, TS 15066 does not apply to non-industrial robots although the safety principles may be useful in this field.

Basic principle consists on the necessity of a safe control system which provides the safety related performance for monitoring safety related parameters, e.g. speed, position, force etc. Once this condition is satisfied, collaborative robots can be used for collaborative tasks without fixed guards. Safe controller should be an essential contribution to the reduction of accidents.

Main specifications listed in the TS 15066 concern three main collaborative tasks [9]:

- Hand Guided.
- Safe Separation Monitoring.
- Power and force limiting.

### 4.1. Hand Guided

TS15066 establish various requirements for safety in the mode called Hand Guided. However they are similar to the ones listed in ISO1028. Basically, robot guidance is still considered as a low-risk task if a safe speed monitoring is activated. Human operation acknowledgement and the safety-three-position dead man allow this task to be faced also with actual technology. See the Fig 6.

Note:

Safe Speed monitoring does not mean that the velocity and/or positions are measured by redundant sensors but that the actual measuring systems are certifiable as PLd/SIL3 devices.

### 4.2. Speed and separation monitoring

TS15066 establish various requirements for safety in the mode called safe and separation monitoring.

Among them, it is important the identification of how calculate the minimum separation distance, and the procedure to establish maximum safe speed. Furthermore, various indications are listed for identification of potential collision. TS15066 foreseen also that robot controller has to implement methodologies to avoid potential collision, and to notify the collaborator about the robot state (hazards, warning, etc.). Furthermore, it indicates the safe position and velocity monitoring of the collaborators as an extremely useful instrument to preserve safety. See the Fig 6. [10]


*Fig 6. Examples of the cooperation modes: 1) Hand guided, 2) Speed and separation monitoring, 3) Power and force limiting*

### 4.3. Power and force limiting

Section on power and force limiting is extremely full of interest. In fact it lists various important aspects, and among them the:

- Technological requirements.
- Medical/biomechanical requirements.
- Ergonomic requirements.
- Marking and instructions.
- Testing and validation.
- Documentation of tests.

## 5. RISK ASSESSMENT AND RISK MINIMIZATION

According to the Machinery Directive, the machine builder is required to perform a risk assessment for the machine design and also include an assessment of all the work operations that need to be performed.

### 5.1. Risk assessment

A risk estimation is made for each risk source, i.e. indication of the degree of risk. According to EN ISO 13849-1 the risk is estimated using three factors: injury severity (S, severity), frequency of exposure to the risk (F, frequency) and the possibility you have of avoiding or the injury (P, possibility). For each factor two options are given. Where the boundary between the two options lies is not specified in the standard, but the following are common interpretations (To calculate the performance level required - PLr) : [12]

**S** Severity of injury

- S1 slight (normally reversible injury).
- S2 serious (normally irreversible injury or death).

**F** Frequency and/or exposure to hazard

- F1 seldom to less often and/or exposure time is short.
- F2 frequent to continuous and/or exposure time is long.

**P** Possibility of avoiding hazard or limiting harm

- P1 possible under specific conditions.
- P2 scarcely possible.

By setting S, F and P for the risk, you will get the PLr Performance Level (required) that is necessary for the risk source. Finally, the risk assessment includes a risk evaluation where you determine if the risk needs to be reduced or if sufficient safety is ensured. See the Fig 7. [11]

### 5.2. Reduce the risk

If you determine that risk reduction is required, you have to comply with the priority in the Machinery Directive in the selection of measures:

1. Avoid the risk already at the design stage. (For example, reduce power, avoid interference in the danger zone).
2. Use protection and/or safety devices. (For example, fences, light grids or control devices).
3. Provide information about how the machine can be used safely. (For example, in manuals and on signs). [12]

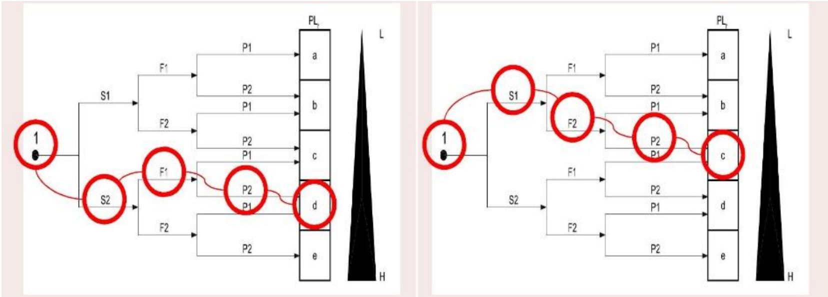


*Fig 7. Risk estimation (left - conventional robots, right - robotic coworkers) [6]*

## 6. APPLICATION DEVELOPMENT OF ROBOTIC CO-WORKER BAXTER BASED ON ROS

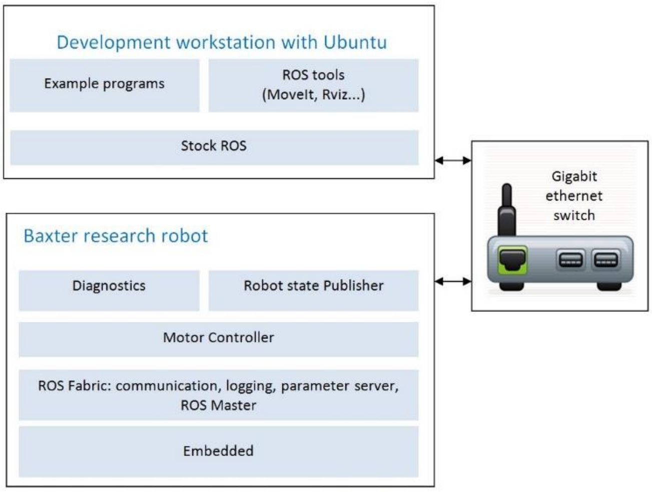


*Fig 8. Baxter research robot software developers kit*

Many software engineers use software packages SDK (Software Developers Kit) during the development of robotic applications. The same applies with the robot Baxter. Developed programs designed to control the robot are tuned on the robot through the operating system of the robot called ROS (Robot Operating System). Development workstations are connected to the robot Baxter, represented as a master, for the purpose of debugging of custom applications. See the Fig 8.

Using of the very core of SDK is considered to be very useful to get the access to the source code developed for accessing, monitoring and management of all robot´s peripherals (motors, sensors, etc.). Application developers can thus shortly come to an essential knowledge from the area of the individual joints control to a defined position, camera control, etc. Respecting the certain principles of ROS interface, the robot can be programmed in various programming languages such as Python, C++, etc. Example of the source code of the application pick and place is depicted on the Fig 9. [13]

```
*pick_and_place.py
    def performing(self):
        #~ try:
            while not rospy.is_shutdown() and not self.mustStop_performing:
                self.pick()
                if self.mustStop_performing: break
                self.place()
        #~ except:
            #~ self.baxter.no()
            #~ self.setState("ready")

    def pick(self):
        lock=self.parent.coordinator.lock[self.side]["pick"]
        lock.acquire()
        try:
            t=self.baxter.gripper[self.side].post.open()
            self.arm.move_to_joint_positions_pid(self.pos["pickup"],1.8,0.03)
            t.join()
            self.arm.move_to_joint_positions_pid(self.pos["pickdown"],1,0.01)
            self.baxter.gripper[self.side].close()
            self.arm.move_to_joint_positions_pid(self.pos["pickup"],1,0.05)
        finally:
            lock.release()

    def place(self):
        lock=self.parent.coordinator.lock[self.side]["place"]
        lock.acquire()
        try:
            self.arm.move_to_joint_positions_pid(self.pos["placeup"],1.8,0.03)
            self.arm.move_to_joint_positions_pid(self.pos["placedown"],1,0.01)
            self.baxter.gripper[self.side].open()
            self.arm.move_to_joint_positions_pid(self.pos["placeup"],1,0.05)
        finally:
            lock.release()

class MainWindow:

    def __init__(self,master,baxter):
        self.master=master
        self.baxter=baxter
        self.post=Post(self)


        self.baxter.loadAll()
```

*Fig 9. Preview of source code for the application pick and place*

## 6.1. The application pick and place using ROS

The transfer of material from the conveyor to the packing line, palletizing of the various parts, etc. are considered to be the most used applications in the industry. Generally, these operations are called pick and place.

During the execution of these operations, that are thought to be monotone for machine operators, often tend to increase of inattention and consequently to increase the risk of injury. In another case, there is an operation such is the transport of heavy parts, when the health problems might occur (Backache, neck pain. strained muscles etc.). Robotic workcells are able to perform such operations several times faster and more accurate, whereupon the economists look at the operation "pick and place" especially in terms of financial savings. The robot called Baxter and many other industrial cooperating robots are almost ideal for such operations. They are ideal especially from perspective of direct cooperation between those robots and machine operators. The laboratory ZIMS disposes of such cooperative robot - Baxter. The current research is conducted and simultaneously tested in order to debug the pick and place operation.

From the point of view of robot teaching, it is an easy process so almost every operator in the enterprise might be able to teach the robot to a new operation. Teaching is composed from three simple steps. The first step is to grab the effector of the robot, teach the robot to the position from where the part should be taken (pick). The second step is to teach the robot to the position where to put the part (place). The last one is pushing of the button to save and confirm a new job for robot. Communication between the robot and the machine operator is realized via the robot´s head. Specifically it is via the display on the top of the robot as you can see on the Fig 12. During the teaching of the robotic co-worker to the new job, operators might use instructions that help us to teach the robot and they are able to see the current state of the robot as it is shown on the Fig 10 to Fig 12. An example of the robot´s status that the robotic co-worker is ready to be taught is depicted on the Fig 10.


*Fig 10. Preview of display: the robot is ready to be taught*


*Fig 11. Learning of the robot positions (from and where to place the parts)*


*Fig 12. Performing of the job that is taught by the operator*

More and more, flexible manufacturing requires robots, that are able to act within the personal space of a human and even make direct contact with human operators. To be useful, some robots may need to be powerful and therefore those robots are considered to be dangerous. Safety of the humans who interact with these machines is clearly a main concern in this paper. The safe operation of
the robotic co-workers is a core foundation for humans to establish trust in them. [14]

## 7. CONNECTION OF HOLONS (ROBOTS BASED ON ROS-PLC)

In the following section, the reader will be introduced to communication of ROS holons with autonomous machines based on PLC controller.

Nowadays, the communication with the machines is very important. It is on daily routine to request machines to get relevant data. Then we can collect and process the data to increase the flexibility of the company.

Very important is also the communication of machines to each other. They need to be in touch to satisfy their needs such is receiving the information about
the other machines- their status, processes or sending the information to start the process of other machine and so on. Nowadays almost every of industrial machines is based on PLC (programmable logic controller). The actual trend in robotic world is usage of robots based on ROS (robot operating system). Under the previous sentences we can declare, that generally we have to focus to make a research related to communication between ROS and PLC. The section is not explored, hence we suggest a new concept using the holonic theory. That way we are able to implement robotic co-bots to the company and thus create an intelligent factory of the future [15] ,[16].

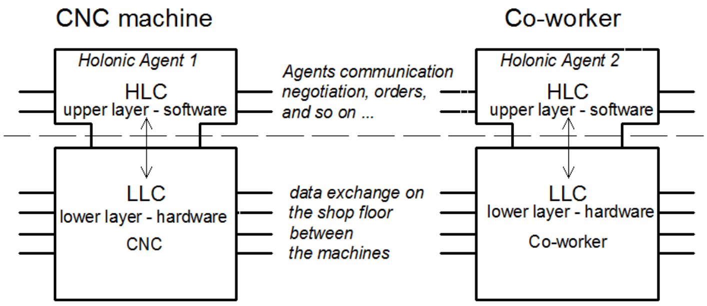


Fig 13. Communication of holons

On the Fig 13 we can see our proposal of intelligent systems communication. There are two machines. The first (on the left side) is CNC machine and the second one is robotic co-worker. Each of the machines is composed of two layers. Upper (high) layer HLC and Lower layer LLC. The article does not deal with the high layer. In this article the HLC is just to compose to the reader our vision of holonic agents communication on the shop floor. Generally, the HLC is used to make an orders, negotiations and other important massages exchanged between the intelligent machines. Let us to present you an example: we have two AGV (autonomous guided vehicles). In the case of HLC, the holonic agents might be able to negotiate about: which one of the AGV is supposed to make an action? talk to each other about their statuses, the AGV might to make a reservation of wagons and so on. The situation on the LLC is absolutely different from HLC. The principle consist of data exchange between the two LLC layers of two intelligent machines. We can imagine data such is information about the actual position of motors, presence of the parts on conveyor, generally information from sensors and so on. [17]

Following the previous ideas, we have made the research and experiment with the LLC communication of two technologies. PLC from Siemens (S7-1200) and Robot Baxter based on ROS. See the Fig 14. The communication is realized via the Modbus protocol.

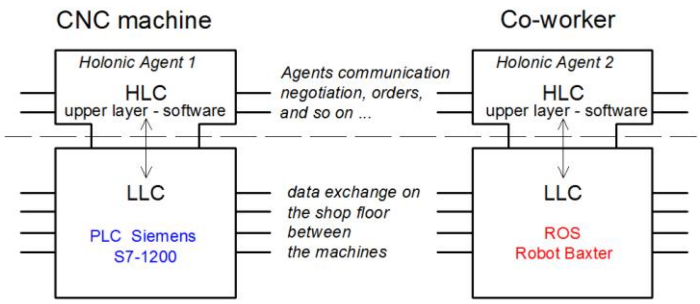


*Fig 14. Communication of two holons ( PLC Siemens and Robot Baxter )*

On the following Fig 15 we present the details of the communication written above on the Fig 14. The results of the research is the data exchange so thus the technologies -robotic co-workers might be able to communicate with the intelligent holonic factory machines.

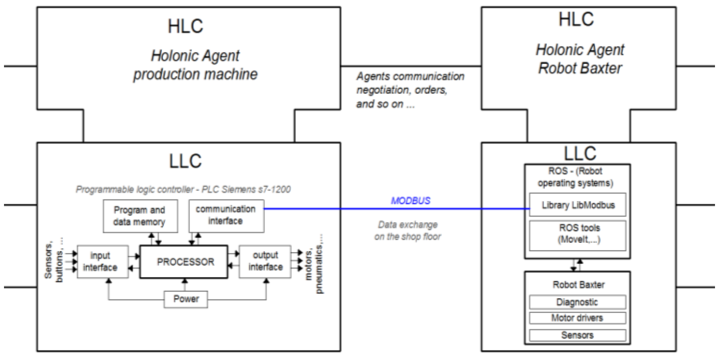


*Fig 15. Structure of the communication of PLC and ROS*

We define two possible ways of the communication channel creation:

1. Direct communication: In this method we can differ some alternatives. WIFI, optical cable, serial communication and others on the lower layer of RM OSI or TCP/IP models and communication standards such are ProfiNet, ProfiBus, CC-Link, IO-Link and others on the upper layer of the models. The channel is created directly via the mentioned possibilities.
2. Using the OPC server: This method is based on another principle. We can see the following Fig 16, on which we present the possibility of creation of communication channel between the LLC Holon´s layers via the OPC server (OLE for Process Control). The new specification was founded at the beginning of 2016. It is a new standard AutomationML for OPC UA. OPC UA is considered to be the technology supposed to create the communication channel and the AutomationML interprets the data to participants. [18]

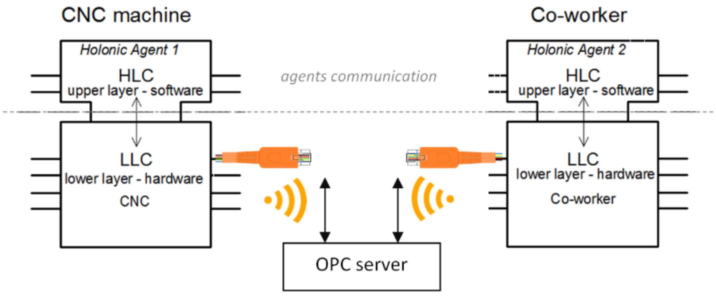


*Fig 16. Communication of holons via OPC Server*

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# 8 TOWARDS A NEW SYSTEMS OF MAINTENANCE

*Miroslav Fusko*

## 1. TECHNICAL SERVICE

We live in a time when our technology is spread across all areas of our lives. The same is true for companies. Increasingly they rely on advanced technology and equipment, as honest human work. The truth is that advanced technology and machinery is increasing quality and productivity to us, but it also means increasing the maintenance and effective care for these devices.

Maintenance is a set of operations (complex work) that are being made to ensure the specifications, an operational state of the art object as well as defining and assessing the actual condition. The main objective of the maintenance is to minimize the total cost of production and profit maximization while maintaining system quality – date – price – reliability.

Correct maintenance is primarily a prerequisite for maintaining the safety and reliability of equipment and the working environment. Secondly, maintenance represents a very dangerous activity and must be done safely by maintaining the protective measures in case of maintenance staff and other people in the workplace. We are already in the modern age with the sophisticated equipment. It is not possible to solve only routine maintenance of machinery and equipment anymore. Therefore, we have to solve a wide complex of works, also called technical service.

This wide range of activity requires the use of theoretical and practical knowledge from multiple disciplines, so the issue of maintenance has become studied topic of multiple disciplines in the last few years (mathematical models, network analysis, processes of wear and fatigue of materials, theory of operational reliability, methods and the technic of maintenance, technical diagnostics, information systems, applications CAx technology and many others).

The economic consequences of optimizing maintenance and recovery using diagnostic techniques are large and represent a significant operational cost savings. Implement an appropriate system maintenance will increase operational efficiency and quality. Within the system, there are collected, monitored and analyzed not only failures but also the wear of important units and components and design of logistics purchase of parts and materials. The strategic objectives of maintenance can then include:

- Initiating and promoting lifelong learning of maintenance manager.
- Initiating and promoting lifelong learning of maintenance specialist.
- Organizing of specialized courses as needed in maintenance practice.

### 1.1. System of complex care

Current trends of development of production and non-production sectors contribute significantly to the growth of the importance of basic funds, embodied in the form of production, but also non-manufacturing machinery and equipment. Keep capital goods in operable state with minimum downtime is one of the objectives and criteria of their operating efficiency, and operational reliability of fixed assets, as a manifestation of the ability to perform the required functions while maintaining the values of set operating parameters in given limits and in time, it is one of the basic indicators of their level quality. System of complex care is an important part of the reproduction of basic funds, his importance for the next period is not only the growth of technical complexity and automated equipment for production and non-production processes. It is also because of the necessity of representation lack of resources for the modernization of existing equipment investment in production and services base. [1]

The objective is:

- Minimize downtime.
- Maximize the availability of machinery and equipment.
- Increase the reliability.
- Increase health and safety.
- Improve the quality of production.
- Minimize maintenance costs. [2]

The elements of comprehensive care:

- Machinery, equipment, technology.
- Technicians and machine operator.

- Objects in which the process of complex care is implementing.
- Energy, operating materials, lubricants.
- Resources, material.
- Finance.
- Information technology and technology. [2]

Hierarchy of system of ensuring the correct operation of the organization is shown in the following Fig 1.

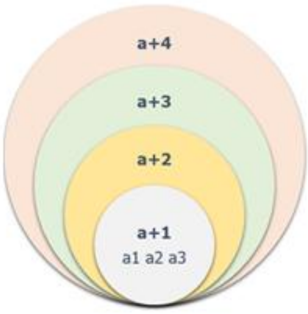


*Fig 1. Arrangement of system*

Key to the figure:

- a1 – technique, machinery, equipment.
- a2 – correcting feature.
- a3 – technical officials.
- a + 1 – maintenance system.
- a + 2 – system of complex care.
- a + 3 – production system.
- a + 4 – system of security activities of the organization. [3]

System of complex care is characterized by large range, complexity, interdependencies and linkages conditionality of their duration. It contains a large number of sub-systems and components that are composed of different types (energy, material, technical, staffing) (Fig 2). A specification of the system of complex care is his continuity, in all conditions and at all organizational levels. [4]

Principles of system of complex care:

1. Planning.
2. Frequency.
3. Prevention.
4. Complexity.
5. Proportionality.
6. Differentiation.

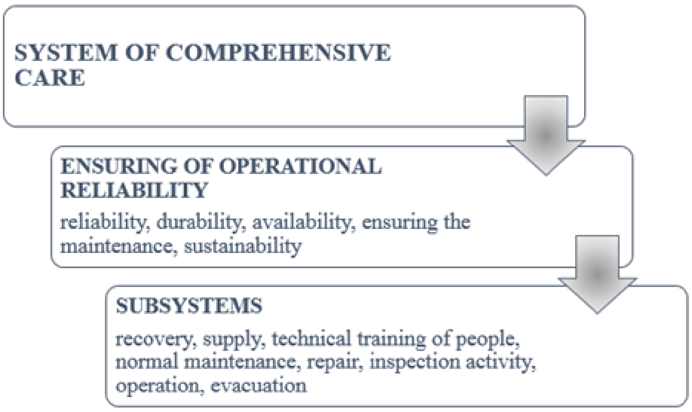


*Fig 2. Decomposition of system*

### 1.2. Elements of technical services

At the market there is a wide variety of companies, which are dealing with technical service. However, each of these companies offers a variety of services portfolio. The following figure (Fig 3), I have divided into three categories the elements of the technical service.

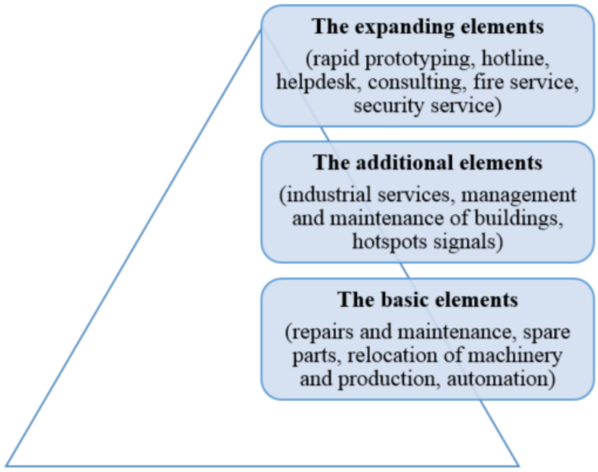


*Fig 3. The elements of technical services*

In the current situation that has developed in the market, it is very important to react flexibly to market requirements and customers. [5] However, not all companies in Slovakia are focused on continuous improvement of their processes. They are mainly small companies owned by Slovak owners. These companies then cannot fully compete with foreign companies. From this state, there are only two possible ways: Either adapt or disappear. Most companies in the world and in our country use different tools of industrial engineering. They mainly focus on lean manufacturing. Lean basic pillars are:

1. The requirements of the customer.
2. Continuous material flow.
3. Pull system.
4. Continuous improvement.

### 1.2.1. Description of elements of technical services

For full provision of services must companies that provide technical services its own offices and workshops, where they have their own training centers and on the other hand, there can be removed very complex disorders that cannot be removed in the fault.

**The basic elements**

**Repair and maintenance**
Who wants to compete today must keep its costs well in hand and the productivity of the company must continue to rise. The basic condition is reliable working machines. Therefore, it is necessary to have a company with an experienced team of engineers, technicians and experts. These companies then take full responsibility for the technical availability of machinery and equipment. Service technicians must be trained on many devices, yet it does not matter whether they are electronic or mechanical elements for conventional or CNC machines. These engineers should have qualifications in industrial mechanics, electronics and mechatronics energy facilities and of course they should know the various machine manufacturers and have partnerships with them. Because only such strong companies will maintain on the market. [4]

Activities: complex repair and maintenance of machinery, audit inspections, provision of spare parts.

**Spare parts**
For manufacturing companies are most of all spare parts for all machines an unthinkable task. These companies usually hold only some critical spare parts. However, companies that provides technical services to more companies, it would be an advantage to hold all kinds of spare parts, because they would be required to immediately deliver a replacement part if something goes wrong in the production process in some company. [6]

Activities: maintaining all kinds of spare parts, the implementation of ABC analysis, and collaboration with suppliers of spare parts.

**Relocation of machinery, manufacturing and entire enterprise**
There are many companies that offer easy relocation or difficult transport. At the transfer of production facilities it is not enough. Relocation of the machine requires planning and precise alignment and starting up the machine directly on a new workplace.

Using preliminary versions of basic components of the adjustment will guarantee that the machine will produce the same quality in a new position, than in the old one. In addition, there have to be installed all electrical connections, building the infrastructure of surrounding e.g. control equipment, cranes and security equipment and of course the newly painting machines according to customer requirements. When talking about complete transfer of companies, it is necessary to think also about office equipment transfer for the appropriate installation of computers and telecommunications. The advantage would be the implementation of the necessary renovation works to the planning and installation of ventilation and air conditioning equipment. [7]

Activities: realization of machinery and equipment transfer, complex planning and care projects relocation of a part of production or the whole enterprise.

**Automation**

Automation is an essential step to maintain the good fitness of the company in order to succeed in the market. The technology of production equipment is still evolving. To remain competitive, companies must be modern to keep up with technological advances in ever shorter intervals. They do not have to invest always in new machinery. In many cases it is the technology of control technology which walked so rapidly forward, while the mechanic is still tally to the current state, although at present it begins to cope. But it is still worth to think about whether it is necessary to invest in new control technology. As a rule, this method can achieve comparable results with significantly lower costs.

Activities: realization of the modernization of machinery and equipment, realization of the conveyor system.

**The additional elements**

**Industrial service**

It is said that who controls his own operating resources, makes preventive measures of accidents at work and fire prevention measures. OHSAS topic is gaining more and more on its importance. Therefore it is not only important to train staff on the subject. It is also important that employees are working with devices, which are safe and efficient. So it's good that companies that are providing technical services are dealing with the issue of providing the various tests. It is good that a company has several portfolios and they have no problem to adapt to the market, such as when there are many small companies and each offers something. Then it is very difficult for manufacturing companies, just as manufacturing equipment is essential for a flawless operating of facility building hardware. Here is an example of some inspections that could be taken to provide the technical service:

- OHSAS.

- Hand electric equipment (drills, hand grinding machines, personal computers, fridge, etc.).
- Ladders and stairs.
- Fire extinguishers.
- Stationary machines and equipment.
- Presses.
- Fire doors and gates.
- Gateway with drive. [8]

Activities: metal production, repair of building technical equipment, cleaning of transport and handling units, treatment and disposal of operating materials, carry out inspections such as: protection against injury and tests for technical services, design and service of industrial air filtration devices.

**Management and maintenance of buildings**

Management and maintenance of buildings is often laborious and time-consuming issue for companies. Each building is here only for a certain time, not forever. If we want to extend the buildings life, we have to put it in the hands of experts. Buildings must be maintained according to legislation and standards. After some time, it is necessary to modernize or to dispose the buildings. We should have also developed manual of building maintenance. It is important to focus on the energy balance of the buildings and environmental protection.

Activities: heating, ventilation and air conditioning systems, building and roof, utility networks, emergency services, winter maintenance.

**Hot spots signals**

They are surface overheating, which notice in time many problems and their prevention can save a lot of money and time to company. Until now, it was difficult and expensive to make thermographic visible these alarm signals. Now the companies can easily take advantage of infrared thermography: fault location over thermal image. Such a service should be for companies providing technical services for granted.

Activities: monitoring a diagnostic machines and devices.

## The expanding elements

### Rapid prototyping

Rapid prototyping is a set of technologies of prototype production through 3D printing. These prototypes are usually not suitable for heavy loads and serve only to the concept of appearance (design proposal). However, in the future, it is considered that this method would be the principal method for the production of spare parts, components or mass production. The principle is the creation of a 3D model, which is then "cut" into thin layers, which are then added and put together in printing process. These models are produced by different methods and from different materials. At present, it is still an expensive method but for the future it has great potential. The advantage is the creation of highly complex prototypes.

### Hot line (call centrum)

This solution is available at a certain time to solve problems that might occur on the device. This solution can be basic or specialized. The basic one solve common operational problems. The specialized one has available specialists who are dealing with more complex problems of machinery and equipment.

### Help desk

At the present the use of information technology is for granted. Because, it is necessary to have such support system (help desk) in the company. It is used in companies as promotion and communication channel between customers and service providers. Support system is mostly addressed with web application, e-mail or call center.

### Consulting

It's the kind of advice that will help companies to make better decisions about what to do and which path to take, what's good for them and so on. With consulting, companies can reach better and faster growth, competitiveness, better knowledge of their business, innovative approaches, and increased productivity and so on. Necessity for consulting companies is their collaboration with universities, where is possible gain of new knowledge which is then applied in industrial practice. They must use: training - different games or trainee programs on the devices, the education of their employees and customers. Consulting companies should include in their portfolio scientific and research activities target edon innovative solutions offers and business processes optimization, to improve the company's activities.

**Security service**
Stationary security service is performed on a continuous presence of security guards on the premises, by viewing and controlling. If necessary, the protection of buildings can be enhanced by guarding dogs. In the area of physical services it provides preventive protection against damage and repressive protection aimed at eliminating the consequences of ongoing insured event. Mobile security service consists of regular or periodic sightings of protected objects within
the specified area defined by protected buildings.

**Fire service**
Fire service is one of the most important ways of building security and protection, which is required by legislation of the Slovak Republic. The basic assumption of fire protection is creating, developing and maintaining the conditions for ensuring effective protection of life and health of people and assets against fire. Field of fire prevention and provision of basic measures to prevent fires is currently being addressed in several ways.

### 1.2.2. Indicators for evaluation of technical services

Objectives of technical services each company provides a variety. Mainly are the improvements in some areas of a few percent, reduction of injuries, disorders and so on. However, the main objective must be to ensure the maintenance operation of machinery, equipment and full of companies into which investments have been inserted, which of course is their appreciation over a period of time. Of course there is then reducing of the cost on technical services, improving reliability and so on. These are then important parameters for increasing the competitiveness and productivity of the company. [9]

Maintenance, however, must focus on the overall production and its serviceability. It is not just some sub-processes with small repairs of machines. We have included here example too repair of conveyor lines, mobile equipment (carts), machinery and equipment and so on. It's also a search for new solutions repairs that are less costly, safety of operation, the number of accidents and others. Therefore is the determination of indicators for technical service is very difficult and choose just to one indicator is still now impossible. It is important to focus more on the selection of indicators from various operational indicators. They always have to choose the indicators that will help standardize the measurement of efficiency not only internally but also across multiple companies with different product portfolio. [6]

Indicators to be used for evaluation is large numbers. Dealt with a lot of organizations that have divided them in several groups:

- Indicators by EFNMS (European Federation of National Maintenance Societies).
  - Number of indicators 14.
- Indicators by norm CEN/TC 319 (STN EN 15 341); CEN (European Committee for Standardization).
  - Number of indicators 71 in 3 types and in 3 levels.
- Indicators by SMRP (Society for Maintenance & Reliability Professionals).
  - Number of indicators 70 in 5 types.
- Indicators by JIPM (Japan Institute of Plant Maintenance).
  - Number of indicators 24 in 7 types. [4]

### 1.2.3. Key Performance Indicators (KPIs)

An important premise for the correct setting KPIs recognition and defining critical success factors for the company. Critical factors of success are those that have the greatest impact on company results. KPIs must be measurable, so they do not talk about activities, but the results. They must be defined so to be the all clear and well understood. KPIs should be defined by the people, it should not be one men show. [10]

In maintenance management is most often used the following KPIs: [10]

**MTTR (Mean Time To Repair)**

$$MTTR = \frac{total\ time\ to\ recovery}{k_{Rep}} = \frac{\sum_{i=1}^{n}(time\ to\ recovery)}{k_{Rep}} \qquad (1)$$

- Total time to recovery is the sum of the times to recovery for all n objects over a given period of time.
- kRep is the total number of periods in the recovery of objects over a given period of time.

**MTBF (Mean Time Between Failures)**

$$MTTR = \frac{total\ time}{k_F} = \frac{\sum_{i=1}^{n}(total\ time)}{k_F} \qquad (2)$$

- Total time is the sum of calendar periods operations for all n objects, including usable and unusable state.
- $k_F$ is the total number of failures of objects during the period of watching.

**Availability (A)**

$$A = \frac{MTBF}{(MTBF + MTTR)} \quad (3)$$

**MRT (Mean Repair Time)**

$$MRT = \frac{total\ repair\ time}{k_{Rep}} = \frac{\sum_{i=1}^{n}(repair\ time)}{k_{Rep}} \quad (4)$$

- *Total repair time i*s the sum of the times of repair for all n objects over a given period of time
- *kRep* is the total number of period of repair objects in during times a given time period

Note. The calculation does not include logistical and administrative delays.

**Medium intensity of recovery $\mu_R$**

$$\mu_R = \frac{1}{MTTR} \quad (5)$$

**OEE (Overall Effectivity of Equipment)**

OEE value in our country moves on average at 40 to 60 %. Many businesses world-class achieved after successful installation TPM value of 85 %. OEE value the first gives the available potentials for the improvement of facilities. According to the rules 80:20 we can help targeted actions to 20 % causes losses to eliminate up to 80 % all downtime. On Fig 4 is scheme of OEE calculation. [10]

$$OEE = (A \cdot P \cdot Q) \cdot 100 \quad (6)$$

$$Availability\ A = \frac{(planned\ operating\ time - interruption\ time)}{planned\ operating\ time} \quad (7)$$

$$Performance\ P = \frac{(normalized\ time/pc.\ \cdot number\ of\ units)}{actual\ operating\ time} \qquad (8)$$

$$Actual\ operating\ time = planned\ operating\ time - interruption\ time \qquad (9)$$

$$Quality\ Q = \frac{(total\ production\ output - number\ of\ rejects)}{total\ production\ output} \qquad (10)$$

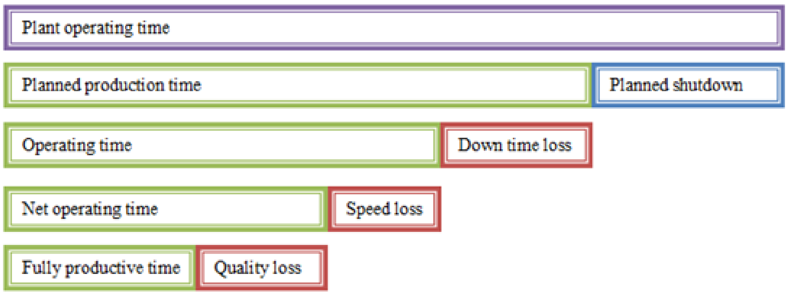


*Fig 4. OEE calculation scheme*

**Readiness**

$$Readliness = \frac{(Required\ planned\ operating\ time - maintenance\ after\ failure)}{Required\ operating\ time} \cdot 100 \qquad (11)$$

Readiness is the ability of the object to be in a condition to perform a required function in the given conditions, a given time point or in a given time, provided that they are provided the required external resources.

**Probability of failure-free operation**

$$R(t) = \exp(-\lambda t) \qquad (12)$$

**Probability of failure**

$$F(t) = 1 - \exp(-\lambda t) \qquad (13)$$

**Intensityof failures**

$$\lambda = \frac{a}{T}; \lambda = \frac{\sum a}{n \cdot T} \quad (14)$$

*t* - total working hours in hours
*exp* - the base of natural logarithms
$\lambda$ - rate of failure per hour
*a* - number of failures (repairs) for total operation periods
*n* - number of monitored devices
*t* - total working hours

## 1.3. Care of the assets

Fixed assets of the company can perform his function only if it is in good technical state. This can be achieved through regular maintenance of machinery, equipment and buildings. The actual performance of the functions by fixed assets is only a certain amount of time during which gradually wears out and his value is transferred to the value of products produced or services provided. After this time, it is necessary to do the rehabilitation of properties. Care of the assets is therefore an activity that has a significant impact on the status of the assets. It is therefore in the interests of the owners or the administrator give them full attention.

### 1.3.1. Description of care processes of assets

If we want good occupy to care of asset we have well established processes. These processes are trough different maintenance strategies, as well as regular inspection of assets, in inventory and inspection of buildings. To the basic processes of care of assets include:

- Continuous repairs and maintenance of assets – lubrication and inspection.
- Preventive maintenance – keep equipment in good technical condition.
- Total Productive Maintenance – the involvement of all in technical services.
- Checking of assets – inspections, control inventory.
- Purchase of goods and services – spare parts, consulting. [4]

The above information are described in various publications. I decided rather to describe the processes in the care of the building. This process consists of processes that are linked to one another: [11]

**Maintenance planning**

The objectives of maintenance planning is to establish a concept for the design or technical and technological equipment requiring maintenance – Maintenance schedule buildings. Contents of the maintenance plan is a schedule of regular preventive maintenance at specified time intervals. It is the basis for ensuring capacity and financial resources. (The basis for creating the maintenance plan is Manual of using buildings – Rules for maintenance of buildings).

**Preparation of maintenance**

This phase contains the following sections:

- Identifying and assigning employees.
- Procurement of materials and spare parts.
- Provide the necessary equipment and devices.

**Realization of maintenance**

In this phase is done, the mere implementation of maintenance. There are necessary to carry out the following activities:

- Collection of technical data and description of the tasks.
- Preparation of the workplace.
- Watching and measurement.
- Testing and inspection.
- Recording information.

**Evaluation**

The course of the implementation the watching evaluation on the basis of records from the implementation of maintenance. Results of evaluation are the basis for standardization of maintenance for individual construction and technological equipment. Evaluate the adequacy of resources and the operational and safety procedures.

**Improvement**

Based on the evaluation of the maintenance process for individual construction and technological devices can achieve an improvement of maintenance processes as follows:

- The maintenance concept.
- Changes in maintenance procedures.
- Modification of individual devices.
- Employees training of operations and maintenance.

In addition to regular maintenance facility manager is obliged to provide professional audit controls of technical and technological equipment. They are in the legislation and may be conducted only by a person having appropriate competence. The results of expert examination are recorded in a report which shall include:

- Identification data of the device on which the check is carried out.
- Completeness of technical documentation.
- Information about device.
- Essentials devices.
- Evaluation.

The report provides the facts on the managed device, including errors and deficiencies found together with concrete proposals deadline for their removal. In the report is also warning of the seriousness of the identified defects, which endangered of safety and reliability of the equipment.

### 1.3.2. Quantification of process of care for tangible assets

A tangible asset is the primary unit of maintenance and is an essential part assets of companies. It is a tangible asset that is used in the company for more than one year. They belong here mainly buildings, machinery, land, individual movable assets and sets of movable assets and so on. During this long period the consumption of the assets in the company wears, whether in terms of physical (material) or moral (economic). If companies want to achieve good results, it is necessary to monitor key performance indicators (KPIs) [9], which should be defined. One of these indicators should be OEE (Overall Equipment Effectiveness). As long as we look on maintenance only as a necessary evil or necessary costs, we will eliminate them mindlessly, then in a few weeks or in a few months, problems arise. For these reasons, it is necessary to quantify the number of indicators in the following areas: [8]

**The continuous repairs and maintenance of property – lubrication and inspect.**

- Total costs on maintenance / Replacement value of assetsx 100 (15)
- Total costs on maintenance / The amount of output (16)
- Total costs on maintenance / Total use of energy (17)

**Preventive maintenance – keep equipment in good condition.**

- Total operating time / Total operating time + Time of downtime caused by maintenance x 100 (18)
- Total time to recovery / Total number of failures (19)
- Cost on preventive maintenance / Total cost on maintenance x 100 (20)

**Total productive maintenance – to involve all staff into technical service.**

- Man hours of maintenance planning and scheduling / Total direct man-hours of maintenance staff (21)
- System of PQCDSM

**Checking of the assets - inspections, control of inventory.**

- The cost of the staff performing inspection or inventory (22)

**Buying items and services - spare parts, consulting.**

- A number of spare parts supplied stock as required / The total number of parts required by maintenance (23)

## 2. NEW TRENDS AND CONCEPT OF TECHNICAL SERVICE

The maintenance strategy, as time changed has developed together with the company. It changed from maintenance after failure through periodic preventive maintenance to diagnostics maintenance, based on discrete or a continuous monitoring of the technical condition and predicting the next period of use to limit state for maintenance, while respecting the principle of proactivity when performing maintenance.

Nowadays, informatization and digitalization prevails in the society. This process cannot avoid technical service. New maintenance strategy are developing at a distance with integrated software technical subsystems such as CNC and NC controllers of machine tools or automobiles. [12] Using this strategy, technical service also enables highly developed telecommunications technology. At the present, it is not problem to e.g. technical condition of machine bearings or the technical condition of selected components of cars was be monitored remotely even from long distances with the intention that the fault is removed or the device will be arranged at a distance. This is done without the presence of staff of technical services and operators are instructed to only what they have to perform.

But it must be pointed out that the machines and equipment’s will always require maintenance performed by workers of technical services. There will always be necessary to provide highly qualified personnel, technical information, spare parts and materials, finance, workshop infrastructure and not least the tools and diagnostic equipment. In the future, theoretical basis for the development of maintenance programs and diverse strategies will be the reliability of technical systems, risk management, special engineering technology, information technology, project management, queuing theory, electronics and electrical engineering, economics and many others. [13]

In the future it will also be necessary to avoid ideas and mistakes of the past that kind of maintenance trend and predictive maintenance will solve everything. This can be only a basis to the organizations, what to build on. I think that it is important that organizations have undergone a maintenance system from the beginning (e.g. from maintenance after fault, preventive maintenance, TPM and so on) because in other way companies will not understand how they operate and will not find the optimal solution for their operating conditions. [13]

### 2.1. Industry 4.0

Program of Society 4.0 and Industry 4.0 become fundamental development program of more economics in the world, for the next years. It combines the efforts of scientists and industry into an integrated system. Industry 4.0 is built on the latest technology applications as is Internet of Things (IoT) and cloud computing, which together with the industrial system creates a cyber-physical systems (CPS). At the present, we are talking about the Industry 4.0 as the future of productivity and growth in the manufacturing industry. Industry 4.0 will change everything from design, production and operation to maintenance of products and production systems. The connection and interaction between parts, machines and people allow the production system to be up to 30 % faster and 25 % more efficient, which will promote mass customizations to a new level. [2]

SMART phenomenon has recently been fully settled among people. When we look around us, we are surrounded by SMART THINGS as telephones, TV, cars, machines, washing machines, cookers (fuzzy logic), fridges and others. It is
the next stage of human development (Fig. 5), which is able to combine all the knowledge that people have learned in different areas. At present, it is already common that companies have automated their processes. This is the first proposition of the smart factory. Traditional production systems use information and communication systems (ICT). In the few years each device will be connected to the Internet. Internet of Things (IoT) is already nowadays one of the key strategic technologies of our time. One of the premises for the formation of Industry 4.0 was also research in the domain of Digital Factory, reconfigurable systems, intelligent systems, automation and simulation and so on. These areas, we also deal with at the Department of Industrial Engineering at University of Zilina. [14]

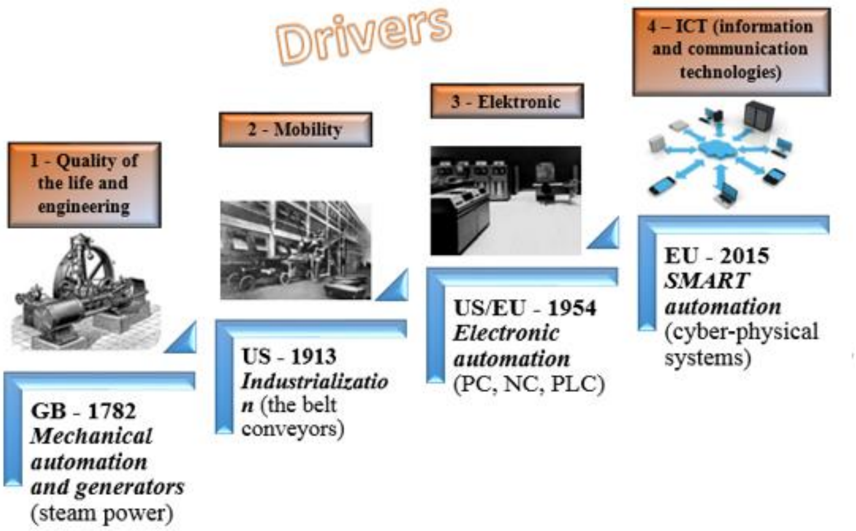


*Fig 5. The development of the industrial revolution*

### 2.2. Maintenance 4.0

Whenever industry has developed or something new was found, the maintenance has also adapted. Today it is the same way, maintenance already has premise to become SMART. Maintenance 4.0 will be an advanced distribution system of components that provides information about the condition and reliability of distribution components for correct management strategy and asset management. This information about the condition and reliability of distribution components are key issues for the right strategy, management and asset management. Prysmian Group has developed an advanced system for monitoring the distribution components that can guarantee real savings in maintenance costs: for example, Par-SMART Aden is a solution based on the label containing the product details on the RFID tags. Using this smart label on the distribution component, we will be able to record the history of monitored components. This solution will be able to watch new and old parts. [15]

Here, however, raises the question: Is this really still maintenance? At the fair in Munich, the company Apple introduced a variety of smartphones and tablets configured for maintenance equipment. Known service provider Bilfinger introduced a new mobile information system (Fig 6) and the concepts of data management for cloud-based solutions. [3] Based on these arguments it can be said that the Internet of Things (IoT) has walked into the world of maintenance. Visitors could take a picture by their mobile phones and share images in real time with colleagues and business partners. [16]


*Fig 6. Smartphone use in Maintenance 4.0*

## 2.3. e-Maintenance

Maintenance gained much attention of experts and people from praxis, for her impact on the operation of the business and business processes by ensuring the safety, reliability and also reduces the life cycle costs of the system. However, maintenance costs are a major part of the total operating costs for business and manufacturing enterprises, because they represents 15-40 % [2] of the cost of manufactured products. Poor maintenance can cause damage to the system and the lack of quality that represents financial losses due to delay, customer complaints and distortion product specifications.

E-Maintenance is increasingly used in many organizations in advanced countries like the United States or in Western Europe countries, not only because it reduces business risks, but also adds value to the process in today's competitive business environment. [17] Despite the potential application of e-Maintenance, it is necessary to consider a number of issues for successful implementation of e-Maintenance system in various frameworks. Growing turbulence in the global environment, increasing the level of automation and ICT (information and communication technologies), calls for sustainability and green production, the increasing complexity of production lines and products, lack of raw materials, the instability of the supply chain, growing emphasis on knowledge generation and application, have considerable pressures on the role of e-maintenance organizations for promoting competitiveness of organizations. [15]

Although research in the area of e-Maintenance in the past ten years has grown rapidly, there is a lack of emphasis on the development (Fig 7) of conceptual frameworks that integrate the fragmented key topics in the research of current e-Maintenance. E-Maintenance research is currently still imperfect, there is a lack of common definitions and universally recognized basic theory, unclear scope of use and lack of commonly defined components associated with e-maintenance. [11]

Attributes of e-Maintenance approach: [2]

- E-Maintenance is strategy.
- E-Maintenance supports decision making at different organizational levels.
- E-Maintenance has great possibilities for cost-effective decisions to be made.
- E-Maintenance integrates principles of maintenance with e-business or e-application technologies such as: telecommunications and web services, mobile, wireless and portable devices and other forms of electronic collaboration.
- E-Maintenance monitors and manages systems and asset over the Internet.
- E-Maintenance integrates production and maintenance systems.
- E-Maintenance collects feedback from remote customer locations and integrates it into the top levels of business applications.
- E-Maintenance creates dynamic and real-time information about maintenance that allows us to use the knowledge of the assets and production systems.
- E-Maintenance includes scientific approaches and methods which forecast a system accuracy and increase productivity for better.
- Competitiveness.

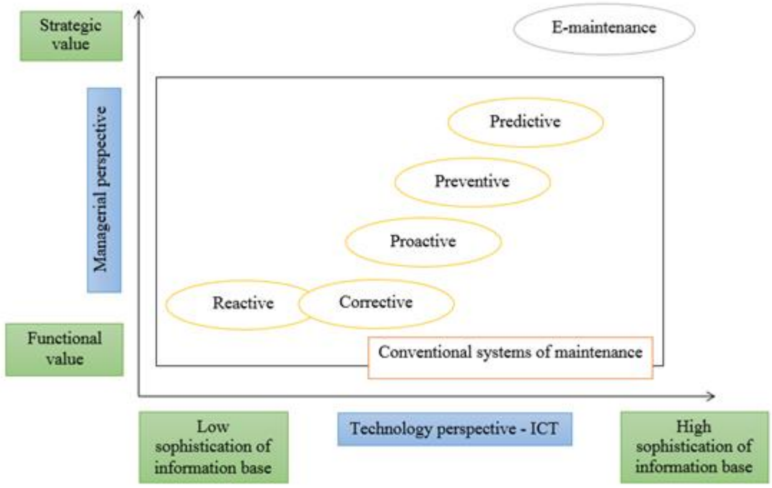


*Fig 7. Position of e-maintenance in development of maintenance*

## 3. THE DEVELOPMENT TRENDS IN SOCIETY

Many people just shake today with their head at the new industrial revolution and the claim that everything will communicate together (IoT). Similar skeptics were even a few years ago when the Internet was rising. However, twenty-six years ago, there were no conversations about the internet in Slovakia. The internet was known only by those who could visit foreign companies and universities. But nowadays the Internet is a necessity and we are having access to it almost everywhere. Internet was initially used only for military communications and later spread around the world. Internet of Things (IoT), has begun to be used by armed forces first but now it gets to everyday life more and more.

But look at the two pictures. First picture talks about shortening the car development. Such a curve is not applied only to the automotive industry. It is similar to many other products. While in 1988 the development took 60 months, at present, it takes 20 months and in 2020 it is estimated to be on the rate at 18 months. All this, will not be possible without industrial engineering (using classical methods and tools, for example Just in Time, Lean, SMED, TPM, Six Sigma) and advanced industrial engineering (using new methods and tools, for example adaptive manufacturing, industrial networks and digital industrial engineering, reconfigurable systems and so on). As can be seen from Figure 8, great asset will be the usage of digital factory and simulations. [16]

Into such a system we must involve service and servicing activities which will help more effective to implement the main process. Next, it must be material flows, workplaces, employees – the change in their thinking and information flow will be an important part too. [18]

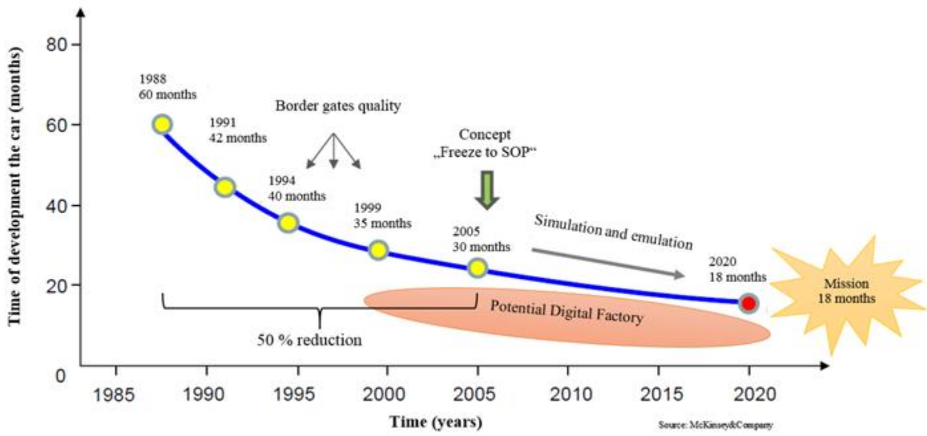


*Fig 8. Shortening the development of new products*

Up to the 2007, the industrial engineering was dealing with the productivity improvement. But in the future it will not be enough. Therefore since the 2007, industrial engineering is engaged in new programs for sustainable development such as innovation, new technologies, research and development, education and consulting. New trend since the 2007, has become a concept of digital factory, which enables companies to better organize their processes and save costs. Important parts of digital factory are: intelligent systems, reconfigurable manufacturing systems, rapid technologies, 3D laser scanning. What is forgotten is the maintenance of machinery and devices. [19] By connecting the digital enterprise and maintenance it must first be addressed monitoring and diagnostics of machines, preventive and scheduled maintenance. Without these premises the further development will simply not move.

On the Fig 9 is shown the development of production systems. At the present we are between flexible manufacturing systems and reconfigurable production systems, but nowadays intelligent manufacturing systems have been already formed. The development of production systems and logistics moves forward, but the maintenance of the facilities is low. Companies declare that they have introduced modern elements of maintenance, but maintenance after a failure is still high rate. [20] Unless companies will not begin to deal with the maintenance now, they will have big difficulties to introduce modern production systems in the future.

The problem will not be only in the implementation of these sophisticated systems, but also in their sustainability. If these production systems want to move on, they must also focus on auxiliary and service processes and people and take them as an equal partner.

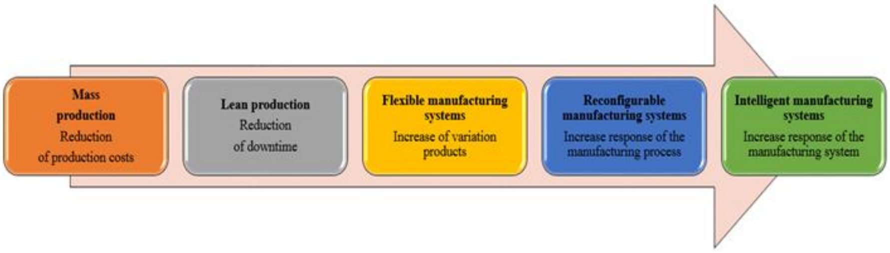


*Fig 9. Phases of development of production systems*

Great potential for increased companies competitiveness will bein digital technologies that are rapidly changing their way in which companies run their operations, innovate and communicate with customers. In the current global environment companies start to lose its traditionalvalue. Innovations become dominate overtraditions, mass customization and not least the fast, modern and sophisticated solutions to meet customer needs. Just take a look at a well rated sci-fi movie that is full of cool and gadget things which already today come into the daily lives of people. [19]

With the rising of Industry 4.0 the term digital is more talked about. To become a digital factory – sometimes called digitalization, it is more and more important factor for the company survival, but the way forward is not always clear and simple. Digital factory must connect people and things through links that allows digital world, i.e. from the penetration of mobile devices and related things, through social networks connecting users but also many services and

the possibility of connections which are offered by cloud. When a company is actually using all that offered technology, immense opportunities for continuous and rapid innovation and differentiation are rising. Entry into the developing field of digital business is for example from Internet of Things through mass customization to 3D printing, put companies in a position from which can be achieve da huge value. [20]

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# 9 MAINTENANCE FUNCTION TO OPTIMIZE PLANT AVAILABILITY AT MINIMUM COST

*Miroslav Rakyta*

## 1. CURRENT STATEMENT IN THE AREA OF MAINTENANCE

In a world of growing expectations, increasingly onerous regulatory constraints, shifting technological paradigms and endless reorganizations – all of which must be dealt with urgently - it is easy to get lost. In this environment, just as most major corporations develop formal mission statements to help them maintain a steady course through an ocean of distractions; it is worth developing a formal mission statement to help maintenance do likewise.

The mission statement must also recognize the customers of the maintenance service. Maintainers serve three distinct sets of customers – the owners of the assets, the users of the assets (usually the operators), and society as a whole. Owners are satisfied if their assets generate a satisfactory return on the investment made to acquire them. Users are satisfied if each asset continues to do whatever they want it to do to a standard of performance which they consider to be satisfactory. Society as a whole is satisfied if assets do not fail in ways which threaten public safety or the environment.

If things didn't fail they wouldn't need maintenance. So the technology of maintenance is all about finding and applying suitable ways of managing failure. Failure management techniques include predictive and preventive maintenance, failure-finding, run to failure and one-time changes to the design of the asset or the way it is operated. [1]

Each category includes a host of options, some more effective than others. Maintainers not only need to learn what these options are, but they also have to decide which are worthwhile in their own organizations. If they make the right choices, it is possible to improve asset performance and at the same time contain and even reduce the cost of maintenance. If they make the wrong choices, new problems are created while existing problems get worse. So the mission statement should stress the need to make the most cost-effective choices from the full array of options. [2], [3] Considering failure management options, note that failures only attract attention because they have consequences. Failures can affect output, safety, environmental integrity, output, product quality, customer service, protection and operating costs in addition to repair costs. The severity and frequency with which a failure incurs these consequences dictate whether any failure management technique is worth applying. So the mission statement should acknowledge the key role of consequence avoidance in maintenance.

It should also acknowledge that most of us work in a highly resource-constrained environment. The most efficient maintainers are those who apply the resources that they do need - people, spares, and tools – as cost-effectively as possible, but not so cheaply that they damage the long-term functionality of their assets. In other words, the cost of ownership of the assets must be minimized throughout their useful lives, not just to the end of the next accounting period.

Finally, the mission statement must recognize that maintenance depends on people – not only maintainers, but also operators, designers and vendors. So it should ac-knowledge the need for everyone involved with the assets to share a common and correct understanding of what needs to be done, and to be able and willing to do whatever is needed right first time every time.

It is these consequences which most strongly influence the extent to which we try to prevent each failure. If a failure mode has serious consequences, we are likely to go to great lengths to try to prevent it. If it has little or no effect, then we may decide to undertake no preventive action. In other words, the consequences of failures are far more important than their technical characteristics. [4]

### 1.1. Maintenance affects all aspects of business effectiveness and risk

The cost of maintenance has also been rising at a steady pace over the past few decades, in absolute terms and as a proportion of total expenditure. In some industries, it is now the second highest or even the highest element of total costs. So in only 40 years maintenance has moved from nowhere to the top of the league as a cost control priority.
The importance of these two aspects of asset management means that many maintenance managers still tend to view them as the only significant objectives of maintenance.

However, this is no longer the case, because the maintenance function now has a wide range of additional objectives. These are summarized in the following paragraphs.

Greater automation means that more and more failures affect our ability to achieve and sustain satisfactory quality standards.

For instance, equipment failures affect climate control in buildings and the punctuality of transport networks as much as they interfere with the consistent achievement of specified tolerances in manufacturing.

Another result of growing automation is the rising number of failures which have serious safety or environmental consequences, at a time when standards in these areas are rising fast. Many parts of the world are reaching the point where organizations either conform to society's safety and environmental expectations, or they get shut down. This adds an order of magnitude to our dependence on the integrity of our physical assets – one which goes beyond cost and becomes a simple matter of organizational survival.

At the same time as our dependence on physical assets is growing, so too is their cost – to operate and to own.  These developments mean that maintenance now plays an increasingly central role in preserving all aspects of the physical, financial and competitive health of the organization. [5]

### 1.2. Successful maintenance program

A surprising number of people believe that effective maintenance policies can only be formulated on the basis of extensive historical information about failure. Thousands of manual and computerized technical history recording systems have been installed around the world on the basis of this belief. It has also led to great emphasis being placed on the failure patterns discussed in the previous section of this paper. Yet from the maintenance viewpoint, these patterns are fraught with practical difficulties, conundrums and contradictions. Some of these are summarized below. [6], [7]

**Sample size and evolution**

Large industrial processes usually possess only one or two assets of any one type. They tend to be brought into operation in series rather than simultaneously. This means that sample sizes tend to be too small for statistical procedures to carry much conviction. For new assets with high levels of leading-edge technology they are always too small.

These assets are also in a continuous state of evolution and modification, partly in response to new operational requirements and partly in an attempt to eliminate failures which either have serious consequences or which cost too much to prevent. This means that the amount of time any asset spends in any one configuration is relatively short.

So actuarial procedures are not much use in these situations because the database is very small and constantly changing. (The main exception is undertakings using large numbers of identical items in an almost identical manner).

**Complexity**

The sheer number and diversity of assets present in most industrial undertakings means that it is simply not possible to develop a complete analytical description of the reliability characteristics of an entire undertaking – or even any major asset within the undertaking.

This is complicated by the fact that many functional failures are caused not by two or three but by two or three dozen failure modes. As a result, while it may be fairly easy to chart the incidence of the functional failures, it is a major statistical undertaking to isolate and describe the failure pattern which applies to each of the failure modes. This alone makes sensible actuarial analysis almost impossible.

**Reporting failure**

Further complications arise due to differences in reporting policy from one organization to another. For example, an item may be removed on one site because it is failing while on another site it is removed because it has failed.

Similar differences are caused by different performance expectations. A functional failure is defined as the inability of an item to meet a desired standard of performance. These standards can of course differ for the same asset if the operating context is different, so what we mean by failed will also differ. For instance, the pump shown in Fig 1 has failed if it is unable to deliver 300 liters per minute in one context and 350 liters per minute in another.

These examples show that what is a failure in one organization – or even one part of an organization – might not be a failure in another. This can result in two quite different sets of failure data for two apparently identical items.

**The ultimate contradiction**

An issue which bedevils the whole question of technical history is the fact that if we are collecting data about failures, it must be because we are not preventing them. The implications of this are summed up most succinctly by [8] in the following statement:

The acquisition of the information thought to be most needed by maintenance policy designers - information about critical failures – is in principle unacceptable and is evidence of the failure of the maintenance program. This is because critical failures entail potential (in some cases, certain) loss of life, but there is no rate of loss of life which is acceptable to (any) organization as the price of failure information to be used for designing a maintenance policy. Thus the maintenance policy designer is faced with the problem of creating a maintenance system for which the expected loss of life will be less than one over the planned operational lifetime of the asset. This means that, both in practice and in principle, the policy must be designed without using experiential data which will arise from the failures which the policy is meant to avoid.

Despite the best efforts of the maintenance policy designer, if a critical failure actually does occur, [9] go on to make the following comments about the role of actuarial analysis:

The development of an age-reliability relationship, as expressed by a curve representing the conditional probability of failure, requires a considerable amount of data. When the failure is one which has serious consequences, this body of data will not exist, since preventive measures must of necessity be taken after the first failure. Thus actuarial analysis cannot be used to establish the age limits of greatest concern – those necessary to protect operating safety.

This brings us to the ultimate contradiction concerning the prevention of failures with serious consequences and historical information about such failures: that successful preventive maintenance entails preventing the collection of the historical data which we think we need in order to decide what preventive maintenance we ought to be doing.

This contradiction applies in reverse at the other end of the scale of consequences. Failures with minor consequences tend to be allowed to occur precisely because they do not matter very much. As a result, large quantities of historical data are available concerning these failures, which means that there will be sufficient material for accurate actuarial analyses. These may even reveal some age limits. However, because the failures don't matter much, it is highly unlikely that the resulting fixed interval maintenance tasks will be cost effective. So while the actuarial analysis of this information may be precise, it is also likely to be a waste of time.

## 2. TYPES OF MAINTENANCE

Most of what has been written to date on the general subject of maintenance strategy refers to three – and only three – types of maintenance: predictive, preventive and corrective.

Predictive (or condition-based) tasks entail checking if something is failing. Preventive maintenance usually means overhauling items or replacing components at fixed intervals. Corrective maintenance means fixing things either when they are found to be failing or when they have failed.

However, there is a whole family of maintenance tasks which falls into none of the above categories. [10]

On the other hand, the same analytical techniques reveal that it is not unusual for condition monitoring to be technically feasible for no more than 20 % of failure modes, and worth the investment in less than half these cases. (This is not meant to imply that condition monitoring should be not be used – where it is good it is very, very good - but that we must also remember to develop appropriate strategies for managing the other 90 % of our failure modes).

A rather more troubling finding is that most traditionally derived maintenance programs provide for fewer than one third of protective devices to receive any attention at all (and then usually at inappropriate intervals).

The people who operate and maintain the plant covered by these traditional programs are aware that another third of these devices exist but pay them no attention, while it is not unusual to find that no-one even knows that the final third exist. This lack of awareness and attention means that most of the protective devices in industry – our last line of protection when things go wrong - are maintained poorly or not at all.

This situation is completely untenable. If industry is serious about safety and environmental integrity, then the whole question of detective maintenance – failure-finding - needs to be given top priority as a matter of urgency. As more and more maintenance professionals become aware of the importance of this neglected area of maintenance, it is likely to become a bigger maintenance strategy issue in the next decade than predictive maintenance has been in the last ten years. [12]

We are simply checking if it still works. Tasks designed to check whether something still works are known as functional checks or failure-finding tasks. (In order to rhyme with the other three families of tasks, the author and his colleagues also call them detective tasks because they are used to detect if something has failed).

Detective maintenance or failure-finding applies only to hidden or unrevealed failures, and hidden failures in turn only affect protective devices.

If one applies scientific maintenance strategy formulation techniques to modern, complex industrial systems, it is not unusual to find that up to 40 % of failure modes fall into the hidden category. Furthermore, 80 % of these failure modes usually require failure-finding, so up to one third of the tasks generated by scientific maintenance strategy development programs – such as RCM2 – are detective tasks. [13]

## 3. DEVELOPING A MAINTENANCE STRATEGY

It is one thing to decide on a mission. It is quite another to develop and implement a strategy that enables the maintenance enterprise to accomplish that mission.

Given all the day-to-day pressures faced by maintenance managers, the first question is where do we start? Buy a new maintenance management system (MMS)? Reorganize? Invest in loads of condition monitoring equipment? Knock the whole place down and rebuild it?

The answer lies at the beginning of the mission statement, which states that our mission is to preserve the functions of our assets. It is only when these functions have been defined that it becomes clear exactly what maintenance is trying to achieve, and also precisely what is meant by failed. This makes it possible to move on to the next step, which is to identify the reasonably likely causes and effects of each failed state.

Once failure causes (or failure modes) and effects have been identified, we are then in a position to assess how and how much each failure matters. This in turn enables us to determine which of the full array of failure management options should be used to manage each failure mode.

At this point, we have decided what must be done to preserve the functions of our assets. This process could be called work identification. When the tasks that need to be done - the maintenance requirements of each asset – have been clearly identified, the next step is to decide sensibly what resources are needed to do each task. Resources consist of people and things, so the following questions must now be answered [14]:

- Who is to do each task: a skilled maintainer?
  The operator, a contractor, the training department (if training is required), engineers (if the asset must be redesigned).
- What spares and tools are needed to do each task, (including condition monitoring equipment)?

It is only when resource requirements are clearly understood that we can decide exactly what systems are needed to manage the resources in such a way that the tasks get done correctly, and hence that the functions of the assets are preserved.

This process can be likened to building a house. The foundations are the maintenance requirements of each asset, the walls are the resources needed to fulfil the requirements (skills and spares/tools) and the roof represents the systems needed to manage the resources (MMS).

Looking at maintenance requirements in the context of the functions of each asset (by seeking to preserve what the asset does rather than what it /Is), completely transforms the way in which the requirements are perceived. In other words, such a review changes the size, shape and location of the foundations upon which the maintenance enterprise is built. Clearly, when the foundations change, everything built on those foundations must also change. [15]

## 4. RELIABILITY CENTRED MAINTENANCE

Reliability Centred Maintenance is defined as a process used to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context. It entails asking seven questions about the asset under review, as follows [16], [17]:

- What are the functions and associated performance standards of asset in its present operating context?
- In what ways does it fail to fulfil its functions?
- What causes each functional failure?
- What happens when each failure occurs?
- In what way does each failure matter?
- What can be done to predict or prevent each failure?
- What of a suitable proactive task cannot be found?

These questions are reviewed in the following paragraphs.

The objectives of maintenance are defined by the functions and associated performance expectations of the asset. But how does maintenance achieve these objectives?

The only occurrence that is likely to stop any asset performing to the standard required by its users is some kind of failure. However, before we can apply a suitable blend of failure management tools, we need to identify what failures can occur. The RCM process does this at two levels:

- Firstly, by identifying what circumstances amount to a failed state.
- Then by asking what events can cause the asset to get into a failed state.

In addition to the total inability to function, this definition encompasses partial failures, where the asset still functions but at an unacceptable level of performance (including situations where the asset cannot sustain acceptable levels of quality or accuracy).

Once each functional failure has been identified, the next step is to try to identify all the events which are reasonably likely to cause each failed state. Reasonably likely' failure modes include those that have occurred on the same or similar equipment operating in the same context, failures that are currently being prevented by existing maintenance tasks, and failures that have not happened yet but that are considered to be real possibilities in the context in question.

Most traditional lists of failure modes incorporate failures caused by deterioration or normal wear and tear. However, the list should include failures caused by human errors (on the part of operators and maintainers) and design flaws, so that all reasonably likely causes of equipment failure can be identified and dealt with appropriately. It is also important to identify the cause of each failure in enough detail for it to be possible to identify a suitable failure management policy.

The fourth step in the RCM process entails listing failure effects which describe what happens when each failure mode occurs. These descriptions should include all the information needed to support the evaluation of the failure consequences, such as [18]:

- What evidence (if any) that the failure has occurred.
- In what ways (if any) it poses a threat to safety or the environment.
- In what ways (if any) it affects production or operations.
- What physical damage (if any) is caused by the failure.
- What must be done to repair the failure.

A detailed analysis of an average industrial undertaking is likely to yield between three and ten thousand possible failure modes. As mentioned in part 1 of this section, each of these failures affects the organization in some way, but in each case, the consequences are different. The RCM process classifies failure consequences into four groups, as follows [19], [20]:

- Hidden failure consequences: 11 hidden failures have no direct impact, but they expose the organisation to multiple failures with serious consequences.
- Safety and environmental consequences: A failure has safety consequences if it could hurt or kill someone. It has environmental consequences if it could breach a corporate, regional, national or international environmental standard.

- Operational consequences: A failure has operational consequences if it affects production (output, product quality, customer service or operating costs in addition to the direct cost of repair).
- Non-operational consequences: Evident failures that fall into this category affect neither safety nor operations, so they involve only the direct cost of repair.

The RCM process uses these categories as the basis of a strategic framework for maintenance decision-making. By forcing a structured review of the consequences of each failure mode in terms of the above categories, it focuses attention on the maintenance activities which have most effect on the performance of the organization, and diverts energy away from those that have little or no effect (or which may even be actively counterproductive). [21]

It also encourages users to think more broadly about different ways of managing failure, rather than to concentrate only on failure prevention.

## 5. FAILURE MANAGEMENT POLICY SELECTION

Failure management policies fall into two categories:

- Proactive tasks: these are tasks undertaken before a failure occurs, in order to prevent the item from getting into a failed state. As discussed below, RCM further subdivides these tasks into scheduled restoration, scheduled discard and on-condition maintenance.
- Default actions: these deal with the failed state, and are chosen when it is not possible to identify an effective proactive task. Default actions include failure-finding, redesign and run-to-failure.

Scheduled restoration and scheduled discard tasks Scheduled restoration entails remanufacturing a component or overhauling an assembly at or before a specified age limit, regardless of its condition at the time. Similarly, scheduled discard entails discarding an item at or before a specified life limit, regardless of its condition at the time. [22]

Collectively, these two types of tasks are now generally known as preventive maintenance.

**On-condition tasks**

On-condition techniques rely on the fact that most failures give some warning of the fact that they are about to occur. These warnings are known as potential fortunes and are defined as identifiable physical conditions that indicate that a functional failure is about to occur or is in the process of occurring.

On-condition tasks are used to detect potential failures so that action can be taken to reduce or eliminate the consequences that could occur if they were to degenerate into functional failures. This category of tasks includes all types of predictive maintenance, condition-based maintenance and condition monitoring. [23]

**Failure-finding**

Failure-finding entails checking hidden functions to find out whether they have failed (as opposed to on-condition task, which entail checking if something is failing). [24]

**Redesign**

Redesign entails making any one-time change to the built- in capability of a system. This includes changes to hardware, one-time changes to procedures and if necessary, training.

**No scheduled maintenance**

This default entails making no effort to anticipate or prevent failure modes to which it is applied, and so those failures are simply allowed to occur, then repaired. [25]

## 6. MODEL OF SERVICE ACTIVITIES' OPTIMISATION

Increasing the effectiveness of service activities is possible upon designing a model of enterprise service activities as the support activity or support process having significant impact on the main activities, respectively main processes with the purpose to increase the profit and productivity or to reduce the expensiveness/costliness and increase the added value of organisation. Proposal of the service activities model comes out of the present theoretical knowledge basis, analysis of the present situation within the area of service activities and best practices.

The basis for this model proposal is the knowledge of Facility Management structures, which is the area directly following the history of services development and particular support functions development. Work flow to build up the model is as follows:

- Creating the environment, i.e. unifying the principles of planning, decision making, performing and controlling of such activities, as well as making the unity of understanding the service activities as a meaningful function of organisations.
- Removing sizable differences among various sections, divisions, departments, subsidiaries or joint ventures within a group/holding (not just form the organisational point of view) when the responsibilities, respectively sponsorship and consequent activity coordination (for example the coordination in terms of investment procurement, maintenance, practicing the unified technical policy, etc.), are highly questionable.
- Eliminating various disproportions (organisational, technical, controlling, etc.) to increase overall effectiveness, respectively to reduce overall expensiveness/costliness of an organisation and to increase the motivation for performing the service activities in this way.
- Defining the rules of monitoring by designing the key performance indicators (KPI-s) and setting their calculations up, we can measure and assess the performance and effectiveness of service activities. [26]

For the fulfilment assessment of objectives, the key performance indicators (Tab 1) are defined to evaluate the increasing effectiveness of particular Service Activities System items. [27]

*Tab 1. Key Performance Indicators of Service Activities [27]*

| System Item | Objective | Key Performance Indicator (KPI) | |
|---|---|---|---|
| | | Index | Description |
| **Investment Procurement** | Measuring / monitoring the process of Investment Procurement with the purpose to increase its quality. | $KPI_{IP}$ | Indicator expressing the degree of Investment Procurement Process fulfilment. |
| **Service of Production and Technological Means (PTM)** | Reducing the accident rate and increasing the Work Safety Prevention of performing Production and Technological Means Service. | $KPI_{WS}$ | Indicator expressing the degree of Work Safety. |
| | Increasing the Availability of PTM with the purpose to reduce the primary and secondary cost of PTM Service / Maintenance. | $KPI_{A}$ | Indicator expressing the Availability of PTM. |
| | Reducing the Environmental Incidents and increasing the prevention in relation to the PTM Service / Maintenance. | $KPI_{E}$ | Indicator expressing the degree of Environmental Fulfilment. |
| | Increasing the Quality of PTM Service / Maintenance and reducing the number of reclamations. | $KPI_{Q}$ | Indicator expressing the degree of PTM Service / Maintenance Quality. |
| | Optimising the Target Cost of PTM Service / Maintenance. | $KPI_{TCPTM}$ | Indicator expressing the degree of saving and optimising the Target Cost budgeted for PTM Service / Maintenance. |
| | Overall measuring of the quality and effectiveness of PTM Service / Maintenance. | $KPI_{SPTM}$ | Summary indicator expressing the performance and quality of PTM Service / Maintenance with respect to Work Safety, Environmental Aspects and PTM Availability. |
| **Administration of Production Areas and Buildings (PAB)** | Monitoring of fulfilling the Expensiveness / Costliness in relation to the Administration of Production Areas and Buildings. | $KPI_{APAB}$ | Indicator expressing the degree of Expensiveness / Costliness in relation to the Administration of Production Areas and Buildings. |
| **Procurement** | Monitoring of fulfilling the Expensiveness / Costliness in relation to Procurement expensiveness of services, materials, spare parts and so on. | $KPI_{P}$ | Indicator expressing the degree of Procurement expensiveness. |

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