POLITECHNIKA LUBELSKA

Inspirations for Innovation: the Causes and Effects of Progress in Production Engineering

edited by
Dariusz Mazurkiewicz
Anna Rudawska

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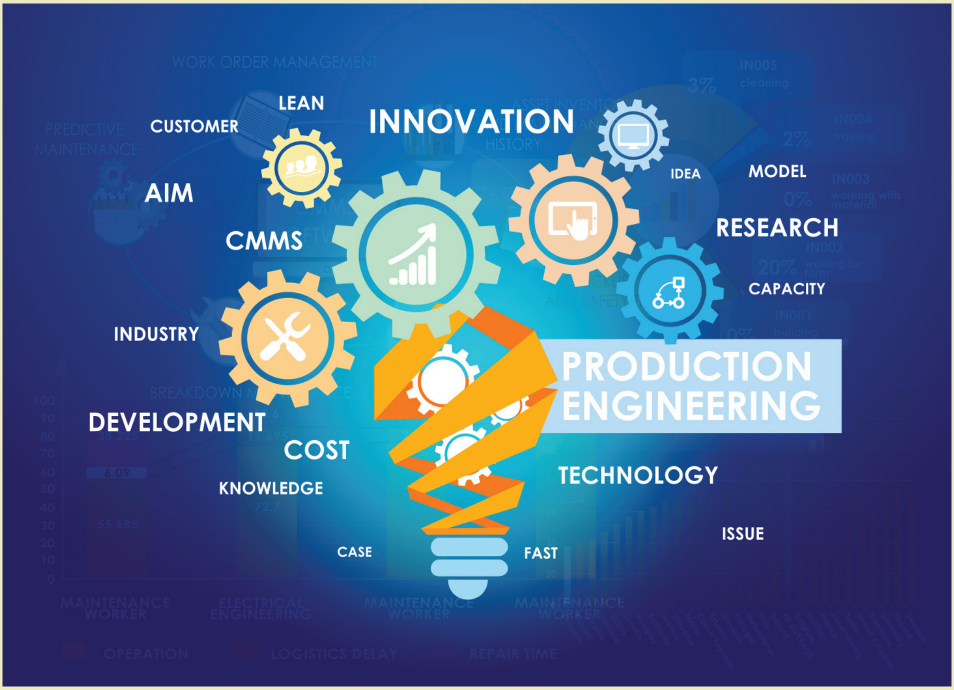

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Monografie – Politechnika Lubelska

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1. **Introduction** – Dariusz Mazurkiewicz, Anna Rudawska

Innovativeness of a company, especially a production company, can be defined as the ability to effectively introduce new or updated products, processes, technologies or methods of organization of production processes [7]. Innovative activities carried out by a company make up an extremely complex process, and innovation is regarded as one of the basic tools of stimulating the development of a company. Owing to innovative solutions, a company can respond to market needs, and sometimes even skilfully create them. Innovation is also an important element of competition. Innovative solutions allow companies to implement cost leadership strategies because they make it possible to achieve money-saving results. They are also an effective instrument of differentiation strategies – innovations enable diversification of market offerings, giving a company the opportunity to position itself as a market leader. Innovativeness should therefore be analysed on many levels and in different contexts. This is particularly important for manufacturing companies, whose competitiveness and market position depend only on broadly understood innovativeness. A company can be called innovative when its activities are characterized by the following set of features [5–7]:

- it engages in a wide range of research and development efforts;
- it allocates relatively large financial resources to R&D;
- it systematically implements new scientific-and-technological solutions;
- it continually introduces innovations into the market;
- new products and technologies represent a relatively large share of its production volume;
- it has the capacity not only to create innovative solutions, but also to implement them; and
- it has a high capacity to adapt innovations from external sources.

The range of innovative activities conducted by a company can be classified according to the type of innovation implemented. There are four basic types of innovation[7]:

- a product innovation is an innovation that consists in introducing new or updated products into the market;

- a process innovation is the implementation of changes in production and delivery methods including changes in techniques, equipment and software (e.g., computerization of the company and automation of manufacturing processes in the company);
- an organizational innovation is the introduction of improvements in the organization of the company itself or the activities that make up the functions it undertakes;
- a marketing innovation is the implementation of modifications in pricing, promotion, packaging, sales, etc.

All of the above types of innovation, jointly or separately, play a special role in the development of production companies. Similar relationships exist for objectives of implementing innovation-promoting activities, with companies usually developing innovations to [3, 7]:

- increase the range of products or services,
- replace outdated products or processes,
- enter new markets or increase market share,
- improve the quality of products or services,
- improve production flexibility and increase productivity,
- increase production capacity for products or services,
- reduce labour costs per unit output,
- reduce material consumption and energy consumption per unit output,
- reduce environmental impacts,
- improve health and safety of employees.

These objectives are primarily related to increasing the company's competitiveness and its market share and improving its production efficiency. There are also companies which implement innovations wanting to achieve several different objectives, for instance, they increase their product range and improve product quality, assuming that this will allow them to enter new markets. In Poland, the most important objective of implementing innovations is to increase the range of products (51.5%) and to improve their quality (50.3%). Almost 44% of innovation-active industrial companies in this country report that an important objective of innovative activity is to enter new markets. Reduction of labour costs is considered an important goal of innovation by only 24.5% of Polish companies, and reduction of material- and energy consumption and reduction of environmental impacts are considered important by about 26% of companies [2, 3, 5, 7].

Most business entities in Poland show low levels of innovativeness. By the same token, their competitiveness on the market, level of gross income, GDP growth, and other indicators do not guarantee the stability of the country's economic system and its resistance to the effects of the so-called turbulent environment. The causes for this state of affairs have been the subject of many studies. Most expert opinions diagnose the existing problems, identifying the barriers and proposing actions that should be taken to eliminate or reduce them or to reduce their negative impact on the effectiveness and efficiency of the innovation system. Comprehensive analysis of the system of technology transfer and commercialization of knowledge in Poland in relation to its motor forces and barriers has been, among others, the subject of a study commissioned by the Polish Agency for Enterprise Development (PARP) [4] as well as numerous government documents (see especially [1]). Various analyses, specialist studies and expert opinions [1–7] demonstrate that typical barriers to the development of the innovation system in the business sector and in research and development include the following problems:

- For most companies, innovation usually means investing in new equipment, infrastructure or software. Only very few entrepreneurs recognize the importance of research and development, and, as a consequence, product innovations have a negligible share in their business activities.
- System incentives for innovative activity are still too weak. Companies allocate little money to research and development. They prefer low-risk purchases of finished foreign technologies and equipment. Companies do not base their activities on long-term development strategies, in particular, those using new, self-developed innovative products and services that would provide a strong competitive advantage.
- A low level of trust and a lack of a real partnership in mutual relations creates barriers to cooperation and undertaking of innovative projects. Entrepreneurs also show little interest in co-operative forms of economic activity and do not look for the maximum benefits that could be obtained from collaborative innovation projects. As a result, the formation of network structures and the awareness of the possibilities of using their potential are very limited.

These barriers also concern companies and research and development units operating in the area of production engineering. On the other hand, the trends in the development of industry, the priorities of innovation, new technologies and the dominant role of production companies in Polish economy incline one to conclude that the challenges and expectations for production engineering are enormous. **Production engineering has all the necessary components to play a significant role in innovative development, becoming both an inspiration for this development and its main driving force.** This idea guided the authors of this monograph and inspired the solutions presented in it. Innovative methods, tools, techniques and research directions, as well as other related issues require as their basis a precise definition of what production engineering is and what it can or should be in the future (i.e. what challenges it currently faces). It is necessary in this case to review national and European Union's innovation priorities, in which a significant role can be played by production engineering. Research and implementation in these areas will be particularly encouraged, among others through funds that could be a significant source of external financing for production companies. Because the present monograph is also addressed to the industrial milieu, it presents methods of introducing innovations in companies and good practices in innovation implementation using examples of domestic and foreign companies which have built their own strategies for development and for gaining a competitive advantage on conscious and effectively implemented innovation-supporting activities.

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2. **Description of the discipline –** Zbigniew Banaszak

Under the Regulation of the Polish Minister of Science and Higher Education of 8th August 2011 on the Areas of Knowledge, Fields of Science and Art, and Scientific and Artistic Disciplines [20], production engineering was added to the list of primary scientific disciplines in the field of technical sciences, next to other engineering-related disciplines such as biocybernetics and biomedical engineering, chemical engineering, materials engineering, agricultural engineering and environmental engineering. This event had been preceded by the introduction in 1998 of a new degree program, *Management and Production Engineering.* One decade earlier still, in 1989, the Institute of Industrial Engineers had for the first time introduced the term 'Production Engineer'. Looking at Production Engineering from this 25-year perspective, it is worth trying to analyse its ever increasing importance, and the promising perspectives for its further development.

2.1. The need – an attempt at reconstructing the origins of the term 'production engineering'

The dynamic development of the discipline called Production Engineering confirms the need for treating it as a separate field of knowledge. This need, or the expectations associated with the name of the discipline, can be identified on the basis of the existing definitions, as well as an analysis of the development of the techniques and technologies used in the course of production and/or delivery of services.

One of the most frequently quoted definitions of Production Engineering is that given by the American-based Institute of Industrial Engineers [30]: "Production Engineering covers issues such as planning, design, implementation and management of production and logistic systems and maintenance of their functioning. These systems are understood as socio-technical constructs that aim to integrate the employees, information, energy, materials, tools and processes during the whole product life cycle. Production Engineering bases on technical, economic, human and social sciences. It uses the know-how of telecommunication informatics, innovativeness, management, public communication and human resources management. Its key component which distinguish it from other technical disciplines is human-factor orientation. The best systems function properly due to continuous improvement of the working environment, in which human labor is the most important factor affecting the efficiency, costs and quality of work"[7, 10].

Wikipedia gives the following definition [21]: "Production Engineering – an engineering discipline dedicated to the principles of the design of products and processes, as well as the fundamentals of control, maintenance, organization and management of manufacturing processes. Production engineering is also understood as a set of activities aimed at effective implementation of the production process from the moment of identification of a need to complete satisfaction of this need".

Definitions coming from other sources do not diverge essentially from the core content of the first definition. A relevant example is given in [22]: "Production Engineering is dedicated to the design, improvement, management and control of integrated systems of people, materials, equipment and energy based on expertise in mathematical , physical, economic and social sciences, as well as the principles and methods of engineering analysis and synthesis. The concept, as it is understood in the West, integrates the design and planning of manufacturing processes with the design, organization and control (management) of production processes. The largest area of activity of ‘production engineering’ is the metal industry, but the same methods are also used in agriculture, mining, construction, services and administration. The standard of production engineering defines the standard of production management and is the basic factor in the development of management science in industry".

Not to multiply entities beyond necessity, let us note that the few definitions cited above already point to the need for the development of Production Engineering as a discipline. The name is a combination of two terms: ‘engineering’ and ‘production’. The meaning of the first term, best explained by the following definitions: ”Engineering (from Latin *ingenium*, meaning ‘cleverness’ and *ingeniare*, meaning ‘to contrive, devise’) is the application of scientific, economic, social, and practical knowledge in order to invent, design, build, maintain, research, and improve structures, machines, devices, systems, materials and processes. The discipline of engineering is extremely broad, and encompasses a range of more specialized fields of engineering, each with a more specific emphasis on Particular areas of applied science, technology and types of application" [23]. And the definition given in [24]: “Engineering is the science, skill, and profession of acquiring and applying scientific, economic, social, and practical knowledge, in order to design and also build structures, machines, devices, systems, materials and processes.” And also a definition proposed by The American Engineers' Council for Professional Development in which ‘engineering’ has been defined as “The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions; all as respects an intended function, economics of operation or safety to life and property. One who practices engineering is called an engineer, and those licensed to do so may have more formal designations such as Professional Engineer, Chartered Engineer, Incorporated Engineer, Ingenieur or European Engineer. The broad discipline of engineering encompasses a range of more specialized sub disciplines, each with a more specific emphasis on certain fields of application and particular areas of technology. An engineer is a professional practitioner of engineering, concerned with applying scientific knowledge, mathematics and ingenuity to develop solutions for technical, social and economic problems” [23]. “The word ‘engineer’ is derived from the Latin roots ingeniare (‘to contrive, devise’) and ingenium (‘cleverness’). The work of engineers forms the link between scientific discoveries and their subsequent applications to human needs and quality of life “ [36]. In that context production engineering can be seen as a branch of engineering that involves the design, control, and continuous improvement of integrated systems in order to provide customers with high-quality goods and services in a timely, cost-effective manner. It is an interdisciplinary area requiring the collaboration of individuals trained in industrial engineering, manufacturing engineering, product design, marketing, finance, and corporate planning.

The word 'production', in turn, stands for [25] “The processes and methods used to transform tangible inputs (raw materials, semi-finished goods, subassemblies) and intangible inputs (ideas, information, knowledge) into goods or services. Resources are used in this process to create an output that is suitable for use or has an exchange value”. The term ‘production’ is wider than ‘industrial’, as well as ‘manufacturing’ as it is concerned with the design, development, implementation, operation, maintenance, and control of all processes in the manufacture of a product. So, the correspondence of both terms: ‘production’ and ‘engineering’, suggests that ‘production engineering’ stands for the processes and tools by which the strategic and core procedures are checked along with the necessary facilities, equipment, personnel, and supporting business functions used by a given organization to produce its products and services.

This means that the term Production Engineer highlights the role of the human factor, which determines the characteristics of the products designed, the ways they are obtained (processes and their organization), as well as the tools used in these processes (available techniques and technologies). The role of the human factor is also manifest in the decision-making processes connected with what will be produced, where, when, how, in what quantities, and at what cost, etc. The answers to these interpenetrating and complementary questions require knowledge that combines the experience of technical sciences with the achievements of economic and management sciences, liberal arts, social sciences, as well as ergonomics and social communication.

The approaches found in the literature of the subject, even though they are based on different assumptions and definitions, are consistent about one thing – the systemic nature of production engineering. One of such approaches defines the object of Production Engineering using the following analogies: if the object of Electrical Engineering is to engineer an electrical product or system, and the object of Computer Engineering is to engineer a computer or a system of networked computers, then the object of Mechanical Engineering is to engineer a mechanical or thermal product/system and the object of Manufacturing Engineering is to engineer a process or a system that results in a manufactured product; if so, then the object of Production Engineering should be to engineer a process or a system that manifests itself in a synergy of a triple helix client–designer–producer whole. An alternative approach, which takes it that a manufacturing system can be viewed as an integrated combination of processes, machine systems, people, organizational structures, information flow, control systems and computers, designed and operated in order to properly support a coherent manufacturing strategy, proposes that in that context Production Engineering can be seen as a methodology associated with the optimum design, analysis, operation and control of manufacturing systems, a discipline that fosters an understanding of the whole manufacturing process and studies it as a system in order to fulfil the objective(s) of the company.

After so many definitions have been quoted, it is tempting to say that what Production Engineering is, is as plain as the nose on your face. If, however, one wanted to delve deeper to ask about the essence of Production Engineering, the most common reply would be: interdisciplinarity. This feature, as can be easily noted, corresponds to the need for integrating or adopting a systemic approach to the different elements involved in the production process. These elements comprise, among others, knowledge of market requirements, the availability of appropriate technologies, the technical and organizational conditions of production, the maintenance and monitoring of products in use, as well as decisions related to the implementation of new technologies, introduction of innovations, management of integrated production systems, logistics and material flow; maintaining the continuity of work and high labour productivity; analysing production costs; maintaining the quality of products and services; work safety; environmental protection; the principles of crisis management, etc.

Note that specification of the production process should proceed concurrently with the development of the product design. This involves selecting the manufacturing processes and technologies required to achieve the most economical and effective production. The technologies chosen will depend on many factors, such as the required production volume, the skills of the available work force, market trends, and economic considerations. In manufacturing industries, this requires activities such as the design of tools, dies, and fixtures; the specification of speeds and feeds for machine tools; and the specification of process recipes for chemical processes.

Viewing Production Engineering from a systemic perspective allows one to explain its attractiveness as a discipline that integrates different engineering conceptions (including management engineering, software engineering, quality engineering, material engineering, etc.) around the product and its recipient. This perspective allows one to see the different ‘sections’ of the production process associated with the merging of resources of different nature and character (material, financial, energy, human, informational, etc.), and, above all, to better understand the relationships among them. In particular, it allows one to understand the cumulative effects of the decisions taken at different stages and in different areas of the production process. A good example of such multi-faceted decisions are the decisions regarding the arrangement of manufacturing workstations, which must take into account a variety of criteria such as utilization of space, ergonomic operation, and maintenance (periodic inspections and repairs). This means that the adoption of the systemic/system-oriented perspective, allows one to understood Production Engineering as a holistic approach to the production process, both in terms of production stages (from the assessment of market needs, through the design of the product, to its manufacture and distribution) and the possible techniques and methods of production (including a manufacturing technology, production organization, human resources management, financial management, etc.). In particular, this means that local decisions should be evaluated from the point of view of the effects of implementation of the whole process.

The need, outlined above, for systemic integration of the elements that determine the fulfilment of the criteria characterizing both the production process and the end product obtained in the process, that is the need for the development of production engineering, can also be justified by analyzing the stages of evolution of production systems. If one assumes that the primary focus of manufacturing is to turn raw materials into a new or updated product in the most economic, efficient and effective way possible [2], one can view ‘manufacturing engineering’ as involving research, design and development of systems , processes, machines, tools and equipment. The stage of manufacturing also deals with the integration of different facilities and systems for producing quality products (with optimal expenditure) by applying the principles of physics and the results of manufacturing systems studies.

Traditionally, the manufacture of a product is usually preceded by a stage of technical preparation of production which encompasses design-and-technology-oriented preparation of production (related to the design of the product) and organizational preparation of production (related to the organization of the manufacturing process). Since a 'product' is defined as an item that has value added to it during the production process, this fact has to be taken into account during the design, development, implementation, operation, maintenance, and control of all processes in the manufacture of a product. Automation of the above tasks implemented in dedicated decision support CAx systems (e.g., CAT – Computer Aided Testing, CAE – Computer Aided Engineering, CARC – Computer Aided Robot Control, CATS – Computer Aided Transport, and CAA – Computer Aided Assembly) is part of the area of management engineering covering the functionalities subject to personnel management, material resources and warehouse management, product development management, innovation management, supplies, production, production safety, distribution, implementation of development projects of the production system, as well as marketing, sales, and capital management.

Integration of the above-described concepts of manufacturing engineering and management engineering, reflecting the naturally interwoven processes of product design and design of its manufacturing processes leads to Production Engineering – a system linking the manufacturing system with its complementary system of computer integrated management, which coordinates its operation, e.g. an ERP-type system.

2.2. Research – Quo Vadis Production Engineering?

The example of many of the leading economies in Europe, North America, Japan, as well as China and India shows that the development of Production Engineering keeps its pace [6, 17, 18, 35], and after 25 years still presents a challenge both to developing countries as well as advanced economies. The current state of domestic knowledge of the scientific discipline Production Engineering presented in the monumental monograph *Inżynieria produkcji. Kompendium wiedzy* (*A Compendium of Production Engineering*) [10] has naturally followed a series of earlier events. If we assume that this over 1,000-page-long *Compendium* is the tenth ‘milestone’ in the development of Production Engineering in Poland, the preceding nine ‘milestones’ on this path of development include, in a chronological order, launching of a degree program in Management and Production Engineering (1998), founding of the journal ***Production Management*** – now ***Business Administration*** (1998), founding of **The Polish Society for Production Management** (2000), the development and legislation of ministerial curriculum standards for the degree program Management and Production Engineering (2005), creation of **the Polish Academy of Sciences (PAS)** ***Committee for Production Engineering*** (2009), launching of the international journal ***Management and Production Engineering Review*** (2010), the establishment of the scientific discipline of Production Engineering (2010), the publication of a series of 22 academic textbooks for the degree program Management and Production Engineering (2011–2014) and the creation of a large, nationwide cluster called **Knowledge and Innovation Community in Production Engineering** (2014). Each of these milestones has paved the way for the next stages of development of Production Engineering.

In addition to the above-mentioned ‘milestones’, there were also many other pioneering projects, which, so to speak, anticipated the current state of development of this discipline. The website of the PAS Committee for Production Engineering [7] features a kind of manifesto entitled ***The Essence of Production Engineering***, which lists 10 areas of scientific research recognized as falling within the discipline of Production Engineering:

- Organization and management of production and services – design of manufacturing processes, organization of production, time management, scheduling of production orders and use of management information systems.

- Selected topics in manufacturing engineering – management of processing of materials into usable products, including manufacturing of machine elements using shaping, dimension-changing, surface finishing, and joining processes.
- Innovation management – development, measurement and management of innovation processes.
- Management of production and service projects – in particular, topics in project execution management (scope control, task updating, schedule control, and cost control), as well as risk management in the execution phase.
- Optimization of supply chains and logistics – optimization of flow of materials, information and financial resources through the organization's network aimed at producing and delivering products or services to the consumer and ensuring process profitability and continuity.
- Quality management – the problems, philosophy and essence of quality management oriented toward improving the functioning of companies.
- Decision support systems. Management of production knowledge – the use of decision analysis methods, mathematical models and artificial intelligence tools to meet the financial and operational objectives of production management.
- Forecasting, modeling and computer simulation – problems of technological, economic and demand forecasting, as well as modeling and simulation of product design, process design, scheduling of production tasks, design of production logistics, and project management.
- Shaping the work environment. Work safety – the problems of shaping a safe work environment using computer modeling and simulation of the anthropotechnical systems found in production engineering.
- Efficiency, productivity and organization of companies – research focusing on managers' actions and decisions and the use of new business models and new systems and methods of management which give shape to new organizational solutions in the company.

The above-mentioned areas are reflected in the work of the four sections of the PAS Committee for Production Engineering: *Management of Production and Projects*, *Methodology of Innovation and New Technologies*, *Quality and Safety of Work* and *Human Resource Education and Development.* Much of the work carried out by these sections concerns future directions of development of production engineering [1, 4, 9, 13, 16, 19], as well as the need and opportunities for human resource training [3].

Parallel to the work done as part of the activity of the sections of the PAS Committee for Production Engineering, many researchers carry out investigations, the results of which are presented at new scientific conferences, for example, ***The 2nd International Scientific Conference on New Trends in Management and Production Engineering – Regional, Cross-Border and Global Perspectives***, Cieszyn, 14-15 May, 2015 organized by the University of Dąbrowa Górnicza, Dept. of Management and Production Engineering, University of Žilina, Dept. of Managerial Theories and VŠB – The Technical University of Ostrava, Faculty of Economics. Another example of the conference for industrial engineers is the annual International Scientific Conference of PhD. students and young scientists **InvEnt** organized since 2006 by the University of Žilina in cooperation with other universities. In 2016 it will be the11th conference organized by 12 universities from Slovakia, Czech Republic and Poland.

Reports on many studies are published in international journals such as the quarterly ***Management Systems in Production Engineering*** [26] (published since 2011) and ***Production Engineering Archives*** [27] published since 2013 by the Institute of Production Engineering at The Częstochowa University of Technology **Magazine Proin** (earlier **Productivity and Innovation**) published since 1999 by the Zilina University in Zilina and also since 2005 at the Bielsko-Biala University [39, 40].

Since Production Engineering encompasses issues such as planning, designing, implementing and management of production and logistic systems and maintenance of their functioning, it can be understood as a set of socio–technical constructs that aim to integrate the employees, information, energy, materials, tools and processes during the whole product life cycle. Moreover, basing on technical, economic, human and social sciences, Production Engineering uses the know-how of telecommunication, informatics, innovativeness, management, public communication and human resource management. That is why it is crucial components are human–factor orientation and optimization of the work environment, which is the most important factor influencing the efficiency, costs and quality of labour.

“An important number of international institutions deals with Production Engineering problems, i.e. The Association for Operations Management, Production and Operations Management Society, American Society for Management Engineering, The European Industrial Research Management Association, The International Foundation for Production Research, The

International Academy for Production Engineering, German Academic Society for Production Engineering, Japanese Operations Management and Strategy Association, Chinese Institute of Industrial Engineers, Asia Pacific Industrial Engineering and Management Society, The Philippine Institute of Industrial Engineers, Brazilian Association of Production Engineering and Central European Institute of Technology. Poland has been represented since 1997 by the Polish Association for Production Management composed of 21 sections located at main research institutions all over the country" [3].

The vast majority of study reports in the field of Production Engineering concern dedicated solutions and selected innovative technological, organizational or social engineering solutions. Relatively few studies are devoted to the problems of Production Engineering (per se) clustered around topics such as Process Engineering, Quality Management, and Innovation Management [3], or the study of the effects of the cultural characteristics of different countries on the development of Production Engineering [6, 11, 12, 13, 18]. When we think about the potential directions of Production Engineering research that could contribute to the development of this discipline and ignore those lines of research which seek to delve deeper into the individual problems it encompasses related to the implementation of innovative manufacturing technologies (Digital Factory, Additive Manufacturing and 3D Printing), new materials, IT solutions, etc., it is worth concentrating on those prospective directions which follow from the previously presented systemic nature of the term 'production engineering'. From the systemic perspective, production engineering is a subsystem of a larger system, which entails it enters into interactions with other subsystems. Possible interactions can be associated with the restrictions imposed on the development of production engineering related to the requirements of globalization of enterprises and mass customization of production orders. An example of this is the currently observed tendency to expand product-service lifecycle design into a new discipline of Service Engineering. Service Engineering can be defined as a technical discipline concerned with the systematic design and development of product-services aiming at increasing the value of the overall solution along the lifecycle. Unlike traditional engineering whose aim is to improve only product functions, Service Engineering aims to increase the total satisfaction of customers/users and to match their specifications by improving both the functionality and/or quality of the product and the service contents during the provisioning process and along the solution lifecycle.

A further example of the systemic approach to Production Engineering is the distinction made between its end products: goods and services. Since a production system can be defined as an organization in an industrial sector whose aim is to create manufacturing goods and commodities and/or provide services, hence products and/or services provided by a company are similar often in terms of "*what* is done" but they are different in terms of "*how* it is done". This is illustrated in Figure 2.1, which shows a continuum of goods and services [34]. The potential behind the dual nature of the production process such a distinction creates, manifests, for example, in the fact that companies can change their profile (e.g., from the main producer to a subcontractor) or their line of business (e.g., to combine the roles of producer and distributor).

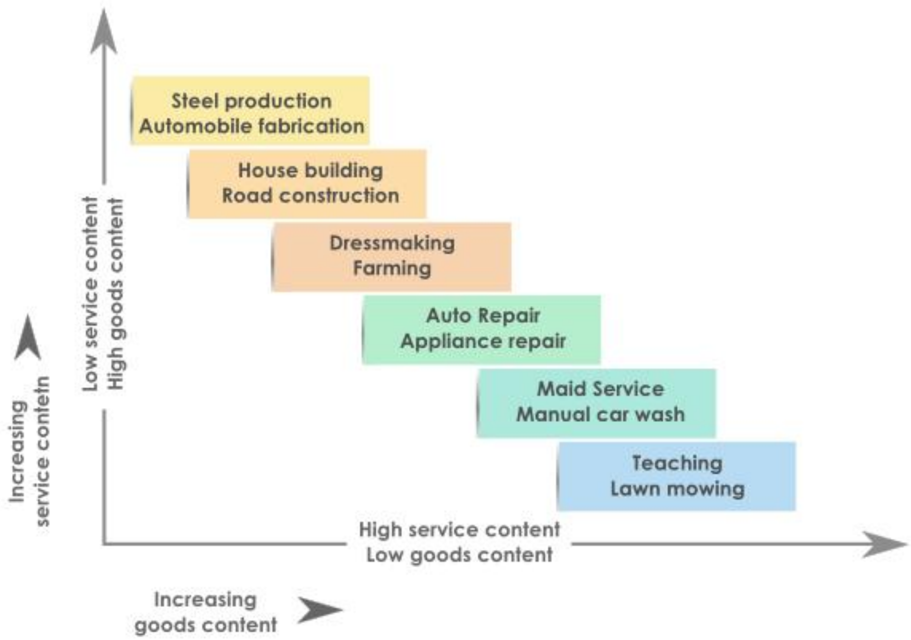

Figure 2. 1 -The goods–services continuum [34]

In particular, given the limitations associated with the globalization of companies, this entails development of research related to organizations and companies operating in network structures (the harbingers of this trend are various types of supply networks and transportation grid networks).

Another prospective direction of research is delineated by the limitations imposed by the requirements of sustainable development (sustainable manufacturing, sustainable production and consumption). The development of this direction is heralded by the germinating methodologies Industrie 4.0 and cyber-physical systems [32, 33].

A separate category of research is that associated with the constraints imposed by the increasing customization of production orders. The related requirements of quick response to orders and reliable fulfillment of commitments necessitate the search for new solutions to the organization of production. Well known examples of such solutions, which have been used for a long time and are recognized for their role in supporting the effectiveness of enterprises, especially small and middle sized ones (SMEs), are benchmarking and outsourcing. Other methods, such as coopetition, crowdsourcing, and trust management still require scientific and practical research in the area of their usefulness for SMEs. Coopetition occurs when companies interact with partial congruence of interests. They cooperate with each other to reach a higher value creation compared to the value created without interaction and struggle to achieve a competitive advantage. Coopetition takes place when companies that are in the same market work together in the exploration of knowledge and research of new products, at the same time that they compete for market-share of their products and in the exploitation of the knowledge created. Crowdsourcing can be applied for many purposes such as production (co-creation), availability of standby human resources, problem-solving in research and development, project or venture funding (crowdfunding), forecasting, organisation, tasks performing, innovation/idea generating, problem solving, classification, decision-making/support, or propagating information. In turn, trust management regards "the activities of creating systems and methods that allow relying parties to make assessments and decisions regarding to the reliability of potential transactions involving risk, which are bounded up with other parties (reliability assessment of other units) as well as to allow players and owners of these systems to increase and correctly represent reliability of themselves and their systems (building own reliability)" [5].

In the context of the discussed challenges of customization of orders, it is worth paying attention to study [3], whose authors note that: "Production systems expectations have evolved with changes in the consciousness of clients and their awareness of possibilities of raising their demands. Important and dynamic development of production systems starts with raising options for application of automation and information technology (Figure 2.2). For this reason, a single product or short series can be produced on individual demand without resigning from product quality (i.e. producing cars with equipment adapted to the client's needs)."

In summary, from the perspective presented here, production engineering research can be expected to develop in two basic directions: toward deepening the scope of the discipline specified in its definition, e.g. the creation of customized order engineering, or toward extending that scope, e.g., sustainable production engineering.

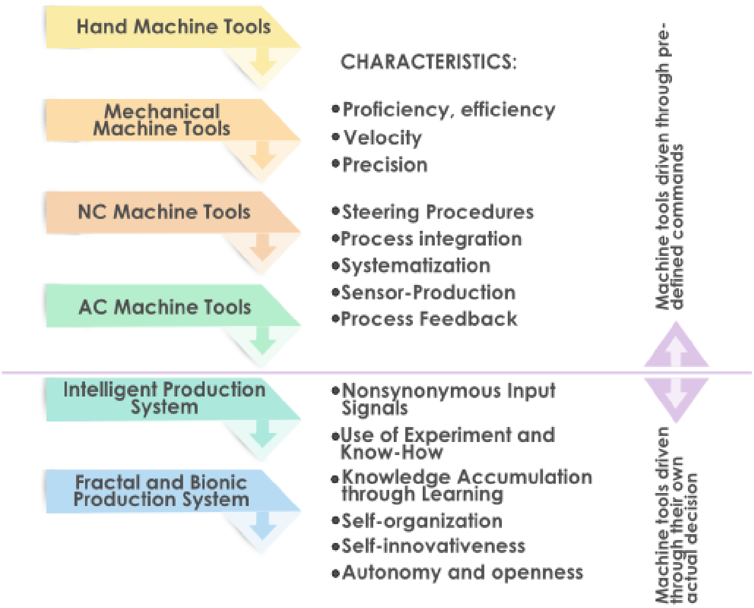

Figure 2.2 - Example of development of machining systems resulting from the development of automation and information technology [3]

2.3. Education – a voice in the discussion

The development of the means, methods and techniques of production engineering is not accompanied by equally dynamic changes in the education system. If education is understood as the processes of acquiring knowledge and upbringing as well as the development of skills, transfer of knowledge and development of specific qualities and abilities, and if production engineering can be seen as a combination of manufacturing technology with management science, then a production engineer typically has to possess a wide knowledge of engineering practices and has to be aware of the management challenges related to production. In order to be able to accomplish the production process in the smoothest, most judicious and most economic way, a production engineer has to have a theoretical and practical knowledge of a large number of separate problem-oriented methods and techniques and be aware of their mutual interactions influencing the whole production process.

As already mentioned, Production Engineering covers issues such as planning, design, implementation and management of production and logistic systems and maintenance of their functioning. These systems are understood as socio-technical constructs that aim to integrate the employees, information, energy, materials, tools and processes over the entire product life cycle. Production engineering is based on technical, economic, human and social sciences. It uses the knowledge of ICT, management, social communication and methods of stimulating employee creativity. This means that knowledge related to market requirements, new technologies, and the technical and organizational conditions affecting the course of production, maintenance and monitoring of products in use should be taken into account already at the stage of designing a new product. At the stage of manufacturing, a contemporary production engineer who works in a company should be able to take decisions related to the implementation of new technologies, introduction of innovations, management of integrated production systems, logistics and material flow; maintaining the continuity of work and high labour productivity; analysing production costs; maintaining the quality of products and services; work safety; environmental protection; the principles of crisis management, etc.

A model example of an academic program for production engineers, is the one offered by the University of Campinas, São Paulo, Brasil [28]. This 4200 hour full-time day program (289 ECTS credits), which can be completed in 10 semesters, assumes that "production engineering concerns the planning, design and management of sociotechnical systems, i.e., organizational systems involving people, materials, technologies, financial resources and the environment. Unlike professionals in the field of administration, production engineers receive solid training in the fundamental disciplines of the exact sciences (physics, chemistry and mathematics) and a broad range of specific engineering disciplines, together with disciplines in the fields of administration and economics. This broad training puts production engineers in a unique position compared with other graduates in professions and allows them to appreciate problems in industrial and other business environments from a global rather than a piecemeal perspective. Although they are not specialists in specific fields of engineering, production engineers are able to understand the root causes of industrial problems and identify the technologies needed to solve them. They therefore play an important role in the creation, implementation and dissemination of technological innovations. The specific areas of knowledge they work with include management systems overall, covering the planning and implementation of management information systems, industrial process control systems, technology management, quality systems and systems for improving efficiency. In view of these characteristics, it is hardly surprising that production engineers are some of the most sought after professionals for management positions in today's job market. Students who graduate as production engineers at the Limeira campus will have received training with various features that distinguish it from training offered on other programs. In addition to training in basic mechanical engineering and solid specific, modern, up-to-date professional training, the program seeks to stimulate creativity and self-confidence. Graduates will be fully qualified to plan and control production and to design work organization. The program aims to develop students' entrepreneurial spirit and their ability to manage resources" [28]. It is worth noting that the program Management and Production Engineering offered by Polish universities, whose core curriculum is the closest to the Brazilian model, is a 3,500 h two-stage program with courses taught over 7 semesters (210 ECTS points, stage 1 undergraduate program) plus 3 semesters (90 ECTS points, stage 2 graduate program).

The production engineer has to possess a wide set of skills, competences and attitudes based on market and scientific knowledge. These abilities are fundamental for the performance of coordinating and integrating professionals of multidisciplinary teams. The production engineer should be able to [14, 31]:

- **Scale and integrate resources.** Usually required to consider physical, human and financial resources at high efficiency and low cost, yet considering the possibility of continuous further improvement
- **Make proper use of math and statistics** to model production systems during decision making process.
- **Design, implement and refine products, services, processes and systems** taking into consideration the constraints and particularities of the related communities.

- **Forecast and analyse demand**. Select among appropriate scientific and technological knowledge in order to design, redesign or improve product/service functionality.
- **Incorporate concepts and quality techniques** along the entire productive system. Deploy organizational standards for control proceedings and auditing.
- **Stay up-to-date with technological developments**, making them available to enterprises and society.
- **Understand the relation between production systems and the environment**. This relates to the use of scarce resources, production rejects and sustainability.
- **Manage and optimize flow** (information and production flow).

As already mentioned, in Poland, historically, the first academic program devoted to Production Engineering, which best matched the profile of the discipline, was Management and Production Engineering. This degree program is currently offered by more than 30 Polish universities, with courses taught over 7 semesters (210 ECTS) – stage 1 leading to an undergraduate diploma in engineering, plus 3 semesters (90 credits) – stage 2 leading to a master's diploma. Depending on the type of university, students majoring in Management and Production Engineering are required to complete a 1–3 month apprenticeship. A graduate in Management and Production Engineering acquires advanced knowledge of production engineering in the automotive, precision, aerospace, machinery and electromechanical industries, including consumer goods, shipbuilding and printing industries. This concerns in particular the type of production in which automated and highly efficient processes use advanced material technologies (metal forming, casting, polymer processing, bonding), machining technologies (machining and non-conventional processing) and assembly technologies. Moreover, a graduate acquires advanced knowledge and practical skills in the field of organization and management. Students are prepared to lead teams and manage design units, economic units and personnel in industrial companies. To compare, a program in Industrial Engineering and Management offered by the University of Oulu in Finland [29] covers a similar array of subjects, with undergraduate studies taking 6 semesters (190 ECTS) to complete, and MA courses being taught over further 4 semesters (120 ECTS). Graduates can continue their studies in postgraduate programs leading to doctorates in technical sciences. There are many publications devoted to education in Production Engineering, including [8,15,16, 37, 38].

Currently, 15 Polish academic centres have the legal capacity to offer doctoral degree programs and conduct defences of doctoral dissertations in Production Engineering. Probably this year (2016), the Faculty of Mechanical Engineering of the Cracow University of Technology will be the first academic institution to be awarded the right to confer postdoctoral degrees in this discipline.

The earlier-mentioned series of 22 academic textbooks published in the years 2011–2014 meets the current needs of undergraduate and graduate students of Management and Production Engineering. Due to large interest, some of these books have already been reissued. Postgraduate students will have the opportunity to draw knowledge from the monograph *Inżynieria Produkcji Kompendium wiedzy*, which is planned to be published this year. Looking at the dates of the successive 'milestones' on the pathway to this monograph, it is easy to see that professionals who have erected those 'milestones' were educated in a variety of different disciplines, often quite distant from one another. University lecturers who teach courses in Management and Production Engineering, the authors of the textbooks and monographs mentioned in this chapter, and, finally, members of the PAS Committee for Production Engineering, who are responsible for the education of future production engineering personnel and researchers, have gained their experience specializing in different fields such as mechanical engineering, automation, IT, ergonomics, etc. **What has united them, enabling the creation and development of the new discipline, is the belief that expertise and experience in a single area are inadequate when confronted with the complexity of technical problems encountered in production today. They have been brought together by their conviction that the complex, systemic nature of the objects they want to shape requires a new, systemic approach combining knowledge of different areas, different experiences and skills.**

This means that the new generation of engineers and scientists will be able to look at the problems they encounter in a holistic manner, and thus to seek appropriate 'sustainable' solutions that will not require making numerous adjustments to the previously adopted solutions. What may guarantee development in this direction are new textbooks and teaching aids accentuating the need for a systemic approach to and/or systemic thinking about the challenges of production which are inspired by not always justified and often unbridled consumption. To meet the challenges of Production Engineering, understood as an interdisciplinary area requiring the collaboration of individuals trained in industrial engineering, manufacturing engineering, product design, marketing, finance, and corporate planning, it is necessary to implement a system of apprenticeships. A well-organized, well-conducted and appropriately assessed training practice is worth a thousand words heard in lectures and classes. Following the example of other organizations, such as the Accreditation Board for Engineering and Technology, Inc. [30], Poland should also introduce certificates confirming the qualifications of engineers in this discipline.

And, last but not least, just as it is difficult to speak of good alumni without good teachers, it is difficult to speak of good teachers without their will to master their discipline. Practice makes perfect – without continuous self-improvement (e.g., by using outsourcing) and without continuously relating one's own achievements to parallel achievements in other cultures and environments, it is difficult to gain mastery of one's discipline.

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3. **The future of production engineering –** Dariusz Mazurkiewicz

Product, process, organizational and marketing innovations are regarded as some of the main factors raising the competitiveness of an economy. To function properly, innovative manufacturing companies do not only need a properly functioning economic subsystem, i.e. an appropriate business environment, but also effective and efficient innovation-financing institutions and business support infrastructure institutions acting as intermediaries in the commercialization of innovations. What also plays a role is the proper functioning of the social subsystem – a culture of innovation and entrepreneurship in society and a social infrastructure, particularly a system of education and a science sector that meet the demands of knowledge economy. Proper functioning of enterprises also depends on an adequate quality of the spatial subsystem; in particular, companies need access to basic technical infrastructure and specialized innovation infrastructure [4, 10]. These issues raise a number of challenges for production engineering, at the same time constituting the future of this discipline when viewed from the perspective of innovative development and strategies for the development of production companies.

In recent years, companies have implemented many new technological solutions aimed at improving the quality of manufactured goods or limiting losses. On the one hand, this has been due to the new possibilities offered by production engineering technology, on the other hand, companies have been forced to use more and more modern technical means to face the challenges of constant competition, growing customer requirements and the pursuit of innovative products. The main aim of using the new technical means has been to achieve greater efficiency, and thus to reduce operating costs. As a consequence, machinery and technological equipment have become increasingly complex, putting growing demands on their users. This, among other things, entails the need to use appropriate methods and techniques to ensure the durability and reliability of entire, often very complex and sophisticated, production systems. Of course, it is not possible to discontinue further development of manufacturing techniques and technologies, which means that today's huge demands will soon become a thing of the past, a step in the history of the development of the innovative production company.

Production companies continually implement solutions associated with the use of, typically computer-aided, methods and techniques of automation of production, industrial diagnosis, monitoring of technological processes, etc. [1, 5, 9, 11, 12, 17]. Computer systems supporting production, quality management and process control, such as CAPPC (*Computer Aided Production Planning and Control*), CAM (*Computer Aided Manufacturing*), or CAQ (*Computer Aided Quality Assurance*), are used on a daily basis in many companies, similarly to CMMS (*Computer Maintenance Management Systems*) maintenance support systems. All of them, being typical computer support systems, are capable of collecting large amounts of data on the course of the technological process, the monitored technological parameters, failures and their identification, as well as repair work and maintenance actions. These *big data,* which are often underestimated by many managers, are an invaluable source of information which, when properly used in operational decision-making, can bring significant and tangible financial benefits at a negligible cost [3]. A good example here is provided by financial institutions, such as banks, which have mastered to perfection the ability to collect and process information concerning their clients, this way building effective marketing strategies. Annual profits generated by the banking sector are the best proof. The importance of the ability to efficiently manage production data is also borne out by recommendations of Frost & Sullivan's report [2], which shows that production in the field of advanced technologies and general production already account for 14% of data stored worldwide and that these data hold a huge potential for large-data-set-based and analytical solutions. In the case of the manufacturing industry, the authors of the report believe *big data* will become the global currency of the future.

In the case of production companies, a manager or an operator of a system which collects large amounts of different types of data is faced with the necessity to continually make decisions, observe and analyze changes in the parameters measured and predict the consequences of further changes in quality characteristics. Analyzing data generated by a typical diagnostic system, an operator has to deal with several problems – the substantial amount of data appearing every second of the system's operation and relating to a large and often variable number of objects, the high dynamics of change and the necessity to quickly analyze and validate signals. Not without significance are also randomness, interference, the vast complexity of problems, or the possibility of the occurrence of errors. Some systems, such as maintenance systems, additionally require the operator to make decisions under uncertainty, in situations when no information is available about the probabilities of the occurrence of the individual states (safety / danger / alarm), and one can only predict future values of the analysed signals, which, to make matters more complicated, form a discrete time series. The so-called information overload and difficulties in effective analysis and processing of collected data which require sophisticated tools, extensive knowledge and experience, represent a challenge to many companies. These issues are also an important area of innovation-supporting activities in production engineering.

Modern means of transmitting information, for example, enable effective monitoring of the state of machinery and equipment, and other computer-aided methods and techniques allow the processing of data using inference and forecasting, even in situations in which part of the values or states can only be described in highly imprecise verbal terms (e.g., low pressure, medium temperature, high consumption). A solution that guarantees a high efficiency and innovativeness of data processing is the use of automated decision support systems, whose task is to increase the efficiency and shorten the time of decision-making and to verify generated signals on the basis of relevant rules of inference. Tasks of this type can be carried out by an appropriate expert system based, for example, on forecasting of future values of the analysed time series with simultaneous verification of possible false alarms using rules of inference and the generated forecast values. Such an advisory (expert) system can support various activities, such as, for instance, diagnostic observation of the test object (in the case of complex monitoring systems). An advisory system usually integrates a few basic components, the most important of which are an inference engine, a knowledge base, a database and an explanation facility, as well as a dialog box, also referred to as a user interface. An expert system is designed to carry out specialized tasks which require professional knowledge and experience in its application. A corresponding computer program represents a level of experience and problem-solving skills comparable with the knowledge and experience of an expert in a well-defined field. A particularly important and difficult problem that has to be solved during the construction of an advisory system is the acquisition of sufficient knowledge for the system drawn from experts or from big data.

At this point, the reader will probably find that the solutions described are too advanced and significantly exceed the capabilities of a typical company which does not have its own R&D department. In addition, solutions of this type, due to the different characteristics and needs of each company, are not universal. Although, the market does offer industrial data archiving systems, their authors themselves mention in advertisements the increasing difficulties in managing large sets of process data and a high degree of complexity of processing the data into useful information. Such systems can only be used for archiving of data and simple data searches or trend analysis. Similarly, CMMS/EAM software available on the market merely enables reporting, based on which, the user has to predict future states or likely future occurrence of certain events on his own. This means these programs do not have the capacities that should characterize business intelligence solutions supported by industrial automation solutions for 21st century technology. This is because such solutions require individual implementation, and often long-term, multi-stage development in the broadly understood area of production engineering.

Therefore, to use the knowledge hidden in the large collections of technological data each company collects, managers have to change their way of thinking. In the first place, they have to become aware of the benefits of increasing the degree of advancement of production systems, particularly with regard to automated collection and processing of knowledge. It is also necessary to fit in the development strategy of a company, long-term, multi-phase development of the components of the production system (e.g., development supporting the maintenance of the system) integrated with other areas of the company's activity. Of course, all this should be done with the use of advanced IT tools. This way of approaching the problem is recommended, among others, in the Polish government's document on foresight of priority, innovative technologies for automation, robotics and measurement techniques. The authors of that study list the following priority technologies: modern methods and algorithms for modeling, control, and diagnosis of industrial processes; technologies used in knowledge engineering and expert decision support systems for integrated control and management; and measurement systems integrated with technological processes. Similar priorities are also mentioned in the National Foresight Program “Poland 2020", which emphasizes the need for the development of advanced information methods and technologies shaping the competitiveness of economy. The priorities include expert systems for the control of industrial devices and processes, and acquisition and representation of knowledge and analysis of knowledge using intelligent systems for supporting decision-making processes in economy. These issues are analyzed in detail in further chapters of this monograph.

The earlier-mentioned strategy of long-term, gradual development in the area of production engineering, based, among others, on knowledge engineering technologies designed to support the processing and efficient use of data, cannot be implemented with the sole use of the resources of a typical company. Innovation-supporting activities of this type should be conducted in cooperation with an experienced and competent research center, which requires another change in the way of thinking of the managerial staff. In the first place, managers have to become aware of the benefits for the development of the company resulting from such cooperation. This is easy inasmuch as a significant number of government and EU assistance programs within the new EU financial framework (until 2020) are based precisely on the promotion and financing of research and development studies carried out by companies in cooperation with research centers. Of course, particular support is given to priority areas, which include production engineering. Additionally, for the purposes of EU funding in 2014–2020, each region has identified its own, individual ‘smart specialization’, which is, among other things, the basis for obtaining financial support for research and development activities of companies under the Operational Programme Intelligent Development (OP ID), whose most important objective is to support research and development projects carried out jointly by businesses and the science sector and to implement the results of this research on the market. OP IE is intended to enable effective transition “from idea to market”, by transforming ideas into new products, services and technologies. Funds will be allocated to projects which fit in the concept of smart specialization, that is, are related to those fields of economy and science which hold potential for the development of countries and regions. Intelligent Development has the second largest budget among programmes for the years 2014–2020 and is the European Union's largest research funding program. The funds of the programme are intended to contribute to the development of innovation in the Polish economy, primarily by increasing companies' expenditure on R&D. The actions taken as part of OP IR will focus mainly on strengthening the links between business and science, thereby increasing the degree of commercialization of R&D in the country and their practical use in the economy, as well as on the support and development of innovative companies. Smart specialization means that activities and financial resources are to be concentrated on a limited number of R&D and innovation priorities indispensable for mobilization and use of endogenous growth potentials for the development of areas of economic activity that are vital to each individual province. For example smart specializations of the Lublin province [15] are innovations, computer science and automation technologies. Currently, these areas of economy and science are associated with intensive research and innovation; at the same time they enable the development of innovative products and services in various areas of the economy, which directly translates into a significant increase in the competitive advantage of enterprises implementing them. Both computer science and automation pervade many areas of science and technology, creating, as a result of technological convergence and integration, a new range of innovative products and services, also in the area of production engineering.

Innovative activities carried out by a company make up an extremely complex process, and innovation is regarded as one of the basic tools of stimulating development. However, only very few entrepreneurs recognize the importance of research and development, the role of their own human resources and their impact on the internal innovative activity, as a consequence of which, product innovations have a negligible share in businesses. If so, it is time for a change.

Another problem that requires a change in the way of thinking of managerial staff is cooperation in the field of innovation between enterprises and the research sector, which too often does not proceed in a manner that would be satisfactory to both parties. This is due to the existence of many barriers to cooperation [10], some of which are listed in the Introduction to this monograph. Each of the parties has its individual tasks to perform, which in the future will ensure the effectiveness of the research and implementation activities undertaken by them. Some of these tasks also concern the people who manage companies, their way of thinking, their expectations and the way they function in the area of innovation. Firstly, entrepreneurs still often understand the concept of *innovation* incorrectly, failing to see the importance of innovation-supporting cooperation among institutions, and the consequences this lack of understanding has at the company level. Innovation is a trendy, often overused concept, which, more often than not, is treated as a ‘key’ to obtaining attractive financing from external sources, mainly for investments in hardware. Unfortunately, companies spend only negligible sums on research and development, underestimating the importance of R&D for their current and future market position. Instead, they prefer to purchase finished foreign technologies and equipment – a decision that is burdened with low risk. In their activities, they mainly focus on the current situation (how to survive and stay on the market), failing to create long-term growth strategies that would be based on their own innovative products and services and which would provide a strong competitive advantage, also in the area of broadly understood production engineering.

Entrepreneurs have unjustifiably low confidence in the potential, knowledge and R&D capabilities of the scientific sector. They still cling to the stereotype of the scientific community being interested primarily in ‘science for science's sake’. The low level of confidence and a lack of a real partnership in mutual relations creates barriers to cooperation and undertaking of innovative projects. Entrepreneurs also show little interest in co-operative forms of economic activity and do not look for the maximum benefits that could be obtained from collaborative innovation projects. As a result, the possibility of forming network structures and the awareness of the benefits they may bring are very limited. The corporate sector is too often characterized by a lack of awareness of the vital role of innovation in economic development. Companies, being focused on current activities, do not create long-term development strategies and do not cooperate with other entities, thus failing to produce, on both the demand and the supply sides, effective innovative solutions supported by conscious knowledge of the complexity of the production systems operating in modern industry.

It is the complexity of production systems that necessitates the use of the achievements of computer science and management, and the need to develop modern production systems is driven, among other factors, by the desire to improve product quality, increase production efficiency, enhance availability and reliability of production systems and maximize performance and productivity while minimizing expenditure [5, 18]. In production engineering, a good example of an often underrated area of potential innovative growth of any company is maintenance. Until not so long ago, the role of maintenance services was regarded as subsidiary, and only recently, due to the gradually changing awareness of entrepreneurs of how important it is to ensure full reliability of a company's technical infrastructure, has maintenance been recognized as a key process in almost every business entity. Ensuring the reliability of the technical infrastructure poses many challenges to businesses, especially in the conditions of tough competition when continuous improvement of manufacturing systems, the development of technologies applied in them and automation of production determine the success of companies. Effectiveness of maintenance services depends on the quality and efficiency of the transmission of information processed on the basis of generated data. In addition, development of conceptions in the area of maintenance, such as TPM (*Total Productive Maintenance*), RCM (*Reliability Centered Maintenance*) and

CBM (*Condition Based Maintenance*) and the high expectations of achieving the target level of efficiency in the maintenance of machinery and equipment have prompted the creation of computer support tools for quick processing of data. Computer systems for maintenance and maintenance management have been used in response to the need of industrial entities to gain a competitive advantage in terms of increasing direct participation of maintenance costs in the company's variable costs, developing automation, and collecting and managing tacit knowledge, i.e. intuitive knowledge possessed by employees [1, 11].

Defining of the needs of industry confronted with the possibilities of building software tools contributed to the creation of specialized information systems for supporting maintenance (Fig. 3.1) called CMMS (*Computer Maintenance Management Systems*).

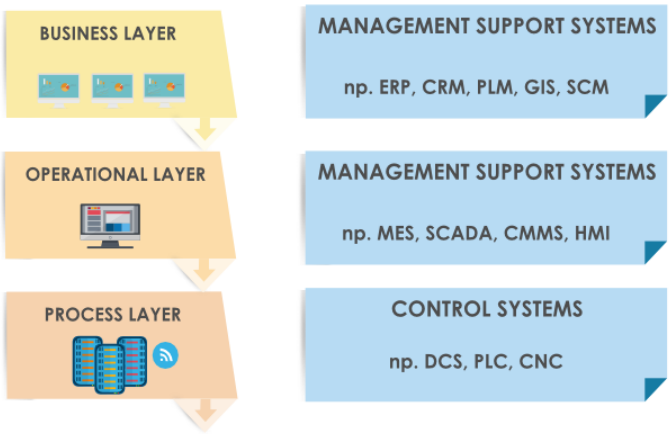

Figure 3. 1 Computer business management systems [7]

CMMS perform the following functions (Fig. 3.2) [7]:

- management of the inventory of company assets,
- maintenance planning,
- registration of events associated with production equipment (e.g., maintenance routines, repairs, failures),
- planning of maintenance budget,
- management of parts warehouses.

An introduction of a CMMS system in a company is connected with investment costs, which is why before a decision is made to implement the system, a detailed analysis of the potential benefits is carried out, mainly by determining the rate of return on investment. The dynamic development of CMMS is dictated by the continuous needs reported by companies which recognize the necessity of using computer support in solving the problems of plant maintenance reliability. The efficiency of such systems increases particularly when they are integrated with already implemented systems supporting business management. One example is integration of CMMS with ERP systems. In this case, cooperative interaction involves exchange of data on operating costs, warehouse inventories (and changes in them), personnel work times or planned maintenance. According to Żółtowski [18], introduction of a computer support system in a production engineering environment contributes, among others, to an approx. 17% reduction in investment in new parts, an approx. 19% reduction in material costs, and an approx. 20% improvement in equipment effectiveness.

Figure 3. 2 - Examples of functions of CMMS [7]

The continuity of the functioning of a business entity and a high reliability of technological equipment, which is usually highly complex and advanced, can only be ensured by using non-standard innovative technological and organizational solutions. Extremely effective solutions can be found in the area of advanced and fully automated knowledge and control engineering.

As mentioned in the first part of this chapter, such solutions use big data. Unfortunately, in most cases, the opportunities of innovative development in production engineering are used incompetently and ineffectively by those in charge, who fail to perceive the unique potential of innovation, which is within easy reach.

Regardless of the type of production, for many companies automation, next to computerization, will probably be the future of innovative development in production engineering; this especially concerns robotization of production systems. According to data of the Central Statistical Office quoted in report [6], in the year 2013, 12,031 robots and manipulators were used in Polish companies, an increase of approx. 10% compared to the previous year. The density of robotization in 2011 was on average approx. 14 robots per 10 thousand human workers employed in industry, a number that grew to 19 robots in 2013, which was still much below the world average, which in that period increased from 55 to 62 robots. The most industrialized countries of the world have robotization indexes of about 300 robots per 10 thousand human workers employed in industry. In view of this, more and more Polish companies decide to gradually introduce robots into production lines, availing themselves of the growing offer of industrial robots, particularly special-purpose robots with an extended arm reach or an increased positioning accuracy [6]. Also, the fast-improving quality and falling prices of industrial cameras encourage many innovative companies to use them as components of the production process, dedicated to monitoring the quality of production and feedback control of production [14]. An important area for innovative development is the joint use of vision systems and robots. As the authors of [13] believe, the progress in the integration of these two areas made in the recent years is an unstoppable trend. Increasingly shorter production runs and growing quality and reliability requirements mean that robotized workstations will have to be characterized by greater flexibility and reliability. Supplemented with functions of automatic data collection and processing, they will operate as autonomous machines in self-improving organization of production, thus becoming the basis for the fourth industrial revolution, i.e. economy 4.0, as discussed in the previous chapter.

To effectively respond to market needs, a modern production company must often produce goods in short runs, keeping prices at a mass production or high volume production level. The increasing demands on quality, reliability and innovativeness of products are not easy challenges to meet. To achieve these goals, it is not enough for companies to implement new solutions aimed at improving and optimizing the production process. As noted by Krzysztoporski [8], producers have to face the challenge of many new technologies, ranging from mobile solutions and analytics to the Internet of Things, nanotechnology and many others. The combination of these technologies makes the production industry become one of the most technologically advanced industries. To meet these challenges, managers must not only show greater creativity in solving problems [16], but also change their mode of thinking about innovation and engage in innovation-promoting activities with support from research institutions. A great opportunity for this type of activity is provided by government and EU support programmes for innovative development of businesses which cover a large part of the costs of such activities. If managerial staff know how to use their intellectual resources in creating a development strategy for their company, and build their new potential in cooperation networks with the support of external financing – they stand the chance of significantly strengthening the position of their companies for many years to follow.

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4. **Innovation priorities in production engineering in Poland and the EU** – Anna Rogut

The current priorities for innovation in production engineering are derived from the idea of sustainable development. This idea has its roots in the 1970s and the famous *Club of Rome* report on the limits to growth [26]. The main theses of that report, concerning essential resource constraints to further growth of the human population *and the global level of consumption*, were confirmed by many subsequent studies [22, 34-35, 38] and became an inspiration for the formulation of the concept of sustainable development.

The basic assumptions of sustainable development were defined in *the Rio Declaration* on Environment and Development [37] (UNEP 1992), and *Agenda 21* [36] (UN 1992). In Poland, these assumptions were incorporated into the following documents regarding strategies for the sustainable development of the country and its regions: *Trzecia fala nowoczesności. Długookresowa strategia rozwoju kraju* [25], *Strategia Rozwoju Kraju 2020* [29], *Koncepcja Przestrzennego Zagospodarowania Kraju* [27], *Krajowa Strategia Rozwoju Regionalnego* [28], *Strategia Zrównoważonego Rozwoju* [30] and *Polityka Ekologiczna Państwa* [31]. These documents stressed the importance of:

- creating conditions for the harmonization of socio-economic development with care for the natural environment;
- gradual elimination of processes and activities which are harmful to the environment and human health;
- promoting 'environmentally friendly' management methods and
- accelerating environmental restoration wherever there has been a violation of the natural balance.

In the European Union, the idea of sustainable development was elaborated in the strategy *Europe 2020* [6] and the accompanying documents, especially the projects *Resource-efficient Europe* [8-12] and *An Integrated Industrial Policy for the Globalisation Era* [7]. The former described a vision of structural and technological changes to be introduced by 2050 leading to a transition to a low-carbon, resource efficient and climate resilient economy. The latter, complementary document defined the scope of support for technologies and production methods that would allow EU countries to reduce the use of natural resources and increase investment in existing natural assets.

The latest emanation of this approach is the concept of circular economy, also called closed-circuit economy, whose tenets and priorities for production engineering are discussed in this chapter.

4.1. Circular economy

The development of circular economy was inspired by a specific combination of environmental and economic factors. Among the environmental factors, the key issues were the growing 'ecological overload' and the depletion of non-renewable natural resources (Figure 4.1). Ecological overload was measured in terms of the so-called 'ecological footprint' i.e. the size of the biologically productive area necessary to produce resources and products consumed by the human population, along with the size of the area needed for waste storage and absorption of emitted pollutants [39]. According to the latest estimates, the world's ecological footprint is one and a half times the size of the biologically productive surface of the Earth [19, 32].

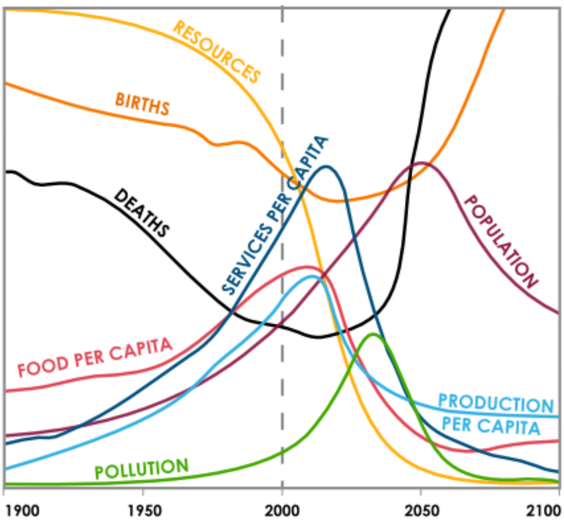

Figure 4.1 - Economic inspirations for circular economy [22]

Among the economic factors, the major role was played by the growing and practically unpredictable prices of resources and energy as well as the high and constantly growing competition and the accompanying stagnant demand (in many markets) [20]. All these factors resulted in a shift from the linear model of economy towards a circular economy.

The linear model of economy is based on the take – make – use – discard principle. By contrast, the circular model (Fig. 4.2) promotes an 'open' product life cycle and proclaims the principle of zero waste. According to this principle, every product has to be designed and manufactured in a way that enables its disassembly and return to the biosphere or reuse. Elements that are returned to the biosphere are operational components, (usually) manufactured from non-toxic and biodegradable ingredients, which are returned to the biosphere directly or in a cascade of consecutive uses. Elements that can be reused are long-term use components (such as motors) made from technical materials (e.g., plastics), designed in a way that enables their re-processing and repeated use [14].

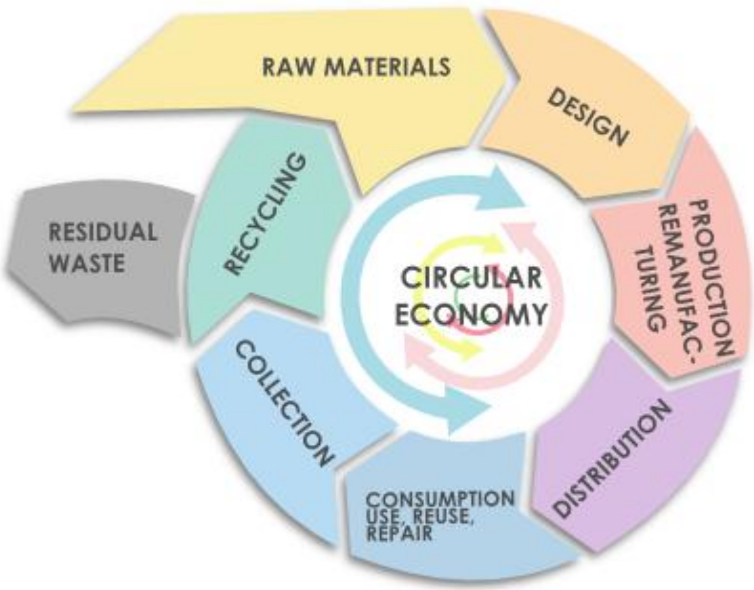

Figure 4.2 - The circular economy model [14]

The model of circular economy was complemented by a shift towards renewable energy and replacement of the concept of consumer with the concept of user. This latter change initiated the development of new types of relationships between suppliers and buyers of goods/services, replacing – wherever possible – sale and purchase with leasing, renting or shared use, and where not (yet) possible – encouraging buyers and obliging sellers/manufacturers to return/accept returns of goods which have ended their service life and send them for recycling/utilization [40, 41].

This has created a new context for action in production engineering, especially in those areas in which increasing of eco-efficiency and boosting of eco-innovation are significant driving forces (Box 1).

Box 1 : Eco-efficiency and eco-innovation

Eco-efficiency is a new management philosophy which encourages the search for solutions that deliver benefits of both economic (production of competitive goods/services) and environmental character (reducing environmental pressures and resource intensity of production). It is measured as a ratio between an environmental index and an economic index. There are four main types of this ratio:

- environmental productivity (EE_{EP}=production value/environmental impact), which specifies the value of production per unit of environmental impact,
- environmental intensity of production (EE_{EIP}=environmental impact/ production value), which specifies environmental impact per unit of production value,
- environmental improvement cost (EE_{EIC}=cost of improvement/environmental improvement), which specifies cost per unit of environmental improvement,
- environmental cost-effectiveness (EE_{ECE}=environmental improvement/ cost of improvement), which specifies achievable environmental improvement per unit of cost, or other sub-indices, for example, energy (primary or total), natural resources, capital, labor, etc.

Eco-innovation stands for all those innovations that lead to sustainable development by reducing environmental pressures and/or increasing the resilience of the environment to pressure and/or ensuring greater efficiency and responsibility in using natural resources [21, 24].

An additional context for action has been created by analyses of the diversity of ecological footprints left by different sectors. These analyses have shown that the sectors which are most burdensome to the environment (most energy-consuming; emitting the largest amounts of greenhouse gases, nitrogen and sulphur oxides, volatile organic compounds and atmospheric aerosols; and producing the largest amounts of waste, including hazardous waste) include:

manufacture of chemicals and chemical products, manufacture of metals and rubber and plastic products, food industry, mining and quarrying, manufacture of pulp, paper, coke and energy; water and air transport, and construction. Some of these sectors are sectors dominated by small and medium-sized enterprises (SMEs) or sectors in which SMEs play an important role. Other SME-dominated sectors which are burdensome to the environment are the production of electrical and optical equipment, the production of furniture, wholesale and retail trade, storage and communications [1].

All this has marked out the key priorities for action in production engineering for the next few decades. In the case of Poland, these priorities are all the more important since:

- according to the recent Eco-innovation Scoreboard [21], Poland is one of the countries which rank last in terms of intensity of implementation of eco-innovations (Figure 4.3) and,
- according to data from the European Environment Agency [3], it is one of the EU countries with the highest material intensity and energy intensity of production, and a weak dynamics of reducing industrial waste.

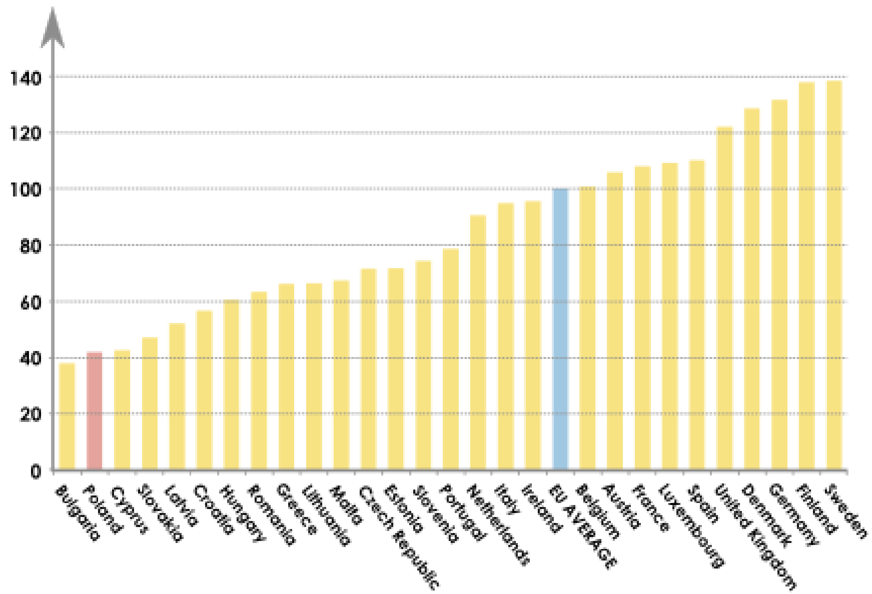

Figure 4.3 - Poland in the ranking of the Eco-innovation Scoreboard [21]

The position of individual countries on the Eco-innovation Scoreboard is based on an assessment of five groups of indicators:

- eco-innovation inputs,
- eco-innovation activity,
- eco-innovation outputs,
- resource-efficiency outcomes of eco-innovation and
- socio-economic outcomes of eco-innovation.

Eco-innovation inputs are measured in terms of: (i) public spending on environmental and energy R&D as a share of GDP; (ii) total number of R&D personnel and researchers per total number of employees, and (iii) total value of 'green' investments per capita. Eco-innovation activity is measured in terms of: (i) share of firms which have implemented innovation activities aimed at a reduction of material input per unit output as percentage of the total number of firms; (ii) share of firms which have implemented innovation activities aimed at a reduction of energy input per unit output as percentage of the total number of firms; and (iii) number of ISO 14001 registered organizations per million population.

Eco-innovation outcomes are measured in terms of:

- number of eco-innovation related patents per million population;
- number of eco-innovation related scientific publications per million population, and
- eco-innovation related media coverage per numbers of electronic media.

Resource-efficiency outcomes of eco-innovation are estimated on the basis of material[1], water[2], and energy[3] productivity and the intensity of greenhouse gas emissions[4]. Socio-economic outcomes of eco-innovation are estimated on the basis of: (i) share of exports of products from eco-industries in total exports; (ii) share of employed in eco-industries and circular economy in total number of employees across all companies, and (iii) share of revenue in eco-industries and circular economy in total revenue across all companies [21].

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[1] GDP / domestic material consumption.
[2] GDP / domestic water consumption.
[3] GDP / domestic energy consumption.
[4] $CO2$ / GDP.

We are also among countries which leave a relatively large ecological footprint. To see this, it is enough to compare the size of the ecological footprints left by companies operating in the sectors exerting the greatest pressure on the environment. Also, comparisons among EU countries show that Polish companies operating in these sectors, especially smaller firms, exert more pressure on the environment than companies operating in other countries. This indicates that Polish companies are characterized by a significantly lower eco-efficiency than their counterparts in other countries, which translates into their lower competitive position in three ways. First, they lose their low-cost advantages as they have to increase production costs wanting to implement current and future economic instruments designed to encourage the transition to more sustainable patterns of development. Second, they fail to gain technological advantages. Thirdly, they fail to build image advantages (as they do not adhere to the principles of sustainable development).

4.2. Priorities for production engineering

Circular economy, and more broadly – sustainable development, have become the content of one of the pillars of *Europe 2020* strategy, dedicated to sustainable development [6]. The achievement of the goals related to this aspect of the strategy significantly depends on technological development, oriented towards increasing resource efficiency [38, 39]. Some go as far as to claim that this development will result in 'green revolution' and the next wave of innovation (Fig. 4.4).

Aspirations for such a revolution are manifest in the research priorities for production engineering listed in the flagship initiatives under the *Europe 2020* strategy, especially *A Resource-efficient Europe* [8] and *An Integrated Industrial Policy for the Globalisation Era* [7].

The project *A Resource-efficient Europe* aims (among other things) to outline the vision of structural and technological changes that will have to take place by 2050 to achieve a shift to a low-carbon, resource efficient and climate resilient economy. The project, hence, points to research priorities that will lead to decoupling of economic growth from resource use and result in a transition to a low carbon economy, better use of renewable energy sources, increasing energy efficiency and modernization of transport (Box 2).

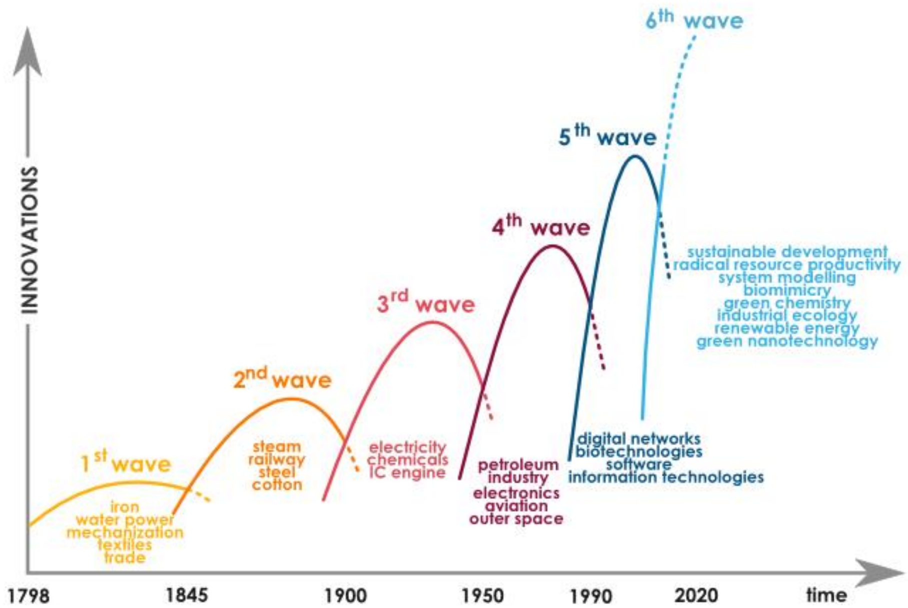

Figure 4.4. Waves of innovation [23]

Box 2: ***Resource-efficient Europe***

Priorities for production engineering [8]:

- improvements and more radical changes in energy, industry, agriculture and transport technologies, including low-carbon technologies and recycling,
- optimization of production processes,
- improvement of design of products and services,
- new methods of reducing inputs, minimizing waste, and improving management of resource stocks,
- new management and business methods,
- new logistics management methods,
- new products and services, and new patterns of consumption,
- alternatives to fossil fuels for each of the sectors of economic activity, and technologies, processes, products and management methods boosting energy efficiency,
- technologies, processes and management methods increasing water efficiency and efficient use of water resources,

- technologies, processes and management methods reducing resource intensity of production and increasing the efficiency of use of other resources (besides water),
- effective management and monitoring.

A more detailed description of these priorities can be found in *An integrated industrial policy for the globalisation era* [7], which lists technologies and production methods that can help reduce the use of natural resources and increase investment in the EU's existing natural assets. These technologies, reffered to as key enabling technologies (KETs), include nanotechnologies, micro- and nanoelectronics, advanced materials, photonics, biotechnologies and advanced systems for industrial processing [9, 15]. KETs (among others):

- create the possibility of developing smart nano and micro-devices and systems, and open the way to breakthroughs in areas such as healthcare, energy, environment and manufacturing;
- they have an extremely wide range of applications in all goods and services that require the use of intelligent control systems, especially in the automotive, transportation, aviation and aerospace industries as well as in the energy sector (management of energy production, storage, transport and consumption through intelligent electrical networks and installations);
- they pave the way for progress in many different areas, such as aerospace, transport, construction and health care. Advanced materials facilitate recycling, lowering carbon emissions and the demand for energy and raw materials that are scarce in Europe;
- they provide the technological basis for economical conversion of sunlight to electricity and a variety of electronic components and equipment such as photodiodes, LEDs and lasers;
- they create conditions for the use of alternative, sustainable and less environmentally harmful industrial and agri-food technologies, thus promoting gradual replacement of non-renewable materials currently used by various industries with renewable materials, etc.

Characterized in this way, these technologies mark out the research priorities for production engineering, which are all the more important as they are part of a special development strategy of the European Commission. This strategy places (among others) an increased focus on:

(i) innovation for KETs; (ii) technology transfer and supply chains; and (iii) joint strategic programming and demonstration projects. An integrated framework for KETs aims to (among other things) ensure coordination of EU and national activities so as to achieve synergies and complementarities between those activities and the pooling of resources where necessary and establish an external KETs Issues Group that will advise the Commission on KETs-related policy issues [5, 13].

Another group of priorities, this time related to a low carbon economy and energy efficiency, is defined in *A roadmap for moving to a competitive low carbon economy in 2050* [2, 10]. These priorities cover all those areas of research/technology that will make it possible to dramatically reduce emissions of greenhouse gases (Figure 4.5), in particular:

- Research/ technology related to electricity. This research is expected to lead to an estimated increase of the share of low carbon technologies in the electricity mix from around 45% today to around 60% in 2020, including through meeting the renewable energy target, to 75 to 80% in 2030, and nearly 100% in 2050. The expected outcome is an almost complete elimination of CO2 emissions by 2050. Given this, another priority is research related to the growing use of renewable energy sources. And because many of them are characterized by a variable output, investments are also necessary in research in the area of smart grids.

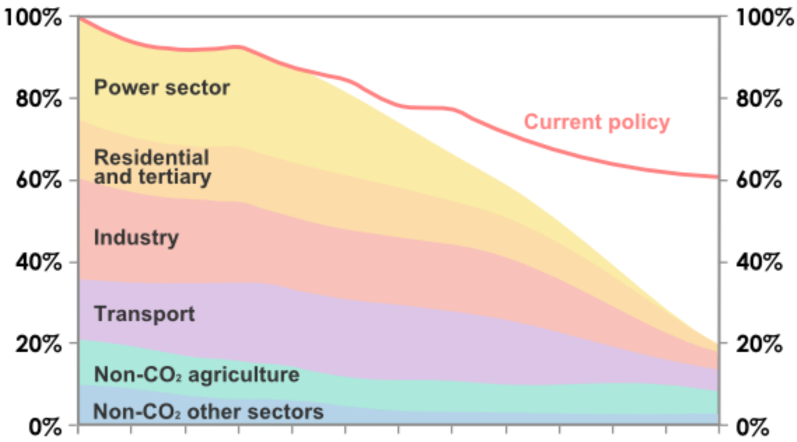

Figure 4.5. Schedule of reducing domestic greenhouse gas emissions in the EU [10]

- Research supporting the transition to a more efficient and sustainable transport system, including in particular: (i) new engines, materials and structures; (ii) new fuels and propulsion systems; (iii) better information and communication systems.
- Research leading to the improvement of the energy performance of buildings, which is all the more important since new buildings built from 2021 onwards will have to be nearly zero-energy buildings.
- Research in the area of more advanced resource and energy efficient industrial processes and equipment, increased recycling, development of CO2 capture and storage technologies as well as abatement technologies for non-CO2 emissions (e.g. nitrous oxide and methane).

The catalogue of priorities is continued in the document *Towards a circular economy: A zero waste programme for Europe* [14, 18]. The problems discussed in this document include, among others, areas such as [14, 16, 18]:

- reducing the quantity of materials required to manufacture a particular product/deliver a particular service (lightweighting);
- durability of products and lengthening products' useful life;
- reducing the consumption of energy and materials in production and use phases (efficiency);
- reducing the use of materials that are hazardous or difficult to recycle in products and production processes (substitution);
- designing products that are easier to maintain, repair, upgrade, remanufacture or recycle (ecodesign);
- recycling of critical raw materials, which include antimony, beryllium, borates, chromium, cobalt, coking coal, fluorspar, gallium, germanium, indium, magnesite, magnesium, natural graphite, niobium, phosphorite, platinum group metals, heavy rare earth metals, light rare earth metals, silicon, and tungsten;
- the use of by-products for production (industrial symbiosis);
- conversion of waste (e.g., municipal, construction, food waste and hazardous waste) and recyclable materials obtained from plastics, glass, metals, paper, wood, rubber and other recyclable materials into resources, and introducing innovations in recycling and reuse ;
- development of business models encouraging wider and better consumer choice through renting, lending or sharing services as an

alternative to owning products, while safeguarding consumer interests (in terms of costs, protection, information, contract terms, insurance aspects, etc).

Updated research priorities for production engineering are listed in the document *Circular Economy Package 2.0: Some ideas to complete the circle* [4]. The areas mentioned there include, among others:

- durability and reparability of products: (i) systems to rate the durability and raparability of products and establish standards to measure these aspects; (ii) design requirements for products guaranteeing a minimum life time and ensuring non-destructive disassembly of products for reuse of each and every component in a new production process; and (iii) extension of minimum legal warranties to up to 10 years while ensuring full functioning of the products;
- reinforcing the demand side: (i) resource-efficient parts and consumables; (ii) product life cycle; (iii) organization of customer services in line with the principles of circular economy; (iv) hazardous and rare substances, and (v) new uses for old products and recycling of waste products;
- product design: (i) modularity of products and processes; (ii) possibility of disassembly of products for maintenance, repair, refurbishment and reuse; (iii) effective protection of personal data in consumer electronics throughout a product life cycle; (iv) the possibility of using recyclable materials; (v) material homogeneity of products, facilitating their disassembly and segregation of waste; (vi) technologies for combining different materials which facilitate their later separation into components consisting of homogeneous materials;
- waste: (i) processing of waste and recovery of raw materials from waste; (ii) logistics of sorting, collection and receipt of used goods and their components.

Similar research priorities for production engineering are defined in the Polish strategic documents, especially *Polityka Ekologiczna Państwa* (National Environmental Policy) [31] and *Krajowy Program Badań* (National Research Programme) [33]. The former focuses on:

- the principles of application of best available techniques (BAT);
- the need for a thorough restructuring of the production and consumption model towards improved energy and resource efficiency

and minimization of the negative health-related and environmental impact of all forms of economic activity and civilizational development;

- the need to use good management practices and environmental management systems, which – in the area of industry – involve (among others) the implementation of cleaner production methods, improvement of energy efficiency, use of alternative materials and renewable energy sources; reduced water use, improvement of management and control of production processes, implementation of life cycle-oriented policies to reduce the quantity of waste, reduction of the threat of catastrophic industrial failures and the development of environmentally safe methods of management of different categories of waste.

The latter document, *Krajowy Program Badań* (National Research Programme) [33], draws special attention to two strategic directions of scientific research and development: new energy technologies and modern materials technologies. The most important aspects of new energy technologies include:

- improvement of energy efficiency and reduction of the demand for fuels and energy;
- reduction of greenhouse gases, dust and waste products;
- design of new generations of materials for electric power transmission and distribution, and new design solutions for upgrading the national electricity system;
- alternative sources of energy and user- and environment-safe technologies;
- clean coal technologies for the production of electricity, synthetic fuels and chemicals;
- technologies using unconventional energy resources;
- nuclear power and related materials technologies, electrical engineering, automation in areas such as fuel cycle, generation IV reactors or the development of probabilistic models and software, and
- hydrogen energy industry.

Among advanced materials technologies, a leading role is played by:

- new, effective technologies for producing metals and metal alloys, chemical compounds, functional composite materials, nanocrystalline, layered and graded materials, usable ceramics, glass materials, refractory materials, polymeric materials, new semiconductors, modified wood, and composite lignocellulosic materials;

- materials with new, unique and designed properties, and specific applications in various areas of life and economy, contributing to sustainable development;
- nanotechnologies for the production of functional materials for applications in computer science, electronics, photonics, power industry, chemical industry, engineering industry, food industry, clothing industry, construction-based industries, biomedical engineering as well as transport, agriculture and defense industry;
- materials and technologies related to the storage and transmission of energy and photonics used in long distance, reliable and efficient information transmission systems;
- new semiconductor materials (e.g., graphene), single crystals, active glass and laser ceramics;
- energy conversion technologies based on power electronics using classic and new semiconductor compounds (silicon, new forms of carbon, wide band-gap semiconductors, organic semiconductors), composite materials with strong magnetic, piezoelectric, thermoelectric and luminescent properties, electrode materials for new type batteries, hydrogen absorbing materials;
- new, health and environmentally safe, high durability building structures and materials;
- new materials and technologies for the reconstruction and strengthening of bridges (including historical bridges);
- unique and improved biocatalysts and metabolites for applications in the pharmaceutical and food industries and environmental protection, as well as environmentally and health friendly biodegradable and biocompatible biopolymers;
- biodegradable lignocellulosic materials.

4.3. Conclusions

Fast and effective implementation of the principles of sustainable development creates the foundation for building a strong competitive position of individual companies and entire economies. This is why production engineering becomes particularly important in areas related to the development of resource-efficient and zero-waste materials, processes and products. These areas include, in particular, organization and management of production, including design of materials, products and systems; engineering of manufacturing processes, including chipless forming processes; optimization of supply chains and logistics, including optimization of material flow; innovation management, including design and development of innovations; and efficiency, productivity and organization of enterprises, including the development and implementation of new business models. Researchers in these areas can count on broad support from a number of actions taken at EU and national levels. These initiatives include:

- Innovation Partnerships for meeting resource efficiency goals, e.g., regarding water, raw materials, and productive and sustainable agriculture;
- Joint Technology Initiatives or other forms of private–public partnerships, as well as Joint Programming Initiatives that pool national research efforts in areas of resource efficiency;
- stimulation of eco-innovation;
- focusing of EU research funding (EU Horizon 2020, cf. Box **3**) objectives, supporting innovative solutions for: sustainable energy, transport and construction; management of natural resources; preservation of ecosystems and biodiversity; resource efficient agriculture and the wider bio-economy; environmentally friendly material extraction; recycling, re-use, substitution of environmental impacting or rare materials, smarter design, green chemistry and lower impact, biodegradable plastics with less impact on the environment.

Box 3. Horizon 2020, the new framework programme for research and innovation

Horizon 2020 is the biggest programme for research and innovation in the history of the EU. It brings together three previous EU research support programmes: (i) 7th EU Framework Programme for research, technological development and demonstration activities; (ii) the part of the Framework Programme for Competitiveness and Innovation (CIP) dedicated to innovation, and (iii) the activities of the European Institute of Innovation and Technology (EIT). The structure of the programme is based on three basic, mutually reinforcing priorities: (i) excellent science; (ii) industrial leadership, and (iii) societal challenges, supplemented by additional specific objectives: spreading of excellence and widening participation; science with and for society; and activities of the Joint Research Centre and the European Institute of Innovation and Technology. Detailed information about this programme is available at: http://ec.europa.eu/research/participants/portal/desktop/en/home.html and www.kpk.gov.pl.

Among national initiatives, worth special attention are strategic research and development programmes, especially the newest, TechMatStrateg programme dedicated to modern materials technologies[5] and numerous joint ventures, such as GEKON, oriented towards the development of environmentally friendly technologies[6].

Each of these initiatives is ultimately aimed to facilitate both the development of innovative models for the circular economy, and maintaining a high competitive position of the Polish and EU economy [11].

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5. Methods of implementing innovation in a production company – Anna Rudawska

5.1. Motives of implementing innovation in a company

Main motives of implementing innovation in different areas of the enterprise are activities [28] that result from a reaction to changing conditions, trends and activities of external and internal environment, and especially from economic changes (Box 1).

Box 1. ***Motives of implementing innovation***

Motives of implementing innovation [8,20,28]:

- Improve and modernise manufacturing processes,
- Modernise the technical equipment,
- Improve productivity,
- Increase effectiveness and quality of work,
- Increase adaptation of the enterprise to closer and distant environment,
- Improve the quality of goods,
- Increase competitiveness (in the aspect of quality, price, quantity and properties),
- Increase export capacity,
- Increase efficiency and effectiveness of various activities of the enterprise,
- Improve organisation and methods of work,
- Improve operational safety conditions.

The motives of implementing innovation can be **positive** (based on benefits arising from execution of innovative projects) or **negative** (arising from the necessity of executing these projects) [18].

The common opinion is that the most effective reason for implementing innovations is **coercion**, which is created when the existence of the enterprise is threatened in competitive conditions. Enterprises that do not implement innovation do not survive on the markets, losing the fight with competition over time [18]. One of the most important economic aspects is **competitiveness**. Innovation is considered to be the key to competitiveness. As far as the rate of changes in technique, technology and organisation is concerned, enterprises that are capable of introducing innovative change will only survive on the market.

The main incentives for Polish companies to implement innovation is competition pressure and wish to remain on the market [9]. An increased interest in innovative activity and cooperation is mostly related to the enterprise's expansion onto new geographical markets as well as with the expansion of foreign companies that are more competitive and able to use their competitiveness in a given industry. Enterprises learn how to better manage their potential, yet they still underestimate the role of innovation in increasing competitiveness. Another barrier is also insufficient knowledge about the core of innovation, its types and sources [22].

In order to be highly competitive, the company needs to undertake many activities, which have been described in the Report on Innovativeness of Polish Economy of 2009 [15]. From among these activities, the companies chose: market share (66.7%), introducing additional product range (40.5%), access to a new local market (31.0%), extending the main product range (26.2%), winning a new foreign market (23.8%), improving product quality (19.0%), complying with EU standards (19.0%), exchanging the existing products for new products (14.3%), maintaining market share (14.3%), reducing production costs (11.9%), improving conditions of work (11.9%) and the requirements of natural environment protection (4.8%).

5.2. Sources of innovation in a company

Some authors believe that **the source of innovation** can be everything that inspires a man to make changes [21], and each innovation has its source (or place in which it was initiated), idea (that became inspiration) and causes (that trigger a given phenomenon) [10]. The source of inspiration can be the environment that stimulates the processes of changes, making it possible to creatively react to the changing surroundings.

Common sources of innovation are **opportunities** that arise due to scientific progress. A new scientific know-how is a base of innovation, creating an area that presents new chances [27].

According to J. Penc [19], the source of innovation can be everything that generates ideas, concepts and projects, and that can become the cause of searching for and undertaking projects, and next implementing and developing these projects (Fig. 5.1).

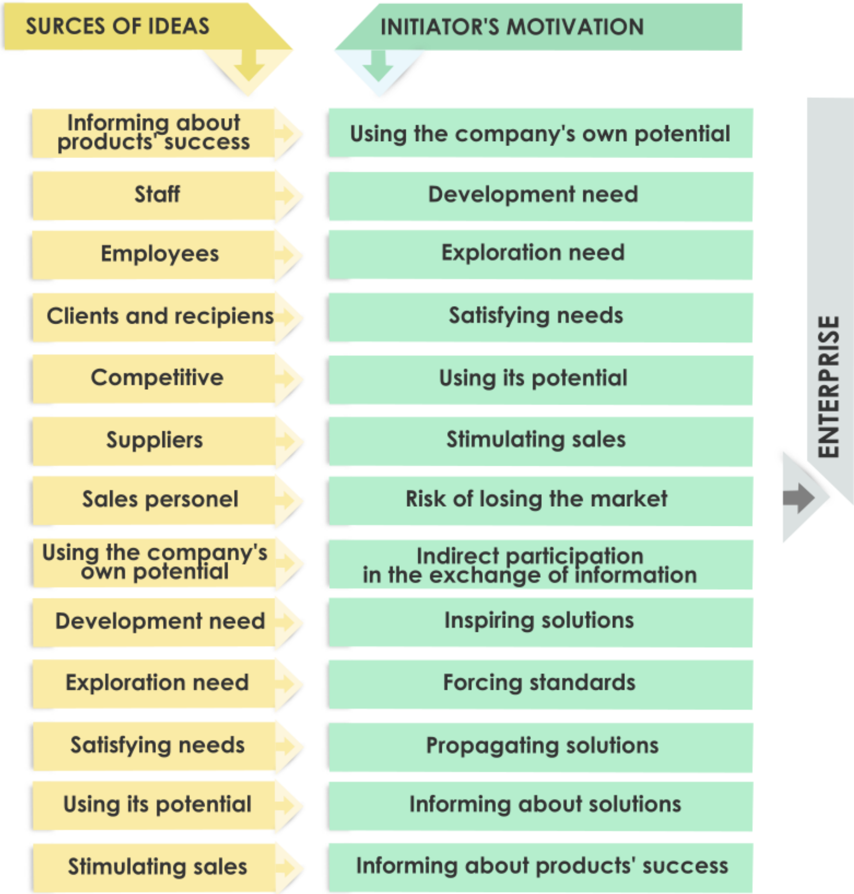

Fig. 5.1 - Sources of innovation for innovative processes in the enterprise ***(compiled on the basis of [19])***

Need is yet another source of innovation. The proverb: "necessity is the mother of invention" renders the core of innovation, as you can say that innovation is a response to a real or perceived need of change [27]. Initially, innovation was caused by unsatisfied fundamental needs: food, clothes, shelter and safety. Now, the motives are very similar, although the needs and extent of their satisfaction are different.

Scientific inspiration, which constitutes a fragment of other sources, is an important source of innovation. Scientific progress brings new opportunities that make a common source of innovation.

There are many criteria of classifying innovation sources, yet the most popular is the division into innovation sources [10, 24]: internal (endogenous) and external (exogenous). An example of innovation sources classification, based on the above division, is presented in Fig. 5.2.

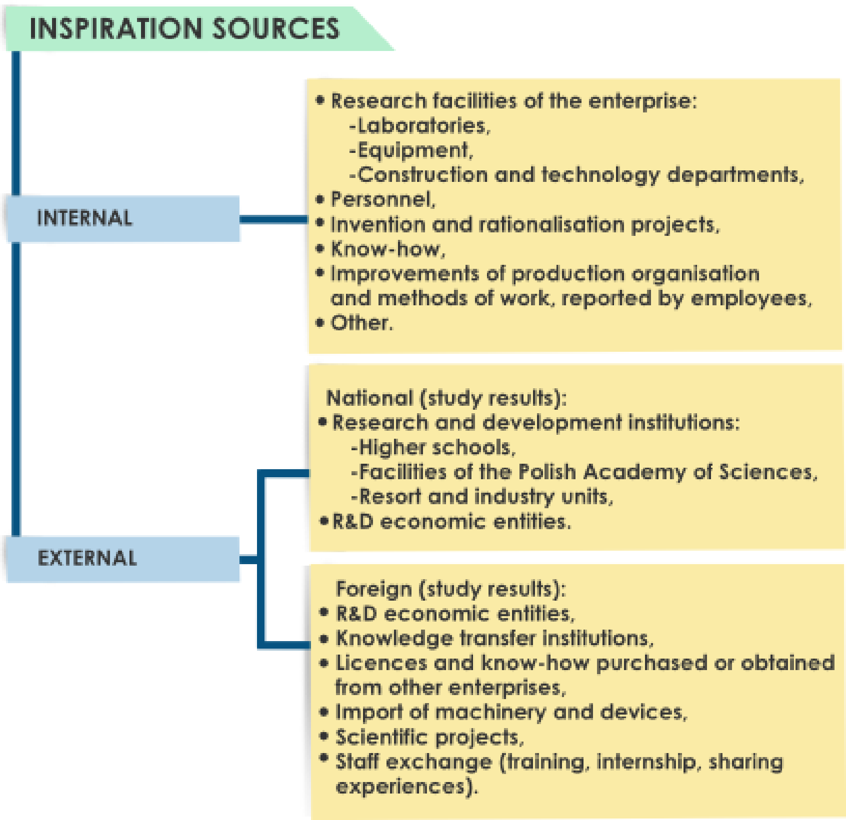

Fig. 5.2 - Examples of internal and external sources of innovation

Internal sources of innovation are the sources inside the enterprise, and, most of all, results of the works of its own research facilities (Box 2). The source of innovation are also all kinds of improvements reported by employees working in e.g. rationalisation teams, quality teams or individually, in effect of reacting to various external and internal changes. They are beneficial for the enterprise for financial reasons.

Box 2. ***Own study***

Own study as a source of internal innovation is mostly used by large enterprises as a basis for launching new products or technologies. Own study is mostly conducted in separate organisational units. A research unit has a service function for other organisational units - and especially for the marketing unit that defines the needs of the customers, as well as production unit, which uses technological solutions prepared in the research unit [24].

According to the data included in the Report on Innovativeness of Polish Economy of 2009 [15], the main internal source of innovation is enterprise owners (in 64.3% of the examined companies of the small and medium-sized enterprises sector) and management (in 47.6% of the examined companies of the small and medium-sized enterprises sector).

Other internal sources of development incentives are: research and development in the enterprise (16.7%), information received from the marketing department (14.3%), creative employees, or elaborations prepared by internal organisational units. External sources of development incentives are mainly clients (45.2% of all examined enterprises), fairs and exhibitions (16.7%), and conferences, seminars and training (11.9%) [7]. Results of the studies included in the Report [15] indicate that internal factors and resources of the enterprise have a crucial role for establishing innovativeness in the small and medium-sized enterprises sector [25].

As for external sources, their use allows the enterprise to quickly improve the technological level of production and achieve economic results in a relatively short time. Databases, containing various information that contributes to the process of innovation, make an external source of innovation (Box 3). The databases provide information about:

- scientific institutions,
- scientific expertise conducted in Polish scientific and research & development units,

- scientific, as well as research and development works,
- consulting and decision-making institutions,
- conferences, fairs and exhibitions,
- data concerning scientists,
- financial sources for innovations,
- initiatives for academic entrepreneurship and various projects and programmes promoting innovation in Poland,
- export, cooperative, franchising and technological offers exchanges,
- solutions offered by different suppliers,
- availability of new technologies and products of various areas of industry and other.

Box 3. ***Databases***

In Poland, just like in highly developed Western countries, a support system for innovative companies is being created. The system combines public institutions, higher schools, NGOs and private companies. Specialised Internet portals, including **Innovation Portal,** as well as conferences on implementing innovation, organised in various places[7], become important sources of information.

When taking up the challenge of introducing changes in an enterprise, it is worth using external support of competent advisers in order to save time and money. When considering implementation of innovation in your enterprise, it is worth using the possibilities offered by **Polish National Innovation Network** (Krajowa Sieć Innowacji - KSI)[8].

The main sources of information about innovations for entrepreneurs are among others [30]:

- Online industry and information websites, such as e.g. Innovation Portal, technologies of the Ministry of Economy, CORDIS, Europe Innova, European Cluster Observatory, Innovation Tools.
- International organisations, such as UNIDO (United Nations Industrial Development Organization) and OECD.
- Publications prepared by public institutions, such as publications of PARP (Polish Agency of Enterprise Development).

[7] http://www.pi.gov.pl/
[8] http://ksu.parp.gov.pl/pl/

- Industry fairs and expositions, as e.g. Technicon Innovations fairs, Brussels Innova or global exposition EXPO 2010.
- Databases of the Patent Office, scientific literature, technical magazines, scientific reviews, professional periodicals, e.g. Chemical Abstracts,
- Private companies providing services of technical information, organisational audit, infobrokering, etc.
- Statistical data, such as Innovation Union Scoreboard or GUS (Main Statistical Office) reports.
- Designing offices or design consulting offices.
- Legal and financial consultancy offices, innovation brokers.
- Trade and professional associations, e.g. Association of European Chambers of Commerce and Industry Eurochambers, Polish Business and Innovation Centers Association in Poland, or The Polish Chamber of Commerce.
- Brokers and consultants in technology, patents and licences.
- Trade and investment promotion departments in embassies.
- Higher schools and other academic institutions, personal contacts.
- Consultancies specialising in process reengineering, organisational changes, etc.,
- Business environment institutions, including science and technology parks, business incubators, technology transfer centres, EU research programmes contact points, Innovation Relay Centres – IRC).

P.F. Drucker [6] points to two areas in which the sources of innovation are rooted. The first area is the enterprise and the sector in which it is active, and the second is a broadly understood external environment of a business organisation. Innovation mostly means tracking seven sources of chances for innovation [6]. In accordance with the above, we can differentiate the following sources promoting innovation, with reference to the enterprise area (irrespective of enterprise kind):

- unexpected - unexpected success, unexpected failure, unexpected external events,
- clash between reality and its imagination,
- innovations stemming from process needs,
- surprising changes in the structure of industry or market.

The sources of innovation, based on external business environment, comprise:

- demography (changes in population),
- changes in perception, moods, or values,
- new knowledge, both in exact science and in other sciences.

Moreover, the presented sources of innovation processes in an enterprise are complementary. The sources of innovation can also be divided into [25]:

- **Demand** – which occur when there is an initial need of change in a given area and a proper solution must be found to satisfy that need.
- **Supply –** which occur when there is an initial solution that is next tried to be applied.

The increased innovative activity and cooperation is mostly connected with the enterprise's expansion onto new geographical markets and participation of foreign enterprises that are much more competitive than Polish enterprises and able to use their competitiveness on the market [4].

Now all enterprises, even the smallest ones, are under extreme pressure of innovation, very often in many areas at the same time (new products, techniques and technologies, organisation, relations with partners, etc.). The efficiency of entrepreneurs in this field depends on their competences, management abilities and strategies they adopt.

The environment in which the companies function, and especially the policy and initiatives of public authorities that are responsible for creating favourable conditions for innovative entrepreneurship, is equally important. The Report on Innovativeness of Polish Economy of 2012 [23] showed several directions of supporting the environment of enterprises that want to launch various innovations (Box 4).

Box 4. ***Directions of action***

Directions of action - European challenges, e.g. [23]:

- What should be done in the European Union is unification of innovation incentives in the tax system and in instruments motivating higher schools and R&D institutions to more intensive business cooperation.
- Horizontal policies should be considered in combination with sector and regional policies in order to support the process of creating intelligent specialisations aimed at increasing collaboration and competitiveness of enterprises.

- Public programmes for supporting innovativeness and competitiveness should be oriented at the need of enterprises to abandon the approach of mitigating the financial barrier for strengthening their knowledge capital.
- It is important to support cooperation of science and business, recognising creativity, stimulating knowledge structures and activities aimed at increasing the demand for innovations.
- Activities that are supposed to increase innovativeness should apply not only to enterprises, but also to the state and education sector.
- Increasing the support for enterprise activities in the area of standardisation and developing institutionalised conditions for promoting their international expansion.
- Undertaking activities aimed at better allocation of EU funds to avoid blocking competitiveness by a low level of innovation.

For a single country, the following source of information can be distinguished [3, 10, 17]:

- own research and development (external local sources),
- buying foreign scientific and technological concepts: licence agreements, know-how, material technology transfer (external foreign sources),
- invention and rationalisation (internal sources),
- scientific and technical information with reference to other R&D work performed by other institutions, patents or available licences.

5.3. Methods of implementing innovation in a company

Enterprises use many methods that allow them to introduce and manage innovations in an orderly and systematic way, and to generate ideas for innovations. The choice of methods of implementing innovations depends on many factors, e.g. [28, 29]:

- readiness of an enterprise to launch innovation,
- involvement of the management,
- motivation of employees and their willingness to execute changes,
- financial possibilities, technical and organisational possibilities,
- current activity of the enterprise,
- plans and assumptions regarding the future activity of the company,

- planned date of introducing changes and other.

Activities can be divided on the basis of the character of executed changes [28, 29]:

- **Defensive** – based on specific products, regular clients, narrow area of action, highly ignoring changes in the environment.
- **Searching** – referring to searching for new products and solutions, monitoring changes, looking for new areas of activity and new technologies.
- **Analysing** – combining both defensive and searching activities.
- **Reacting** – based on fast copying and adaptation of projects taken up by others, yet without introducing the enterprise's own solution.

What has already been put into practice in enterprises were some basic methods of launching innovation, such as e.g. [5, 28]: **"top-down" rule, "centripetal" method, "bottom-up" rule and "step by step" method.** In the **"top-down rule"**, the objectives that indicate directions of changes are assigned to a team of key departments representatives, after an analysis of internal situation. The team prepares basic measures for the set objectives, which may also include the criteria of evaluating the employees. The **"centripetal"** method is used for whole processes, in order to appropriately verify management structures and methods, in accordance with the philosophy of maintaining good relations with clients and suppliers, as well as with the employees of the enterprise. This pragmatic "centripetal" method is mostly used in enterprises where the management is aware about its weak points that affect the quality of products, services or activities and where there is a need of trust-improving examples in order to introduce a broader concept of holistic quality assurance, usually with the help of external consultants. The **"bottom up"** rule is often used in organisations that have achieved a high maturity level and whose employees can react to the problems of the company by providing specific solutions, e.g. by creating task forces composed of employees of various departments, also those who are responsible for direct customer service. However, what is very important is a detailed preparation of meetings and providing their participants with training in the scope of problem solving methods, leading discussions, dealing with conflicts, etc. The **"step by step"** method means gradual broadening of activities. The supporters of changes of different enterprise hierarchy levels undertake initiatives using the existing systems and instruments. They look for allies and seek for support of the management for broader "official" activities. At a later stage, they perform activities that combine the top-down and bottom-up methods with the participation of external consultants.

Methods of searching for and launching innovation ideas comprise [13]:

- heuristic methods of launching innovations (Fig. 5.3),
- methods of spontaneous search of ideas (Fig. 5.4),
- forced contrasting methods (Fig. 5.5).

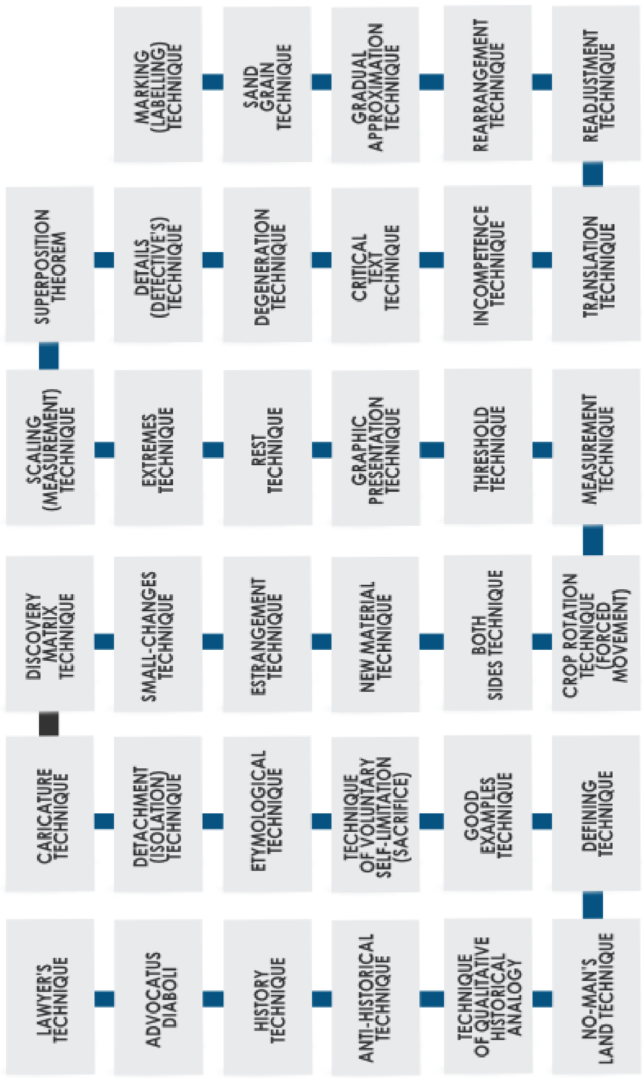

Fig. 5.3 - Heuristic methods of launching innovations [13]

Fig. 5.4- Methods of spontaneous search of ideas [13]

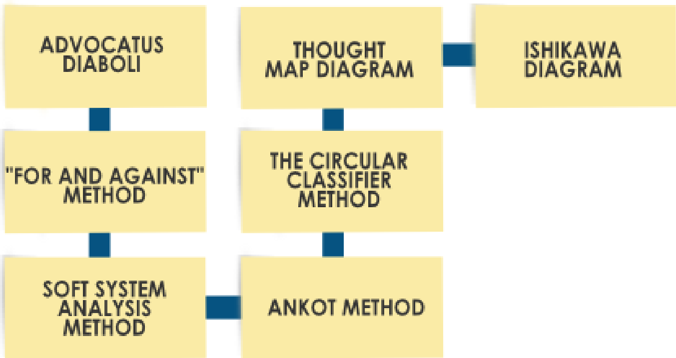

Fig. 5.5 - Methods of forced contrasting [13]

What should be emphasised is that none o the methods is a universal method and most often a specific method for solving a problem is created during a specific activity. During search, preparation and launching of innovations it is necessary to follow heuristic indications that would reduce the costs and increase the efficiency of work during the abovementioned activities. The most important heuristic indications, which are necessary at innovation launching (also preparing and designing), have been presented in Table 5.1.

Table 5.1. The most important heuristic indications (own study based on [1, 13])

Heuristic indication	Characteristics
Think creatively	You can achieve better and more effective results when you use creativity in a methodical way.
Adjust innovation to the objective you want to achieve	Consequently realised the set objective, which should be described in brief and to the point.
Focus on basic elements	Control and verify your activities regularly and focus on basic elements and activities.

Think over innovation to be launched or problem to be solved	Thoroughly analyse each solution (activity) and the way of using available information. Do not take the decisions too quickly or hastily.
Analyse each idea	Analyse different solutions and ideas by juxtaposing both positive and negative features. Only then you will be able to make rational conclusions and decisions.
Avoid overgeneralisation - be precise	Point to a specific, accurate way of conducting research, as it is the only way of launching various innovations.
Aim for simplicity	Aim for simplicity of solutions.
Avoid obvious solutions	Approach obvious activities or solutions critically, as that may lead to many errors.
Previous experiences are only hypotheses	When preparing a new solution, use the existing experience carefully and in a balanced manner, as new solutions (activities) may require entirely new solutions.
Look for ideas collectively	Creating groups of many specialists (very often from various industries), especially interdisciplinary, contributes to the effective preparation of a solution or its implementation.
Present a positive approach	Think positively, as such an approach facilitates preparing an innovative solution and/or its implementation. Do not be discouraged by failure.
Respect personalities of your colleagues	Respect opinions and observations of other people (colleagues), as that affects positive relations with co-workers and the efficiency of team work.
Plan your activities	Proper preparation of the plan and methods of modifying it contributes to the effective and consistent operation.
Observe the deadlines	You must observe the deadlines, as that has an impact on the final effect of an activity and its effective realisation.
Think globally, act locally	Consider the problem globally, by exceeding various barriers. It allows seeing a specific solution.
Limitations can help	Limitations should be perceived as challenges for acting towards changes and, in effect, towards launching innovations.
Satisfaction of the discovered solution should not limit your creative invention	Preparing and finding a solution should make a starting point for creative proposals of successive solutions.

Look for ideas at medium motivation	When looking for new solutions, your emotional involvement should not be to high and you should avoid extreme conditions.
Play with tasks	The best solutions are often developed in a nice and friendly atmosphere.
Take into account the parental effect	Pay attention to the negative sides of your own solutions.
Avoid preparatory approach	Avoid clichés and opinions that are usually insufficient for evaluation of new ideas.
Remember about obstacles	Take into account various obstacles that may occur.
Conduct study in an organised way	Conducting activities in an organised and systematic way increases the efficiency of work and achieving positive results.
Use the best sources of information	Use primary sources of information that make a basis for efficient activity and reliability of solutions.
Sleep over the idea	In order to assess your own idea objectively, analyse it from a certain perspective to highlight both positive and negative features.

When solving the problems with heuristic techniques, choose appropriate technique to a given problem. The choice depends e.g. on the subject, scope and complexity of the problem, as well as on the number of people solving it.

The list of heuristic ways of solving and launching innovation in enterprises has been shown in Fig. 5.3. The characteristics of selected methods have been presented in Table 5.2.

Table 5.2. The selected heuristic methods (own study based on [1, 2])

Heuristic method	Characteristics
Lawyer's technique	The technique is used when the problem is complex or the situation unclear It allows gathering a great number of data or making choices in a short time. The idea behind the technique is that one person is an advocate who supports a given solution, rejecting arguments against it.
No-man's land technique	The technique is based on looking for solutions that are on the verge of two or more scientific disciplines. The method is based on appointing interdisciplinary teams that are supposed to prepare a solution taking into account the topics prevailing in many industries (areas, departments).

Good examples technique	The technique is based on using good, recognised solutions or on conducting simple experiments, the results of which can lead to proposing of a good idea.
Defining technique	The core of this method is precise determination of the terms used, their precise formulation and denotation. Defining clearly determines the scope and area of considerations, and prevents mistakes.
Isolating technique	The technique is based on an assumption that when you distance yourself from a problem in time and space, you will be able to assess it rationally. Looking at a problem from a different perspective makes you see different characteristics of the proposed solution.
Graphic presentation technique	The technique is based on presenting a solution or a problem in a graphic way. You should pay attention to the form of drawings, tables, or charts (shape, colour, elements layout), as it contributes to a better recognition of the problem, as well as preparation and implementation of the solution.

Methods of spontaneous search of ideas have been presented in Fig. 5.4. The above methods are based on brainstorming [1], and the basic rule underlying the method is the lack of a critical approach to the ideas at the stage of creating (looking for) them. The guiding thought in brainstorming is motivating the participants involved in solving a problem to present freely the greatest number of ideas that may lead to preparing a solution.

The main aim of brainstorming is collecting many ideas in a short time to be able to choose the best one [1], (Box 5).

Box 5. ***Brainstorming***

Brainstorming is a very popular technique of developing group decisions. The technique was invented by Alex Faickney Osborn in 1938 and popularised in 1953 in his book entitled "Applied Imagination". Brainstorming can be classified as one of heuristic methods, i.e. methods of solving problems in a creative way. The method is used for generating the greatest number of ideas from which we hope to choose the best solution. What is extremely important here is going away from models and stereotypes and using experience of various fields that may seem not related to the subject of the problem. Obviously, the teamwork is not less important here [26].

Brainstorming is used for solving problems that are not so complicated or difficult and that can be easily defined (Box 6).

Box 6. Stages of *brainstorming*

Three stages of brainstorming [1, 16]:

- **Preparatory stage**, in which the team is formed and the problem formulated.
- **Generating ideas (creative session)**, which is most often performed in a few phases with breaks, and the generated ideas are recorded in such a way as to be accessible to all team members.
- **Valuing ideas (evaluating session)** (most often done by a group of experts), which can proceed in three stages: initial analysis and assessment of ideas, evaluation of ideas qualified for further evaluation, selection of the best option.

A great number of ideas are achieved in a special creative session (creativity session, ideas generating session), which is only devoted to creating (generating) ideas. The principles of creating brainstorming include [12]:

- Positive approach to our own ideas and ideas of other people, while remembering the principle: "do not criticise",
- In the initial (creative) phase, pay attention only to the number of ideas,
- Problems solutions should be original and non-conventional,
- And should motivate to further presentation of proposals while respecting proposals of other people.

Brainstorming varieties have been presented in Table 5.3.

Table 5.3. The selected heuristic methods (own study based on [2,12])

Method of brainstorming	Characteristics
Individual brainstorming	The method is used by a single person who consequently observes all principles of basic brainstorming and skilfully adjusts the rules and procedures to his/her own creative skills.
Mixed brainstorming	The method is based on a methodical technique that triggers a series of creative brainstorming sessions: of small individual teams and larger plenary units. What should be noticed is that the methodical and organisational techniques eliminate weak points of the

	brainstorming method. The creative process of the mixed brainstorming begins with an individual or group session. After the ideas formed at the creative session have been evaluated, the tasks are prepared for further individual brainstorming. Next, the ideas are presented, before the creative session II is started and thus a series of individual and group brainstorming sessions are made.
Philips 66 Buzz Session	The method is based on the 6-minute work of 6 teams. Each team is working separately, and after 6 minutes the teams meet at a common session to create the list of ideas that is next completed during a plenary meeting.
635 Method	The method is a methodological and organisational kind of brainstorming, in which oral proposing of ideas is replaced by a written proposing of ideas on a special form. The idea of the 635 method is that 6 people (each person separately) should present 3 ideas in 5 minutes, however, the ideas cannot be repeated. The procedure is carried on until the form is filled in.
Jumping on the general subject levels	The method assumes jumping through various formulations of the subject, which increases the change of finding an expected solution. Generally, a good formulation of the subject is considered to be one of the elements of success in finding a proper solution.
Gradual precising of the problem	The method uses several brainstorming sessions consecutively, and the subjects are prepared in a specific order. The process starts with general problem formulation and proceeds to getting the problem more and more precise. The successive sessions are supposed to guide the group to the areas that require new ideas.

The core of the forced contrasting method is based on listing and comparing any pair of elements in order to make conclusions by negating, opposing, denying, i.e. by strong, forced contrasting. Contrasting opens the possibilities of learning and understanding. It moreover sharpens, differentiates and guides into the core of the problem or solution.

Forced contrasting is a method that not only facilitates understanding, but also gives great opportunities for finding ideas of solving the problem [1]. The characteristics of the selected methods of contrasting have been presented in Table 5.4.

Table 5.4. The selected forced contrasting methods (own study based on [1])

Forced contrasting method	Characteristics
Advocatus Diaboli	The method is used for difficult and complex problems. It is based on the "negative" opposition. The person functioning as an advocate during a debate is supposed to create the contrasting and opposing argumentation, in a positive sense. The method assumes collecting much information, many observations and data, and enable choosing the solution in a short time.
"For and Against" Method	The method aims at fast and effective assessment of ideas gathered by means of heuristic methods. The "for and against" method is based on a broad discussion that is similar to firing ammunition, which must hit a target. The evaluation of collected ideas is made on many levels, and allows classifying ideas to a given group of ideas. Next, the idea is entered on a special "for and against" method chart and submitted to further evaluation. The method procedure covers the following activities: • Collecting ideas, • Giving each idea an identification number, • Initial evaluation of ideas, • Entering selected ideas on the chart, • Preparing "for" and "against" arguments, • Writing down conclusions, • Deciding about what to do with the ideas (e.g. the idea to be used in the future).
SOFT System Analysis Method	The method is based on making sets of information, and next arranging them in different configurations which can be used for analysis and assessment of the impact of opposite conditions (e.g. now - in the future, strong points - weak points, chances - risks, etc.). The method is used during analysis and strategic planning, and facilitates understanding of the situation and flexible adjustment to market changes.
ANKOT Method (Analiza Kontrastowa Obiektów Technicznych - Contrastive Analysis of Technical Subjects)	The method is a summary of various methods that aim at searching for ideas, solutions and information by denying, contrasting, negating, opposing, etc. In effect, you get instructed how to look for new ideas or solutions. Juxtaposing positive and negative features, and strong and weak points, allows seeing the subject in a proper perspective. One of the varieties of the ANKOT method is the Alszuler algorithm. The objective of the method is getting at a special approach while eliminating contradictions between the properties of compared pairs.

The circular classifier method	The method is based on methodological contrasting, by putting subjects in pairs and creating a logical structure that may be compared to a circle. Images with various intensity of attributes are classified in a radius of the circle, so that the neighbouring points represent related images, and opposite points - opposite images. The studied object is in the middle of the circle. This method makes it possible to complete fields that have not been filled in with ideas.
Diagrams	The diagram method can be used for identifying and visualising the effects, depending on the causes. The method comprises the thought map diagram and Ishikawa diagram.

The Blue Ocean Strategy was created by W. Chan Kim and R. Mauborgne who analysed 150 strategic moves between 1880 and 2000, in more than thirty areas of industry [1]. The authors of the strategy demonstrated that creating new demand is possible in any company and that there are 6 ways for reconstructing the market and releasing new chances, including [1]:

- Reconstructing changing the borders of the current market.
- Focusing on a broad and long-term activity vision, and not only on strategic and operational indications.
- Looking for opportunities outside the existing market demand.
- Implementing the strategy according to a planned arrangement.
- Looking for the ways of overcoming organisational problems connected with strategy implementation.
- Accounting for the execution in the strategy.

Reconstruction of the borders of the existing market covers the following activities, which are focused on [13]:

- analysis of alternative industries,
- analysis of strategic groups,
- analysis of recipient chains,
- analysis of complementary offers,
- analysis of functional and emotional factors,
- analysis of time perspective.

Focusing on a broad long-term vision of activity, and not on the numbers, covers e.g. making a basis of the strategy and using the scheme of four activities: eliminate, reduce, increase and create. Looking for opportunities outside the existing market demand is, in turn, connected with the analysis of the existing customers and "non-customers". Execution of the strategy according to the set arrangement takes into account the following hierarchy [13]:

- usability for the buyer,
- price,
- cost,
- use.

The basis of the "blue ocean" definition is creating a free and unused market space by the enterprises. Therefore, competition is not important and the companies can use their innovative capabilities to the full, in order to form their position. The core of the strategy is innovation of value, aimed at creating new values for the customers and the enterprise [11, 14] (Box 7).

Box 7. Blue Ocean Strategy

Authors of the *Blue Ocean Strategy*, Chan Kim and Reneé Mauborgne, assume giving up the fight with the competence and focusing on a new and unknown market space. The Blue Ocean Strategy is a tool for creating business moves for the companies, which allows them to abandon competition with other companies, and do everything to make competition unimportant [11]. The authors claim that companies which will reach a leading position in the future will succeed not by winning over the competition, but rather by making "blue oceans": a free market space, which is a great growth environment.

W.Ch. Kim and R. Mauborgne construct their strategy on the basis of an endogenous growth theory, which implies that changes in economic structure and the shape of a given industry are induced by internal system factors. That means that the market structure and borders exist only in the minds of managers [11]. Thus, the core of the problem is how to increase demand that, theoretically, is hidden and outside the market borders [14]. The blue ocean strategy focuses on the so-called innovation of value as a potential source of long-term success of the organisation.

The "blue ocean" strategy concept is a kind of a counterweight for a "red ocean" strategy, i.e. occupying the markets that have already been used. The "red ocean" features a strong fight for the client. Competitive products in a given area of industry are often very similar. However, the winner is the company that can offer a better price accepted by the market [14].

The traditional approach requires us to define the industry in the same way as the competition defines it, and to try to be the best by any means, group the products/services according to the generally accepted standards (economic, business, first class tickets) and focus on the known interest group. The more companies representing the same industry do according to the above scheme, the more their strategies look similar. Therefore, in order to revolutionise the activity, we should break the barriers of conventional thinking. We should go outside our business industry and see the activities of others, e.g. manufacturers of complementary goods, but most of all, forget about competing [4].

5.4. Conclusions

Various activities, which are conducted in response to economical changes, trends and external and internal environment activities, are main motives of launching innovation in different areas of the enterprise's operations. These operations are connected with e.g. modernising technical and technological equipment of the plant, increasing productivity, capacity and quality of works, improving the quality of produced goods, and increasing competitiveness.

The main incentives for Polish companies to implement innovation are competition pressure and wish to remain on the market. An increased interest in innovative activity and cooperation is mostly related to the enterprise's expansion onto new geographical markets as well as with the expansion of foreign companies that are more competitive and able to use their competitiveness in a given industry.

Many authors believe that the source and inspiration for introducing innovative changes is everything that inspires new activities, searching new solutions and creating new solutions and projects.

Each company that effectively reacts to changes by implementing innovations has to look for necessary knowledge, financial, technical and other resources, due to its limited competences and, above all, resources. The sources of innovation can be both internal (e.g. results of the study of one's own research and development facilities, all kinds of improvements reported by employees) and external ones. Environment that stimulates processes of changes and allows creative reaction to changing environment is one of such innovation sources.

The efficiency of entrepreneurs in launching innovative changes highly depends on their competences, management abilities and strategies they adopt. Companies use many methods that allow them to introduce and manage innovations in an orderly and systematic way, and to generate ideas for innovations. The choice of methods of launching innovation depends on many factors, including e.g. involvement of the enterprise's management, readiness of the company to launch innovation, financial, technical and organisational possibilities, as well as motivation of employees and their willingness to execute changes.

There are many methods of both searching for and launching innovations, such as e.g. heuristic methods for implementing innovation, methods of spontaneous search of ideas and forced contrasting methods. Each of the method groups is composed of various detailed methods described in numerous publications. The choice of a method is determined by e.g. the nature of realisation of innovative changes. What should be emphasised is that none o the methods is a universal method and most often a specific method for solving a problem, which is often a compilation of various methods, is created during a specific activity.

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6. Tried and tested procedures of foreign industrial companies – Alena Breznická, Alexej Chovanec

6.1. Introduction

In this chapter we deal with the possibilities of using statistical instruments and methods of product quality management with the application of simulation modelling for optimization of production and maintenance. The proposed procedures are illustrated with examples of solutions introduced in mechanical engineering companies in Slovakia.

To sustain competitiveness and increase the level of services provided, organizations have to make permanent innovative changes. Innovation management in mechanical engineering and production is the management of innovation processes related to the operation of an organization, the quality of products or services in the area of organization and processes management, implementation of new (improved) technologies, and development of new, improved products and services [3].

Innovations require the use of modern management methods and appropriate analytical tools and techniques enabling proper reviewing of problems. There exists a whole range of methods, tools, and techniques whose classification is non-uniform, as they represent an array of different disciplines.
Mechanical engineering primarily uses those based on quantitative principles and expressed through mathematical, stochastic or logical models. As a rule, these methods require the collection, preparation and processing of necessary data.

The methods and techniques applied in this study for partial innovations come from several different disciplines of science and overlap in the areas of improvement, optimization, process modelling, implementation of new methods of functional or process management, management procedures, motivating approaches, new enhanced manufacturing technologies, integrating of significantly improved products or services into the production process and their introduction onto the market. The methods may include general analysis of processes and systems, methods of process and system management, decision-making methods, methods of statistical analysis, methods of operational analysis, methods of reliability, security and risk analysis, methods of quality analysis, and simulation, optimization and forecasting methods [8].

Manufacturing and mechanical engineering systems always involve autonomous variables that are interpreted from a physical point of view as a function of time. Breakdown effects (related to the human factor, machines and equipment) always interfere with system activity. They usually form complex, hardly predictable causal sequences. External effects of environs become evident in the form of random deviations in the quantity, structure and quality of material and energy inputs etc., which can only be characterized in statistical terms. We cannot predict precisely when, where, and in which machine or device a defect will occur, or what kind of material will be needed. Requirements for a change of technical, technological and organizational processes bring a certain risk [9] which concerns dynamic, stochastic, complex systems. Some events and processes are hardly predictable; others cannot be expressed in a quantitative way. The relations and links among elements and environs of such systems are very complicated, making the effects and probabilities of their occurrence conditional. Reviewing of impulses and relations in a system is hindered; the possibilities of carrying out an experiment are limited or not feasible. A system can then only be described with a full-range, mathematically complicated model; sometimes a system escapes description. When the review level is decreased, a part of a whole might be garbled and misrepresented [1, 2].

We need advanced, sophisticated research tools for modelling working environments and simulating various decision variants and consequences of the decisions taken to limit the risks of implementing improper solutions.

6.2. A modelling assessment of a workshop process of manufacturing fiberglass semi-finished products

A foreign company has a sub-company in Slovakia which produces glass fiber semi-finished products for specific applications in automotive and consumer industries. The glass fiber semi products are produced in a single-shift operation, and the production is computer-controlled according to a predetermined production plan.

The company’s production hall is divided into two parts. The main part of the lamination manufacturing process takes place in the first part. In the second part, which is characterized as the post-production part, products are finished by forming into the requested dimensions until they reach the required quality; the main manufacturing processes used in the second part of the production hall are glass fibre margin working and glass fibre semi product working with pneumatic equipment designed to cut out, bore and spot-drill orifices.

Generally, we can classify this type of production as workshop production, where the manufacturing process is mainly based on manual work of operators of particular operations with a minimum use of automatic or semi-automatic machine technology. A schematic of such a process is presented in the figure below (Fig. 6.1).

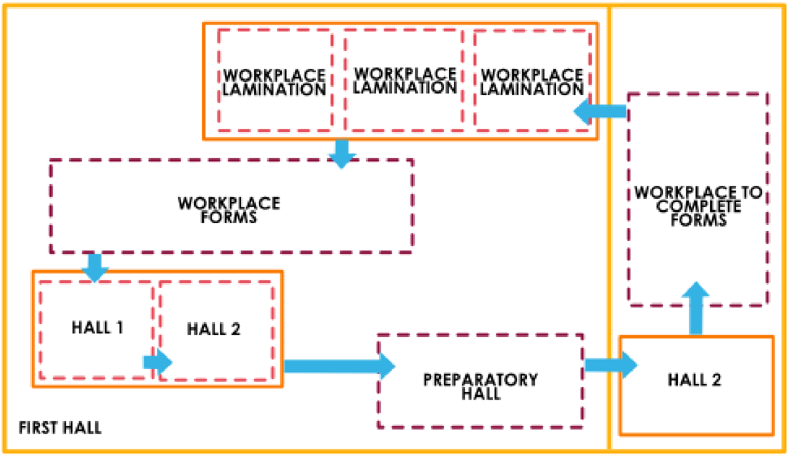

Fig. 6.1 -Flow chart of the organization of the glass fiber semi product manufacturing process

The problem was insufficient capacity of the working station for form spraying with a modified resin, which was caused by the following operational lapses:

1. *The manufacturing operation before spraying was carried out quicker than spraying itself, creating a bottleneck in the production*. The forms prepared for spraying accumulated resulting in:

- Delays in continuous processing of forms in sequence: the room assigned for prepared forms was overfilled causing extension of the handling time needed to move the forms into the form spraying station.
- Each form waiting in the queue, which had not been processed within 30 minutes from its preparation, was (due to minimum static energy on the form surface) covered with dust from the surrounding environment at such a rate that it had to be thoroughly cleaned before spraying.
- Not all forms in the form spraying station were processed according to the production plan on a particular working day.

2. *Working station overload*

Spray application of a gel coat is physically demanding work, requiring the operator to take regular rest pauses in series production. When the working station is overloaded, the pauses are minimized or eliminated, leading to a higher failure rate. In such situations, more time has to be spent in the final phase of processing of a glass fiber semi product at the quality check point and the product repair working station, where surface defects are identified and removed.

3. *Insufficient use of the capacity of the laminating station*

Each form after spraying with a gel coat must go through a 'drying process' before direct lamination. Drying takes one hour of the manufacturing time. Lamination is affected in a negative way by an insufficient workflow due to shorter or longer shut-downs in the manufacturing cycle.

The operators of a laminating station work on a sprayed form; if its gelcoat layer is not sufficiently hardened before lamination, defects (unconformities) will show up on the surface of the laminated semi product. In such cases, the time assigned for lamination on the laminating station is not sufficiently used. The laminating station is overloaded with substitute work due to the lack of forms ready for lamination.

4. *Negative economic consequences*

Failure to fulfil the production plan resulted in an increase in overtime work. To meet the production plan employees had to work additional hours on weekdays and at weekends. An analysis of the technological, spatial and time structure of a process and sub-processes is a starting point for defining the parameters of a problem encountered. The overall process and each of the lower level processes were analysed and described using a conceptual model, illustrated by the block diagram shown in Fig. 6.2.

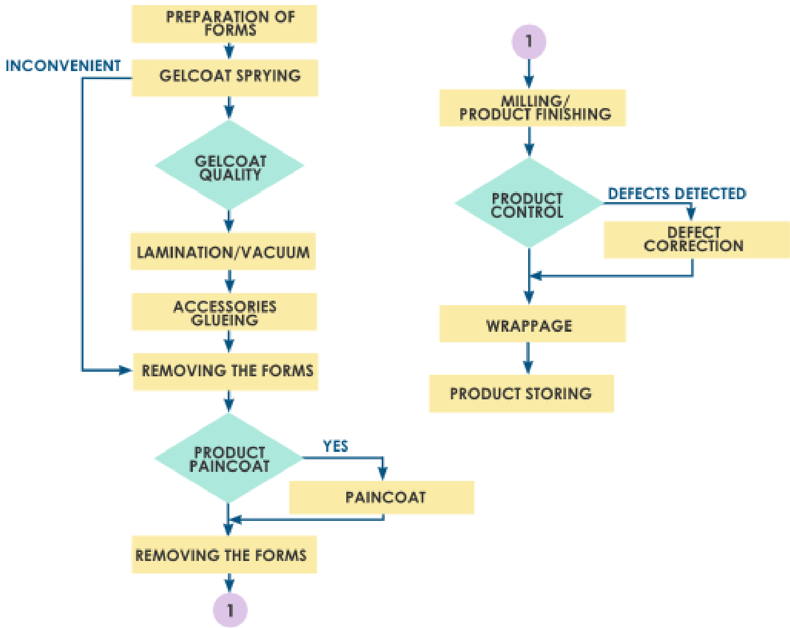

Fig. 6.2 - Block diagram of the overall production process [4]

The company information system provided data which were analysed, processed statistically over the eight months of the manufacturing process and used to define input parameters and assess the actual conditions by simulation modeling. The problems that were defined had a negative impact on the total economic result of the company. Three main parameters were identified on the basis of the analysed data.

1. **An increased share of overhead time** in the total available working time in the monitored period: 24 percent, which stands for about EUR 8,500 expended on wages for overhead time spent waiting for a form. A pie chart showing the amount of overhead time at the working stations of the front hall is presented in Fig. 6.3.

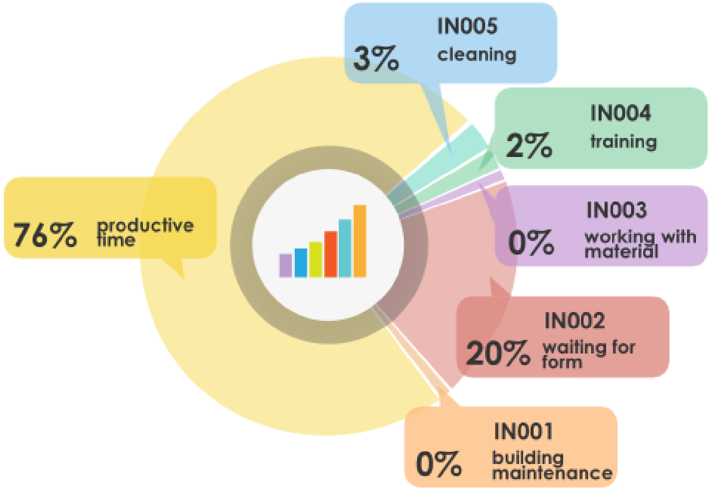

Fig. 6.3 - A pie chart showing the amount of work done during overhead time at the working stations of the front hall

2. Work done at weekends to meet the week's production plan which has not been fulfilled due to loss of productive hours out of the standard working hour fund planned for a particular working week. Workers are paid overtime rates which are 25% higher than their standard hourly pay and weekend rates which are 50% higher than normal pay. The high amount of overtime work performed during the monitored period does not only mean increased personnel costs but also increased hall operation costs. These costs totalled about EUR 12,000 for the monitored period.

3. Costs of poor quality of glass fiber semi products associated with defects caused by laminating a wet or dust-covered form including costs of expert assessment by a quality supervisor totalled 5000 EUR for the monitored period.

Development of the elements of a computer-aided model

A room layout of a working environment identical with the layout of the front part of the company's manufacturing hall was developed using simulation software. It featured the physical elements of the particular processes with their descriptions. The layout of the front hall and flow of material are presented in Fig. 6.4.

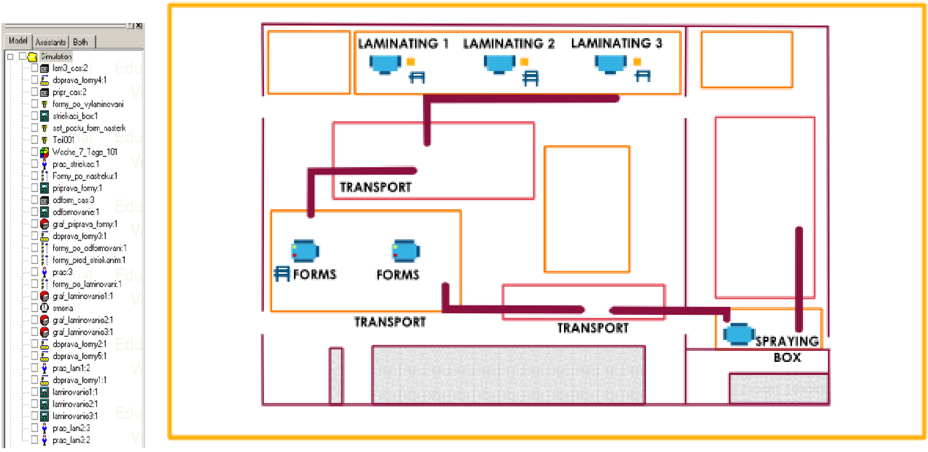

Fig. 6.4 - Layout of the front hall with the elements used

The following elements of the model were defined:

1. *Attributes of a working shift*, needed for the simulation to maintain the semblance of reality with regard to the course of production processes. To set a change in an attribute we set the first and the second part of the change, which are separated with a pause.

We defined the input values needed to start a task (setting the initial number of laminated forms needed to start work on the form-releasing station). We also set maximum storage capacities for forms released from the particular working stations.

2. *Variables*

In the programme environment, we defined three variables needed for the internal logic of the modules: form release, form preparation and lamination. These variable functions allowed us to mimic real life events and situations taking place at the particular working stations, e.g., if the software logics of any module demanded the presence of more employees assigned from a base to perform a particular activity, 'a standardized time' needed to perform this activity would be divided into equal parts (reduced) proportionately to the number of additional employees working at the station.

3. Programming of the behaviour logics of the particular elements within the model

We set the behaviour of the particular elements through programme algorithms with regard to the real performance of the simulation. We entered into the logics of the modules an adequate number of employees allocated to the particular working stations to perform a particular activity (Labor Rule), which was set to a variable value using the variable functions for form release, form preparation and lamination.

4. Connecting the particular modules with an instrument simulating a conveyor

To interconnect the working stations, as well as to define the transport routes in the simulation environment of the simulation programme, we used a container which created the required interface for flow of forms in the process. We defined the time needed for handling among the particular modules, this way also establishing the direction of flow of material, in our case a circular flow of forms. Flow of material in the model is shown in Fig. 6.5.

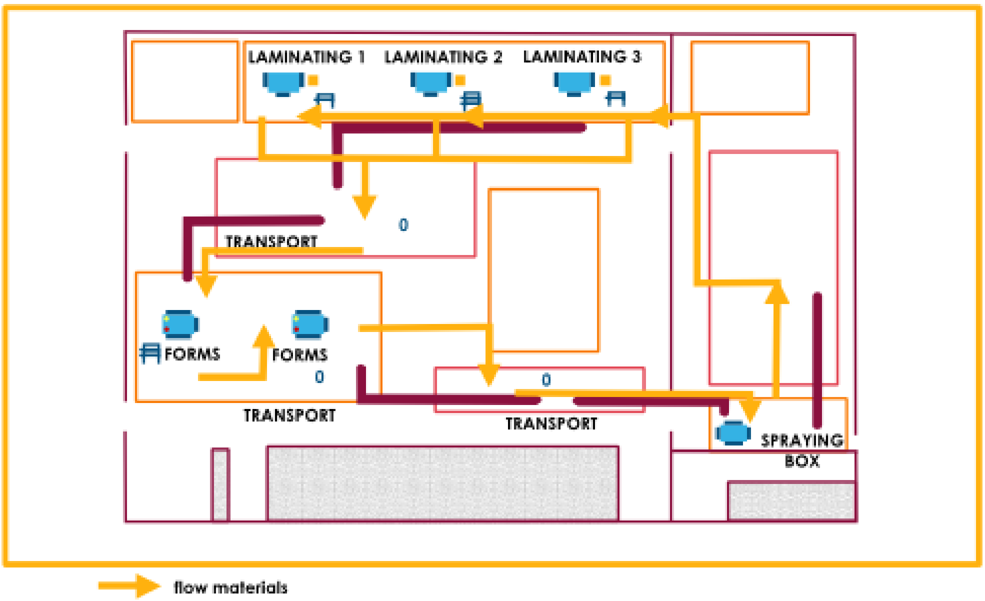

Fig. 6.5 - Flow of material in the simulation model

5. Setting of graphical outputs for monitoring the course of simulation

Having adjusted the general simulation to match the real course of the manufacturing process carried out in the front part of the company hall, we entered graphical outputs into the simulation environment (Fig. 6.6) in order to be able to monitor the course of simulation of the process hindered by insufficient capacity of gel coat spraying. The graphical elements (a pie chart for monitoring the working load of the particular working stations) were used later on to verify the results of the experiments from the point of view of the practical applicability of the selected model in the process of manufacturing laminated semi products.

Verification of the production model

The first step of programming resulted in the development of a model of the investigated manufacturing process which focused on the problems occurring at the gel coat spraying station. The model was assessed for its compatibility with the real conditions of the manufacturing process. Verification of the simulation model and the results of the simulation experiment are presented in Fig. 6.6.

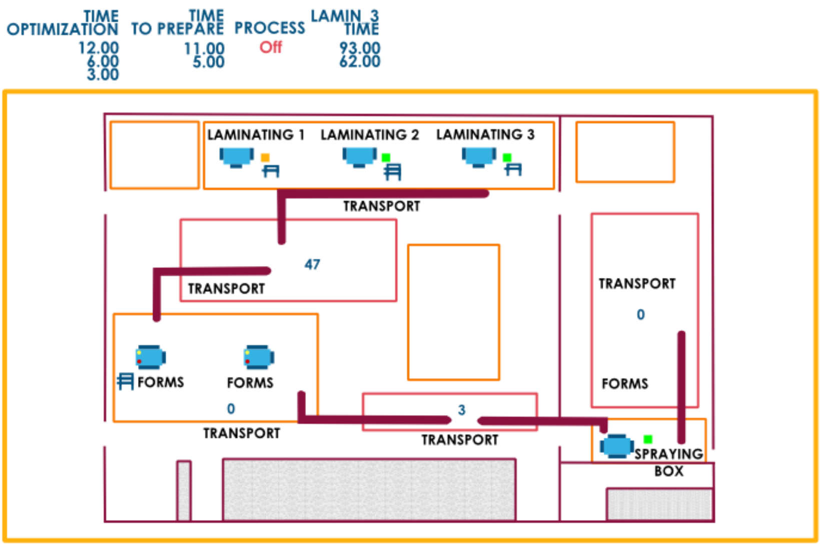

Fig. 6.6 - Verification of the simulation model and the results of the simulation experiment

By monitoring the manufacturing process in the simulation interface of Witness software, we found that our model of production truly conformed to the real behaviour of the process of manufacturing laminated semi products. The resulting statistical indicators expressed graphically approximated the real-life parameters of the defined problem.

The total number of forms processed during a working shift, as given in the standard production plan, is 50, and the minimum number is 45.

The employees working at the laminating station process all the forms that have been sprayed with a gel coat on a given day, which means that at the beginning of the next day's working shift there are no forms ready for laminating and the worker has to wait two hours to begin work. This leads to downtime and a related increase in subsidiary or overhead labour.

There was continuous downtime during the simulation of the manufacturing process at the particular working stations, which accounted for from 15% up to 25% of the total working time. In the real process, these downtimes used to be filled with substitution work, usually overhead-type of work.

Simulation experiments

To assess possible solutions to the investigated manufacturing problem, simulation experiments were run. Three potential solutions which could positively influence the manufacturing capacity of the spraying station were considered:

- Division of the gel coat spraying station into two working stations, with a second employee at the new station using a spraying gun.
- Division of the gel coat spraying station into two identical working stations with two employees using a spraying pump.
- Equipping the existing working station with a gel coat spraying robot.

Experiment no. 1 – the spraying station is operated by two employees, one of them using a spraying gun. The results of simulation experiment no. 1 are shown in Fig. 6.7.

Evaluation of experiment no. 1

The results of the simulation experiment show that the addition of a second worker and the use of a spraying gun lead to a partial improvement in gel coat spraying capacity. However, the outputs from simulation point to a major disadvantage of this solution – an increase in downtime when the employees have to wait for a form.

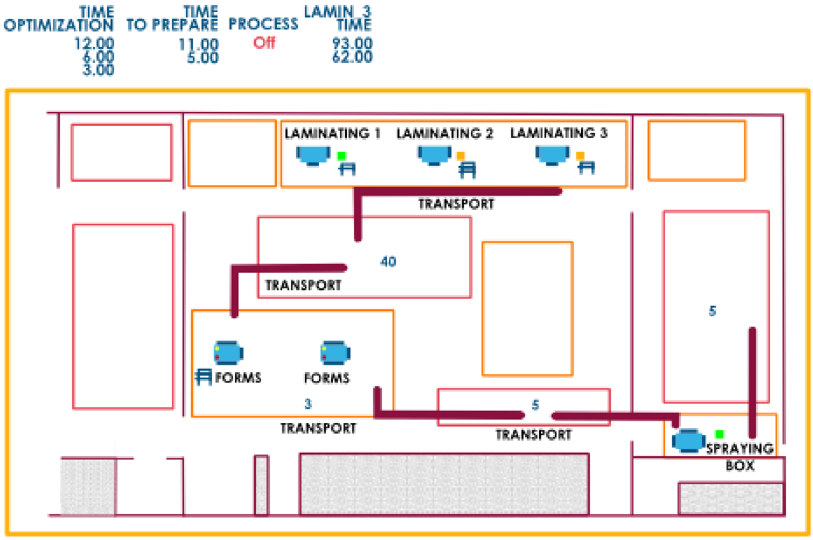

Fig. 6.7 Model and results of simulation experiment no. 1

Experiment no. 2 –Division of a spraying station into two working stations with two employees operating a spraying pump. The results of simulation experiment no. 2 are shown in Fig. 6.8.

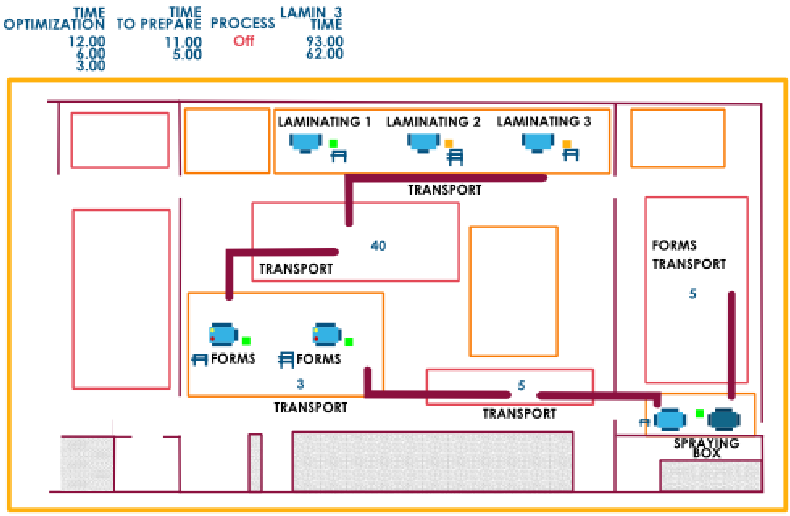

Fig.6.8 - Model and results of experiment no. 2

Evaluation of experiment no. 2

The proposed solution provided a general improvement of the manufacturing process. 58 forms were processed in a manufacturing cycle, as anticipated in the daily production plan. When the working shift was completed, a sufficient number of processing forms were available for the next day's shift. Outputs from simulation (pie charts) indicate that adoption of this solution results in quick reduction of downtimes at the individual working stations: the loss of working time (working capacity) tended toward zero, or more precisely, the remaining downtime was practically negligible for the total cycle of the manufacturing process (the downtime incurred by one working station due to preparation of a form represented 1% of the working time fund).

Experiment no. 3 – equipping an existing working station with a gel coat spraying robot. The results of simulation experiment no. 3 are shown in Fig. 6.9.

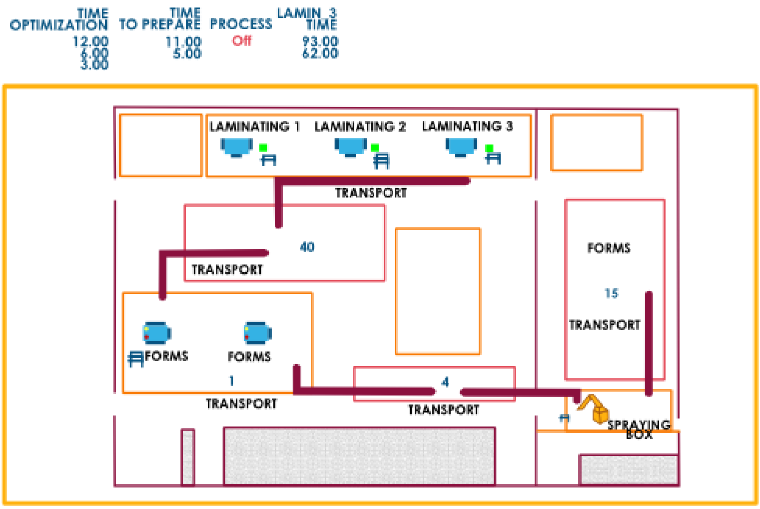

Fig.6.9 - Model and results of simulation experiment no. 3

Evaluation of experiment no. 3

Simulation experiment no. 3 shows that the solution involving the use of a spraying robot gives practically identical results to those obtained in experiment no. 2. Compared with experiment no. 2, the number of forms processed during a working shift in the production cycle was only minimally higher (60 forms, i.e. two more than in experiment no. 2).

Assessment and conclusions

It follows from experiment no. 1 that the solution tested in that experiment cannot satisfactorily eliminate the problem of insufficient capacity of gel coat spraying which generates downtimes at the spraying stations.

An advantage of that solution is that a new work station with a spraying gun is added at a low cost. Experiment no. 1 can be characterized as an 'emergency strategy' for temporary application in practice.

Experiments no. 2 and 3 successfully resolve the problem of insufficient capacity of the gel coat spraying process. The results obtained from simulations of these experiments show that the level of improvement of the manufacturing process is almost identical for these solutions. Introduction of a spraying robot in experiment no. 3 generates only slightly better results in terms of the number of forms being processed in the manufacturing process than the creation of a duplicate working station, which was considered in experiment no. 2.

When selecting a suitable optimization solution, we considered the costs related to putting such a solution into practice. Because of the very high primary costs related to implementation of a robot into the gel coat spraying process and the high maintenance costs, the profit–cost ratio of the solution presented in simulation experiment no. 3 was too low for the solution to be applied in the environment of a low-series production company.

By contrast, the solution tested in experiment no. 2 is applicable. The simulation shows that the selected parameters ensure an expected flow of forms during the manufacturing process, enabling continuous fulfilment of the production plan. The solution allows to minimize production downtimes connected with waiting for a form at the particular working stations, allowing the crew to fully use the working time available during a working shift.

Before the results of the simulation are applied in practice, it is necessary to define the successive implementation steps and the related costs:

- Partitioning of the gel coat spraying station into two separate rooms with a wall partition reinforced with strips of hard foil anchored to a steel console. A similar solution is used at several working stations in the production hall. The costs of partitioning of the working station estimated on the basis of previous implementations of similar solutions in other working stations, would be about EUR 4000.

- Fitting out the working stations with necessary devices and equipment, in particular, three gel coat spraying pumps. The total costs of purchase and installation of three pumps would be about EUR 24 000.
- Partitioning of air intake and air exhaustion into rooms of a newly developed part of the gel coat working station. Slight building adjustments would require an investment of up to EUR 2000.

The experiment “Flow of material in the production process after optimization” is presented in Fig. 6.10.

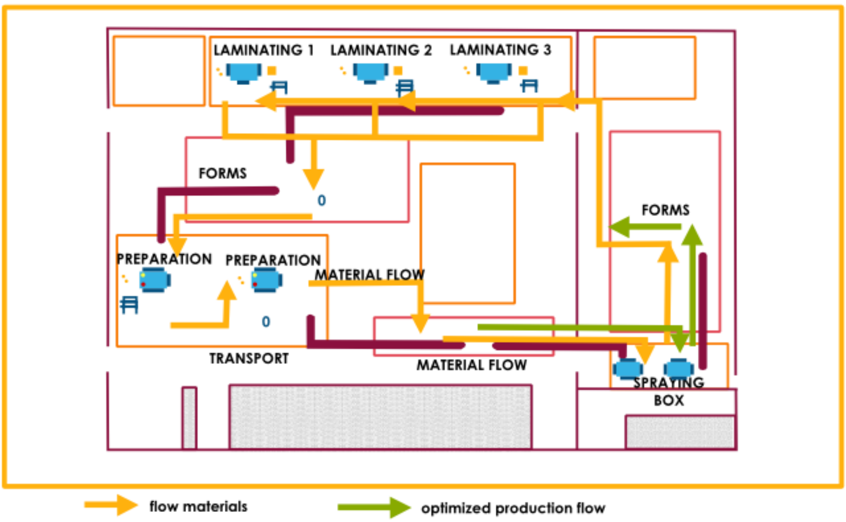

Fig. 6.10 - Flow of material in the production process after optimization

The total costs of implementation of solution no. 2, calculated by summing up the costs of the individual implementation steps are about 30,000 Euros. In the monitored period, the financial loss caused by the low capacity of the gel coat spraying station was about EUR 25,500.

A comparison of the costs of investment in the optimization of the working station proposed in experiment no. 2 and the financial loss incurred during the monitored period due to the low capacity of gel coat spraying shows that the solution is applicable in practice from the point of view of investment payoff. The feasibility of the proposal was confirmed by the simulation.

6.3. Modelling of maintenance-based optimization of availability of the manufacturing line

Designing of manufacturing stations involves estimation of the optimal number of machines that will be required to meet the daily production schedule, or introduction of stand-by machines which could take over the tasks of a failed machine to prevent downtime in production caused by failures. In manufacturing systems which require set-up, maintenance and repairs of manufacturing machines, the appropriate number of maintenance personnel has to be determined. These type of problems are most often solved using deterministic or stochastic methods of operational analysis. However, these methods do not describe the time flow of failure, thus failing to account for additional random effects in the process of ensuring availability of complex systems in real operation conditions [5,6].

Planning of logistic and maintenance systems and modeling of availability of technical systems more and more often require combined knowledge of operational reliability and economic and simulation modelling, and they replace traditional process examination approaches. Modelling allows one to compare the existing maintenance system with a proposed system and to evaluate the benefits of the latter based on data related to using individual maintenance workers, maintenance of individual machines, waiting time to repair, and the repair time of particular machines for a reporting period. Simulation is aimed at finding the optimal number of maintenance personnel [11].

6.3.1. Analysis of maintenance activities in the manufacturing process

A foreign company with a production programme related to components of automobile equipment for diesel systems produces common rail diesel injection pumps and accessories for injection systems.

The manufacturing process is performed in three production lines in a three shift operation. Maintenance of assembly lines is carried out by maintenance personnel with two types of qualifications, namely repairmen and electro-technicians. The electro-technicians are qualified to repair electric defects and the repairmen deal with mechanical defects in any assembly line in order of priority[7]. The defects are classified as electric and mechanical and then work orders for maintenance are issued, which can be divided into three types: classically reported failure, preventive maintenance, and swift repair without reporting from production. All requests for maintenance are registered, and the real time worked by each maintenance worker is registered by an individual order.

The activities related to the identification and removal of defects in machines and equipment are registered by an information system with terminal stations at the particular working stations in the production hall and in individual machines and electro-technical maintenance workshops.

Based on these facts and after consultation at the company, the following conceptual and simulation model was proposed. Electrical engineers repair electric defects and technicians repair mechanical defects occurring during operation at any station in the assembly line. As in each shift there is the same number of repairmen with the same competences, we do not consider an input of adjustments to make the model simpler. The model simulates two kinds of defects, electric and mechanical, i.e. failures causing machine downtime and those which do not cause machine downtime. Downtime does not lead to shutdown of the assembly line due to failure, because material flow is immediately redirected, so the failures do not diffuse in time and there is no subsequent shutdown of the assembly line due to a lack of repairmen. Based on these facts we monitored the working load of each individual repairman. The data represent a time period of 10 months.

The simulation model of a working station is composed of a set of three production machines, containers and conveyors for parts with random time intervals between failures and random duration of maintenance activities carried out by repairmen. The machines process the parts with random intervals between manufacturing operations. To simplify the model, the personnel servicing the machines is not depicted. The system being reviewed is defined by its structure and links among parts, containers, conveyors and maintenance personnel, as shown in Fig. 6.11.

We defined input data according to which the particular system elements and links would behave over time. The data obtained from the information system's registry of interventions for particular machines were used to define input data.

- *Time between interventions by electricians* – an indicator analogical to time between failures (*TBF*),
- Time to repair carried out by maintenance personnel (TTR), and
- *Time between interventions by* technical maintenance personnel.

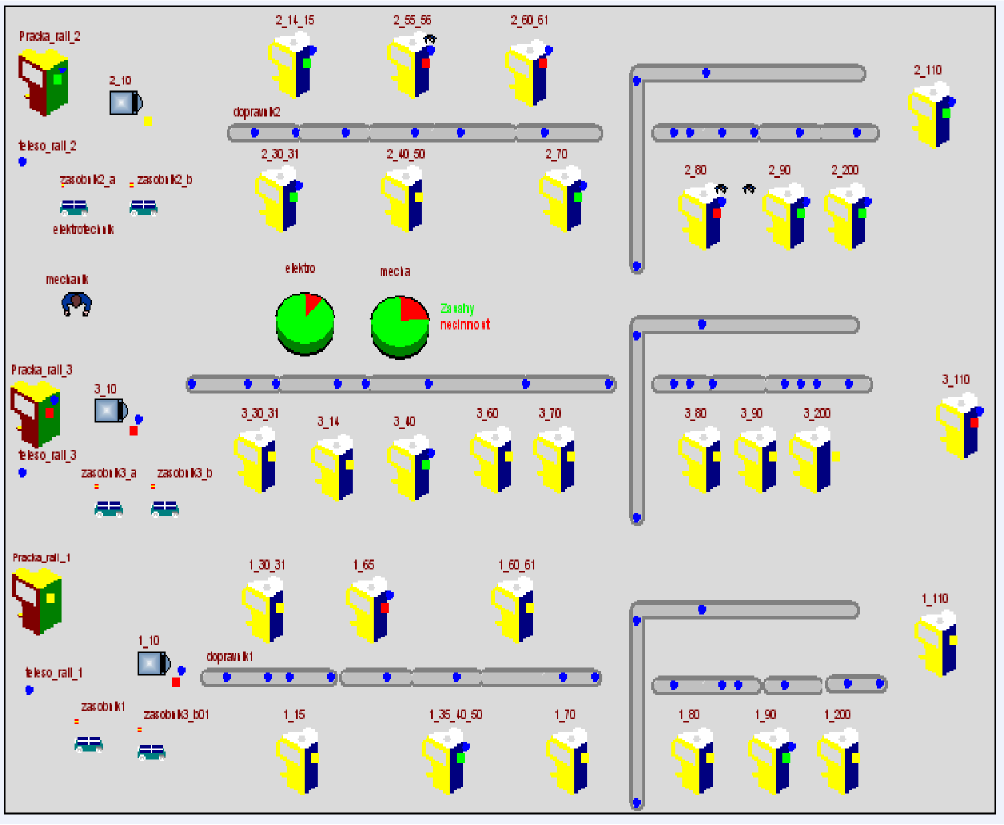

Fig. 6.11 - Model of a manufacturing system with an original solution of the maintenance system

We defined the distribution of probability of the simulation model input data using methods of statistical processing and goodness-of-fit tests. The analyses were performed with STATISTICA software. The results are shown in Tables 6.1 and 6.2).

A goodness-of-fit test for an exponential distribution

Table 6.1 **- Observed and expected rates in an exponential distribution**

Top limit	Observed	Expected
<= 200,00000	26	23.27474
400,00000	15	13.42540
600,00000	4	7.74408
800,00000	1	4.46696
1000,00000	5	2.57665
1200,00000	2	1.48627
1400,00000	0	0.85731
1600,00000	1	0.49452
1800,00000	0	0.28525
2000,00000	0	0.16454
2200,00000	1	0.09491
<Infinity	0	0.12937

Table 6.2- **Computation of the test statistic for the exponential distribution**

Observed–expected rates				
Chi-squared statistic=8.540681 sv=4 p < .073666				
	observed	expected	P - O	(P-O)^2/O
C: 1	26	23.2747	2.72526	0.319103
C: 2	15	13.4254	1.5746	0.184676
C: 3	4	7.74408	-3.74408	1.810174
C: 4	1	5.32428	-4.32428	3.512095
C: 5	9	5.2315	3.7685	2.714632
Total	55	55	0	8.540681

The test statistic is $\chi^2 = 8{,}54$. The critical value of the χ^2 distribution in such a case is $\chi^2_{0,95;4} = 9{,}487729$. So $\chi^2 < \chi^2_{0,95;4}$. As the test statistic is smaller than the critical value of the χ^2 distribution, the null hypothesis H_0 at a significance level $\alpha = 0.05$ is not rejected and, therefore, we can note with

0,95 certainty that the time period between failures is a random variable, which has an exponential distribution. The elements are presented in Fig. 6.12.

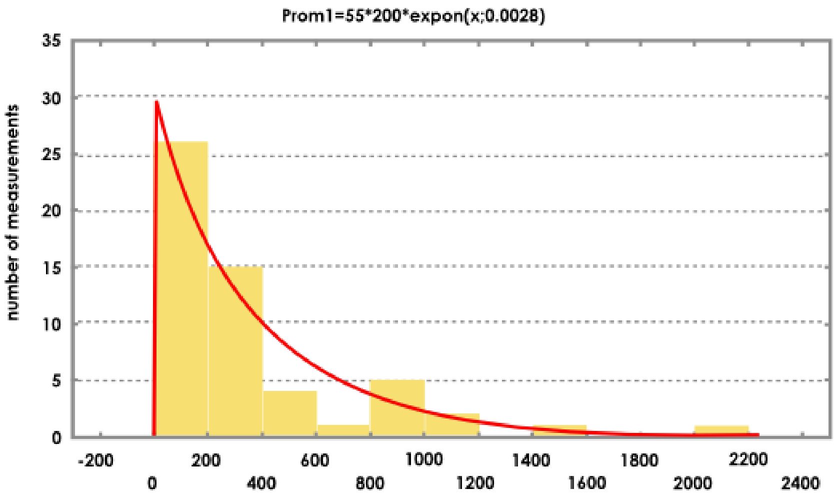

Fig. 6.12 - Histogram and the critical value of the test statistic for an exponential distribution

A goodness-of-fit test for the Weibull distribution

The *test statistic is* $\chi^2 = 18{,}27$. *The* critical value of the χ^2 distribution in such a case is $\chi^2_{0,95;2} = 5{,}99$. So $\chi^2 > \chi^2_{0,95;2}$. As the test statistic is greater than the critical value of the χ^2 distribution, the null hypothesis H_0 at a significance level $\alpha = 0.05$ is rejected and, therefore, we can note with 0,95 certainty that the time between failures is a random variable which does not follow the Weibull distribution.

Based on previous goodness-of-fit tests, we are inclined to state that our random variable – time between failures, follows an exponential distribution. We used the same testing procedure to define the distributions of other statistical input data.

Entry data were defined for elements of the system being reviewed. The particular machines were characterised in terms of types of failures and distributions of time between failures (TBF) and interventions. Kinds and generation of time periods of interventions in removing the failures with distributions of random variables as by results from tested statistical groups. The failures were assigned particular competences of a respective maintenance worker and the maintenance workers were assigned the respective type of observed data.

Variables were defined using the 'breakdowns' option in the 'Edit actions on breakdown' window for input and the 'Edit actions on resume' window for output. The results are presented in Fig. 6.13.

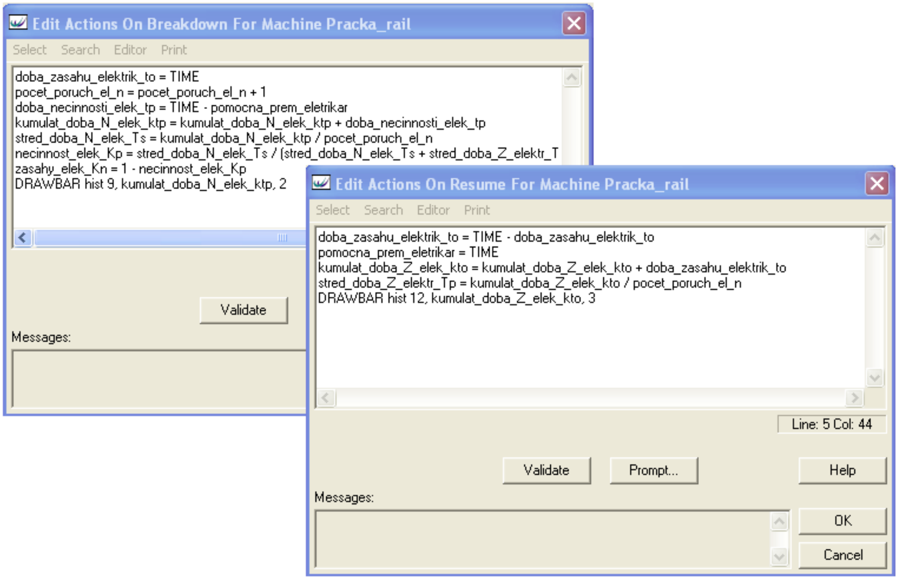

Fig. 6.13 - Actions on input when an electro-technician intervenes

We defined the output parameters to be assessed and selected the form of graphical element display to present our simulation results. We chose pie charts to plot the condition of machines, number of failures and duration of shut-downs, and working load of the individual groups of maintenance personnel.

6.3.2. Simulation experiments and their assessment

Initially maintenance was programmed to be conducted by four employees divided into two pairs of electricians and technicians (Variant 2×2). The next strategy tested involved employment of four universally qualified maintenance workers who would be able to remove all defects of any machine in each line (Variant 4U). In the next two simulations we changed the number of universally qualified maintenance workers (three and five) to monitor efficiency (Variant 3U, Variant 5U). Pie charts showing the working load of maintenance personnel for the particular simulation variants are given in Fig. 6.14.

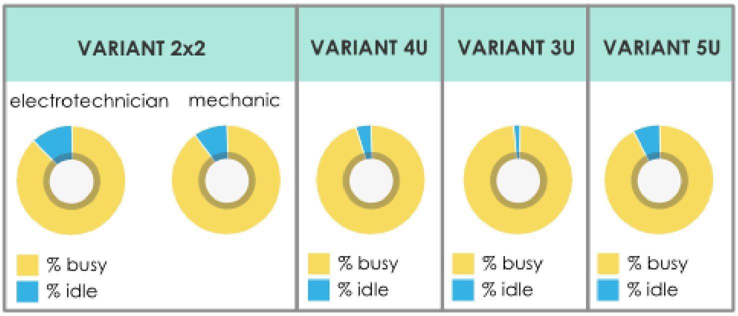

Fig. 6.14 - Working load of maintenance personnel for the particular variants of the simulation

The conditions of the machines in the first production line for the particular simulation variants are illustrated in the column graph below (Fig. 6.15). The working load of the machines in the individual variants was reviewed for each line as illustrated in Tables 6.3, 6.4, and 6.5).

Table 6.3 **- Working load of machines in variant 5 × KVP in line 1**

Line 1 Station designation	**Washing machine roll 1**	**10**	**30.31**	**15**	**35, 40, 50**	**65**	**60_61**
In operation %	78.27	81.82	86.98	79.36	69.17	85.28	83.06
Failed %	11.15	10.54	0.79	10.71	24.79	6.90	8.74
Under repair %	10.58	7.64	12.24	9.93	6.04	7.81	8.20
Station designation	**200**	**80**	**90**	**70**	-	-	-
In operation %	85.22	66.40	82.61	72.28	-	-	-
Failed %	6.46	27.59	8.49	20.25	-	-	-
Under repair %	8.32	6.00	8.90	7.07	-	-	-

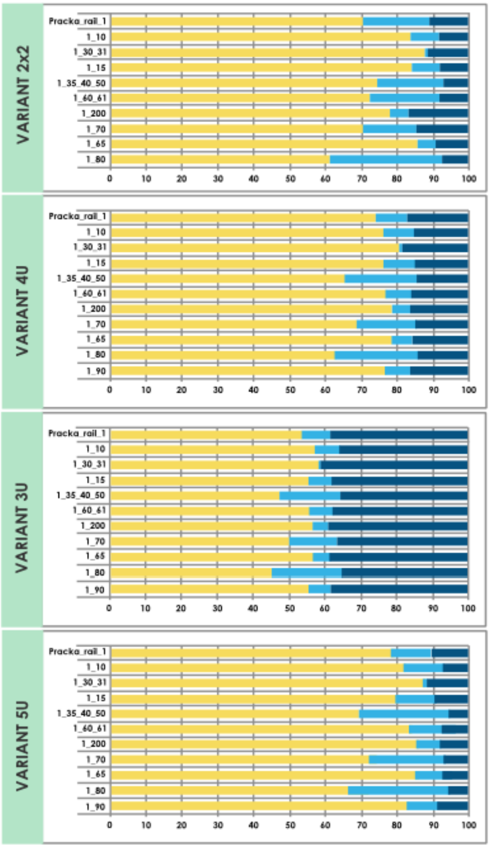

Fig. 6.15 - Machine condition in production line 1for the particular simulation variants

***Table 6.4** - **Working** load of machines in variant 5 × KVP on line 2*

Line2 Station designation	Washing machine roll2	14,15	10	30,31	40,50	70	60,61
In operation %	80.67	83.50	82.52	89.57	67.31	70.18	82.93
Failed %	10.75	10.64	10.20	0.79	26.38	21.02	9.44
Under repair %	8.57	5.86	7.28	9.64	6.30	8.80	7.63
Station designation	**80**	**200**	**55,56**	**90**	-	-	-
In operation %	67.44	85.21	84.25	82.98	-	-	-
Failed %	26.79	6.34	6.90	8.38	-	-	-
Under repair %	5.77	8.44	8.85	8.64	-	-	-

Table 6.5 - Working **load of machines in variant 5 × KVP on line 3**

Line3 Station designation	**Washing machine roll3**	**14**	**10**	**80**	**40**	**60**	**30,31**
In operation %	79.88	76.29	81.44	62.09	65.64	80.11	86.65
Failed %	12.42	12.06	11.65	31.03	26.89	10.18	0.85
Under repair %	7.70	11.42	6.91	6.88	7.47	9.71	12.50
Station designation	**90**	**70**	**200**	-	-	-	-
In operation%	83.84	67.95	82.54	-	-	-	-
Failed %	9.43	22.98	6.81	-	-	-	-
Under repair %	6.72	8.30	10.65	-	-	-	-

The conditions of all lines for the particular variants of simulation in order of their usefulness are illustrated using graphs; an example of such a graph for line 1 is shown in Fig. 6.16.

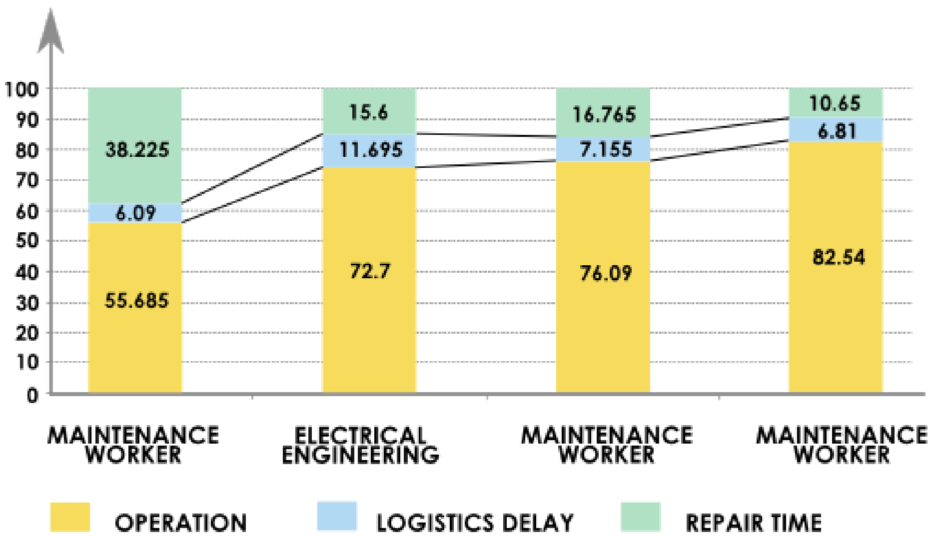

Fig. 6.16 - Conditions in line 1for the particular variants of simulation

Assessing the results, we can draw the following conclusions. The existing system of maintenance provision (2×electro-technicians plus 2×technicians) yields acceptable results with regard to ensuring optimal functioning of the individual machines in the whole system. The variant which involves the employment of four fully trained maintenance workers is more advantageous comparing with the 2×2 variant, because it leads to reduction of average downtime of the particular machines by about 4%. On the minus side, this solution is associated with increased expenses on training of maintenance personnel.

In all variants tested, the maintenance strategy with no competence assignment (all-purpose special training of an electrician–technician) was more advantageous than assigning the competences. The most advantageous variant appears to be the one with five all-purpose qualified maintenance workers who can repair equipment regardless of the failure category. The average operational time in that variant was 82,84%; downtimes of machines were strongly reduced leaving the maintenance personnel time to perform other actions related to daily maintenance, such as control, alignment, lubrication, etc.

The current system of maintenance provision is sufficient in the given conditions. Implementation of other variants of maintenance systems would require changes in the manufacturing process and working load for the particular production lines. It would also be necessary to train the employees to prepare them for work in a changed manufacturing process which would require all-purpose maintenance qualifications.

Application of WITNESS software for the needs of optimization of manufacturing and maintenance processes is very convenient. The programme enables one to combine the knowledge of operations in manufacturing processes, maintenance, operational reliability, and economic optimization methods with simulation modelling, thus replacing traditional process reviewing approaches. Simulation experiments give a visual overview of how maintenance is performed, to what degree maintenance workers are engaged in production activity, how long the machines have to wait for maintenance, what the working load of employees is and other selected output parameters [10]. Such experiments allow one to optimize the number of personnel in the light of other external effects influencing the manufacturing process.

6.4. Possibilities in the modelling of distribution logistic chains

The transport and warehouse operations aimed at delivering material from the manufacturer to the customer and related information, managerial and control activities are designated with the term ‘distribution logistics’ [13].

The aim of distribution logistics is to make requested goods available to the consumers within a defined time, in the right place, in an agreed amount and quality, and at the same time to create an optimum ratio between delivery services and expenses. The point is that the chosen market roads should be optimally supported. Customers tend to reduce more and more the amount of own supplies and prefer to order merchandise in smaller amounts and at shorter delivery intervals. Their requirements force the suppliers to look for suitable delivery strategies ensuring high delivery preparedness and readiness without increasing the costs. The main problem areas of distribution logistics are [9, 10]:

- selection of the location of distribution warehouses,
- material storing,
- commissioning and wrapping management,
- dispatch of material and loading,
- transportation.

6.4.1. Design and development of a supply model

A supply model represents supply delivery, which usually takes place on the axis from a final producer (supplier) – to a central storehouse (or several storehouses) – to a purchaser (hypermarkets). Transportation of goods into storehouses (storehouse supplying) is usually provided by the manufacturer at its own expense, using its own means of transport or through an external forwarder based on requirements (orders) from storehouses. Purchasers supply themselves at their own expense using their own means of transport (a transport route) or through contractual forwarders. The requirements for self-supply (especially orders) come directly from the purchaser (final stage of the supplying process). Different procedures for planning and ordering of goods are applied in ordering goods with a long-term or an almost unlimited term for consumption which have a longer period of storage and different ones when ordering goods that require immediate consumption and have a short storage period. However, for both kinds of goods care is taken about the accuracy of orders (estimates), so that non-effective investment freezing and unneeded occupation of storage surfaces, and, in the case of goods with an immediate term of consumption direct loss caused by damaging of such goods are avoided. Therefore, for different kinds of goods, there are different amounts of reserve stocks, i.e. supplies exceeding estimates held in reserve in case an increased demand occurs at random for any of the goods.

Let us define the structure of a three-stage supply chain:

- The manufacturers V1, V2, V3, V4 deliver short-term consumption goods into storehouses S1 and S3.
- Long-term consumption goods are delivered by manufacturers V5, V6, V7, and V8 into storehouse S2.
- Storehouse S2 subsequently delivers goods into all shops O1, O2, O3 and O4.
- Storehouse S1 delivers goods to purchasers O1 and O2, storehouse S3 delivers goods to purchasers O3 and O4.

The purchasers maintain a certain level of reserves of each kind of goods in their own storerooms (buffers). The same is done by storehouses which dispose of greater stocks. When the stocks of the purchaser fall below a required level, he orders a new consignment. However, the required amount must reach a certain volume meeting the capacity of a means of transport; only then the order is submitted to the storehouse and is realized in accordance with the current working load of the storehouse. Structure of a supply chain is given in the figure (Fig 6.17).

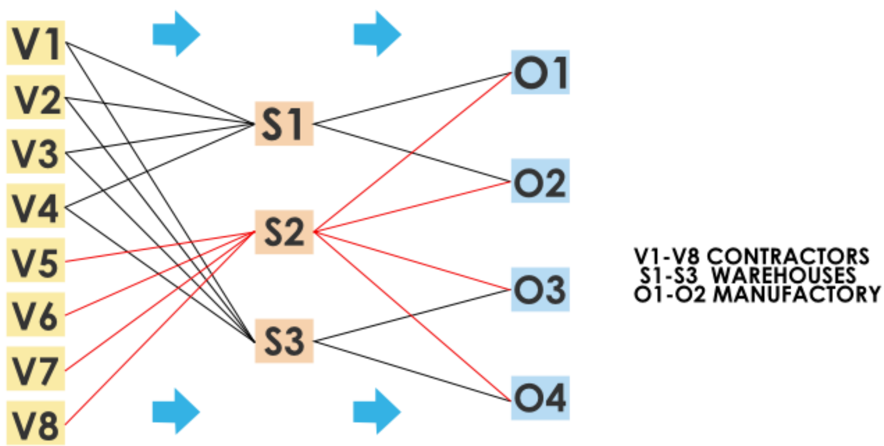

Fig. 6.17 - Structure of a supply chain

Proposed numbers of individual elements in a supply structure:

- 8 manufacturers delivering 8 kinds of goods:

V1 to V4 – deliver short-term consumption goods

V5 to V8 –deliver long-term consumption goods

- 3 storehouses:

S1, S3 – store short-term consumption goods

S2 – stores long-term consumption goods

- 4 purchasers:

O1 to O4 – order and receive goods from storehouses.

Defined distances (km) in the table (Table 6.6).

Table 6.6 - Defined distances (km)

Route	Distance	Route	Distance	Route	Distance
V1 – S1	100	V5 – S2	300	V1 – S3	90
V2 – S1	80	V6 – S2	160	V2 – S3	210
V3 – S1	150	V7 – S2	75	V3 – S3	25
V4 – S1	30	V8 – S2	220	V4 – S3	110

6.4.2. Characteristics and development of a simulation model

The supply model of a trade network is developed in line with the above-mentioned structure. In the model, products are referred to as goods _1 up to goods_8 (Part element). The manufacturers which deliver goods through their dispatching storehouses (Buffer element) are designated as producer_1 to producer_8. From dispatching storehouses, the products (goods) are transferred into storehouses formed by a stock magazine (Buffer elements; a1 up to a3) and a machine (element Machine; storehouse_1 to storehouse_3) in accordance with the proposed structure and supply needs. As each storehouse deals with four kinds of goods, so its buffers a1 up to a3 have each got four departments. The capacity of the individual buffers has been defined. Where supplies fall below the requested level (the capacity is not filled), additional supplies are ordered from a manufacturer. The shops are also defined as buffers (Buffer; b1 up to b4) and machines (Machine; Shop_1 to Shop_3). Buffer capacity is determined here as well (own storehouses). However, own storehouses of shops (b1 to b4) have already eight departments (b1 (1-8) to b4 (1-8)) as they take and subsequently sell each eight kinds of products. When the level of shop stocks decreases (it has been sold), the shop orders the needed kind of goods from a storehouse (storehouse_1 to storehouse_3). The outputs of goods from a shop (consumption, sale) are defined by a random distribution. Transportation of goods from manufacturers to storehouses is conducted by trucks (element designated as Vehicle; vehicle_v1s1 to vehicle_v8s2). The vehicles transport the goods on tracks (element Track; track_v1s1 to track_v8s2). Transportation of goods from storehouses to shops is done by camion transportation (camions), in a program defined through labor element. The consumed (sold) goods go to the final consumer, which is defined through the element of shipment SHIP.

The developed model with highlighted tracks of goods is presented in the figure (Fig. 6.18)

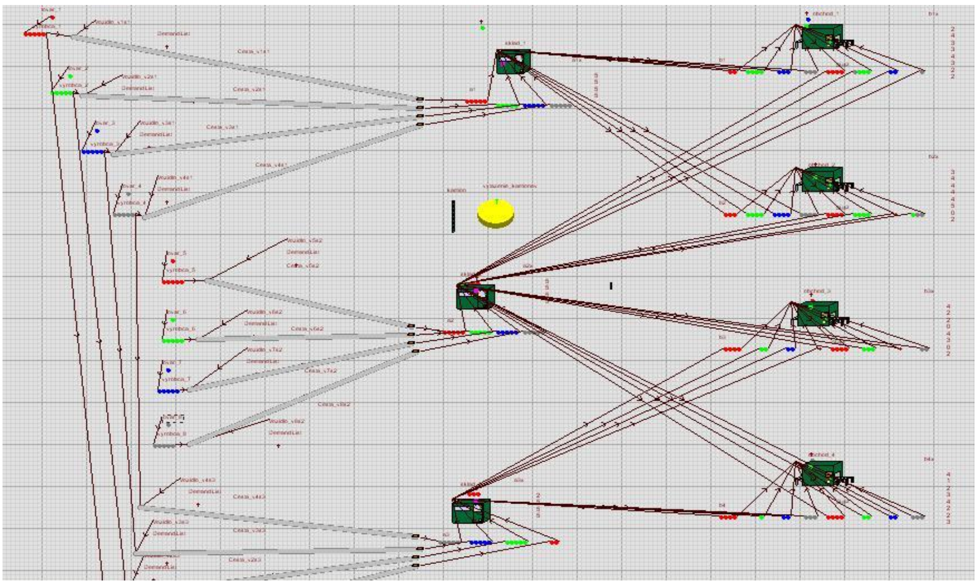

Fig. 6.18 - A developed model with highlighted tracks of goods

Elements of the model:

Goods: goods_1, goods_2, goods_3, goods_4, goods_5, goods_6, goods_7, goods_8 are defined by Part element.

Manufacturers: manufacturer_1, manufacturer_2, manufacturer_3, manufacturer_4, manufacturer_5, manufacturer_6, manufacturer_7, manufacturer_8 are defined by Buffer element.

Tracks: track_v1s1, track_v2s1, track_v3s1, track_v4s1, track_v5s2, track_v6s2, track_v7s2, track_v8s2, track_v1s3, track_v2s3, track_v3s3, track_v4s3 are defined by Track elements.

Vehicle: vehicle_v1s1, vehicle_v2s1, vehicle_v3s1, vehicle_v4s1, vehicle_v5s2, vehicle_v6s2, vehicle_v7s2, vehicle_v8s2, vehicle_v1s3, vehicle_v2s3, vehicle_v3s3, vehicle_v4s3 are defined by Vehicle element.

Storehouses: S1 to S3 are composed of two elements:

- buffers a1 (1-4) to a3 (1-4) defined by Buffer element.
- machines (storehouse_1 up to storehouse_3) defined by Machine element.

For example, the element storehouse _1 takes out the goods_1 up to goods_4 from buffer a1 (1 up to 4) (Edit Input Rule...) and ships them to buffers b1 (1-4) and b2 (1-4) of shops defined as shop_1 and shop_2 by camions (Edit Output Rule...).

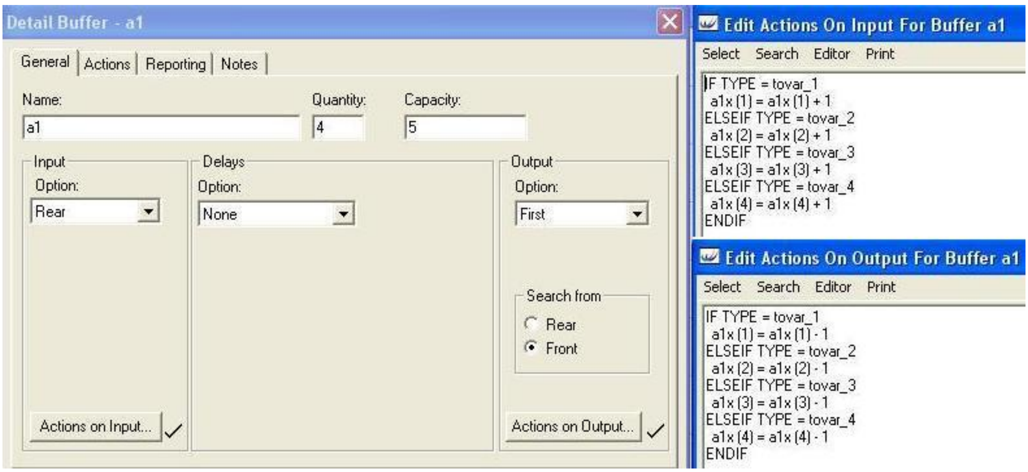

Fig. 6.19 - Setting-up the buffer a1 of a storehouse - storehouse_1

Camions: are defined by Labour element. A camion element has 4 l vehicles defined (Total Quantity).

Shops: O1 up to O4 are composed of two elements:

- buffers (storehouses of shops) b1 (1-8) up to b4 (1-8) are defined by Buffer element.
- machines (shop_1 to shop_4) defined by the element Machine.

For example, the buffer b1 has 8 departments defined (Quantity), as it stores 8 kinds of goods (goods_1 to goods_8), and a capacity 4 (Capacity) of supplying units. The variables b1x (1-8) allow tracking of the amount of particular kinds of goods located in the buffer (own storehouse of a shop). Setting-up of the buffer a1 of storehouse_1 is presented in the figure (Fig. 6.19). Settings of buffer b1 of the shop shop_1 is presented in the figure (Fig. 6.20).

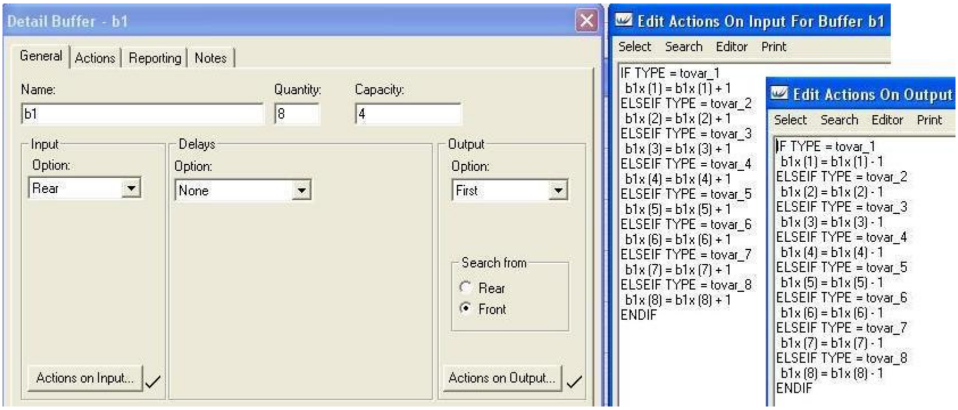

Fig. 6.20 - Setting of a buffer b1 of the shop shop_1

Element shop_1 provides the supply of goods_1 up to goods_8 from buffer b1 (1 up to 8) to the consumer (SHIP). Consumption of goods, time (Cycle Time) as well as the kind of goods being consumed (variable k) is defined by a random distribution.

<u>Variables:</u> a, b, c, d, a1x, a2x, a3x, b1x, b2x, b3x, b4x, e, f, k, x are defined by the element Variable. A variable b1x is defined as a variable of Integer type, and Quantity 8, so up to 8 variables are available b1x(1 to 8).

<u>Graphs:</u> - a pie chart: camions payload,

- Stocks time flow: level_stock_buffer_1, level_stock_buffer_2, level_stock_buffer_3, level_stock_buffer_1, level_stock_shop_2, level_stock_shop_3, level_stock_shop_4_x21. Cut-out from a model with description of elements from goods and manufacturers to the storehouse and elements buffer – shop is presented in the figure (Fig. 6.21).

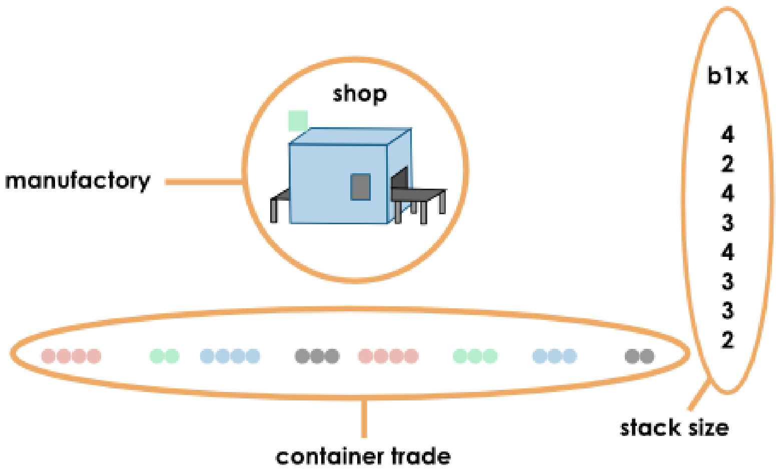

Fig. 6.21- Cutout from a model with description of elements from goods and manufacturers to the storehouse and elements buffer

As the above mentioned elements are defined and set for a model, the others elements of the same kind and their levels are set in a same way with regard to chosen parameters and requirements, e.g.: goods1_ to goods_8, buffer_1 to buffer_3, shop_1 to shop_3.

6.4.3. Aims and possibilities of simulation experiments

The requirements of the model are aimed at making the flows of goods more effective, so they do not create unnecessarily large stocks at particular storing stages. At the same time, they are also meant to prevent shortages or to allow only a minimal deficiency of particular items of goods, at the final stages of the supplying chain – in shops by using transportation capacities.

A time period of about 720 hours (approximately 1 month) was chosen to simulate a proposed supplying model of a shop network sampled for 24 hours. An initial level of storehouses and purchasers was filled with goods to a maximum capacity [8].

The developed model of supplying the shop network can be made more effective by adjustment of:

- storehouses capacity (a1 to a3) of particular storehouses (storehouse_1 to storehouse _3),
- capacities of own storerooms of particular shops (buffer b1 to b4),

- number of camions providing transportation of goods from storehouses to shops,
- number and capacity of vehicles transporting goods from particular manufacturers to storehouses.

Essential data on the number of items being transported, the level of stocks and shops and used tracks and distances as well as usage of transport capacities are the basic data from the point of view of supply. These data are available in the form of simulation statistics and graphs of activities of particular elements. Time flow of stock levels in the buffer of the shop_2 is presented in the figure (Fig. 6.22., Fig. 6.23.) .

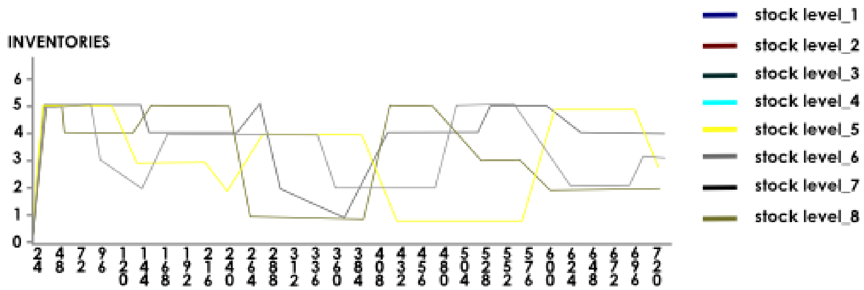

Fig. 6.22 - Time flow of stock levels in storehouse _2

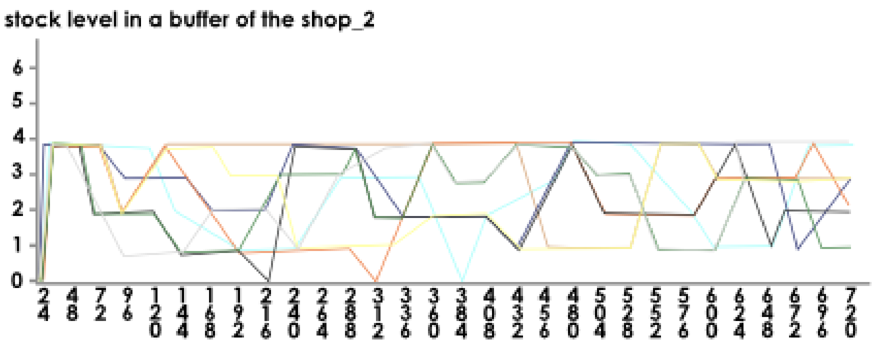

Fig. 6.23 Time flow of stock levels in the buffer of shop_2

6.5. Conclusion

A comparison of time flow charts with levels of stocks in particular buffers and storehouses of the non-optimized and optimized models shows that the storehouses are utilised more effectively [12]. The capacities of particular storehouses were significantly over-dimensioned in the non-optimized model. As a result, all storehouses and buffers for most of the time were generally fully filled, which was undesirable. This resulted in locking-up of a great amount of capital in stocks, as well as using an unnecessarily large storage area and caused huge storage costs as well as non-effective usage of transportation capacities. After having adjusted and decreased the capacities of particular storehouses and buffers and decreasing the number of vehicles and camions and increasing capabilities of some vehicles, the storehouses are filled up to such level of stocks that they provide a smooth operation of shops. Shortages of goods in shops occurred only in an acceptable minimum rate.

Usage of capacities of camion transportation in the non-optimized model was only 3.22%. In the optimized model and after their reduction, the rate of usage was 67.05%. Short-term consumption goods are transported more often in smaller amounts while long-term consumption goods are transported less often and in greater shipping amounts. The total distance covered between manufacturers and storehouses has decreased as well. Usage level of camions can still be increased by reduction of their numbers. But in this case, the risk of insufficient supply of shops and a lack of some kinds of goods might occur.

The statistic indicators show that the optimized model works in a more effective way. It results from a total comparison of both models (an initial and an optimized one) that an optimized model works more effectively. It meets the requirement of a sufficient supply of goods to shops by a more effective use of storehouses and means of transport. In addition, particular parameters can be specified in a greater detail, e.g., to provide a financial assessment of transported goods, to calculate costs for a transportation unit and transportation distance, to estimate the amount of storage room, etc. Further requirements can be formulated to optimize the proposed model based on this specification.

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7. **Determination of the statistical stability of a manufacturing process** – Alena Breznická, Alexej Chovenec

7.1. Statistical quality control

Basic tools used by managers dealing with quality should include seven basic statistical instruments. They are most widely used in operative quality management. Seven basic Instruments enable solving problems of quality improvement in manufacturing areas from determination of conditions by means of production sheets, through looking for ways and possibilities of their solution up to statistical regulation of improved processes. The basic Instruments include a check list, a histogram, causes and consequences diagram, Pareto´s analysis, correlation diagram, flowchart and a regulation diagram. These Instruments have been used also in solving a defined aim of work. Significance and importance of use of statistical Instruments and quality management methods in processes are discussed on an example case involving welding a connector on a copper wire of glued carbon brushes in an unnamed company.

The statistical methods and instruments used in industrial practice can be divided into three categories:

1. simple (basic, elementary) statistical methods,
2. medium demanding statistical methods,
3. more demanding statistical methods.

Simple methods include seven instruments: check tables and recorders, histogram, flowchart, correlation diagram, Pareto´s analysis, causes and consequences chart (Ishikawa´s diagram) and regulation diagrams. Medium demanding and more demanding statistical methods include e.g.: measurement system analysis, verification of manufacturing equipment capability, verification of process capability, statistical inspection, FMEA.

Quality control is defined by STN EN ISO 9000:2005 as a part of quality management aiming to meet quality requirements. Statistical quality control is a part of quality management, in which the procedures of mathematical statistics are used. There are three basic areas of statistical quality control: statistical process regulation, statistical (selective) inspection and methods of design of experiments.

In the process, the inputs are transformed to a product, on which the quality characteristics and quality indicators can be defined. Main problem of quality improvement is a reduction of variability of the values of quality indicators. Usually the variability of values of quality indicators can be reduced based on obtained results and finding such a combination of levels of variables being controlled optimizes process performance. After having indicated the most important variables having effect on the process, it is often useful to simulate relations between input variables and quality indicators of the product. When we know the character of relations between variables, the techniques of statistical regulation of the process can be applied in an effective way – as an instrument of the so called on-line quality control, enabling monitoring of a process and maintaining it in a requested condition. The process of implementation of methods of statistical quality control in organizations usually starts with applying statistical inspection (that is, selective inspection, when a decision is taken whether a batch is to be accepted or not based on results from selection or selections made from this batch), and goes on by implementation of a statistical regulation in a process; then, often the methods of design of experiments start to be applied [1].

7.2. Statistical regulation of processes

Statistical regulation of a process is a set of instruments for maintaining a process stability and improvement of its capability through a reduction of variability. A fundamental question in an organization aimed at the quality is a question, to what extent it is capable of meeting the expectations of the customers. When the expectations of the customers are defined, it is necessary that the supplier be able to quantify the extent to which he can satisfy such expectations. A product, which should be appropriate for use, should be generally produced in a stable or a repeatable process. It means that a process should be able to produce products with an acceptable variability of defined indicators of quality in terms of their defined aims or values.

Statistical regulation of a process represents a preventive approach to quality management, as it enables interventions into a process based on a timely detection of variations in a course of a process aiming to keep it for a long-time on a requested and stable level. Achieving and keeping a process on a requested and stable level is dependent on a comprehensive analysis of process variability, when it is needed to detect, how the process functions, what are its limitations and their reasons, whether they repeat and what kind of affect do they have on a process. Thus, statistical regulation of a process can be defined as immediate and continuous control of a process, which is based on a mathematical-and-statistical assessment of product quality. It provides information for operative and timely interventions into a process [6].

7.2.1. Random and definable causes

Basic principle of an analysis and improvement of processes and systems, defined by W. Shewhart [4] is based on a presumption, that variability of values of quality indicators are caused by two kinds of causes:

- *Random causes;* the causes being a permanent part of a process or a system and that influence all components of the process.
- *Definable causes*; the causes that are not a permanent part of a process or a system; however they occur due to specific circumstances.

A process or a system, which is affected only by a random cause is called a stable process; it means, that it is in a statistically managed condition. Only natural variability is involved in a stable process or in its products. It means, that a variability of output values can be predicted within statistically defined limits. A process whose outputs are influenced by random as well as definable causes is called a non-stable process. It means that it is in a statistically non-controlled condition. It is called non-stable as variability in various time sections is non-predictable. When the definable causes are identifiable and they are removed, the process becomes stable [3].

7.2.2. Determination of the statistical stability of a manufacturing process

Stability of a manufacturing process is the capability to observe technical and technological regulations and specified limit values in a certain time period. Aiming to reveal the causes why the process is violated, it is necessary to use such analysis which enables to seek and eliminate them. A process can be maintained in desired tolerances through statistical analysis. Statistical analysis and process regulation are interlinked and at the same time they influence stabilization of a manufacturing process in three phases [7]:

- definition of an instability of a manufacturing process,
- transforming the process from instable into a stable condition,
- keeping a process in a stable condition.

A regulation diagram ($\bar{x}, R$) for diameter and range was used to define an instability of a manufacturing process, which is one of the most widely used regulation diagrams due to its simplicity. The essence of this diagram is superior sensibility to extreme values within a subgroup.

The diagram determines the stability or instability of a monitoring process, i.e. whether the process has been put under control. In order to define the stability of a requisite amount of 125 products at 2 hour-intervals, the subgroups consisting of 5 products were sampled being assigned for analysis. The values of measured lines of carbon brushes are recorded in the table of measured values [2]. The values of measured lines of carbon brushes are presented in the table (Table 7.1) .

Tab. 7.1 – Table of values measured for SPC

	i	i	i	i	i	i	i	i	i	i
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
x_i	43.36	43.20	42.99	43.38	43.36	43.20	43.16	43.31	43.19	43.11
x_i	43.16	43.26	43.18	43.13	43.16	43.07	43.30	43.30	43.29	43.29
x_i	43.33	43.31	43.06	43.11	43.37	43.03	43.24	43.15	43.04	43.15
x_i	43.12	43.26	43.32	43.17	43.16	43.19	43.33	43.11	43.18	43.26
x_i	43.32	43.18	43.31	43.18	43.25	43.28	43.23	43.20	43.27	43.35
	i	i	i	i	i	i	i	i	i	i
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
x_i	43.25	43.24	43.21	42.99	43.18	43.19	43.33	43.18	43.37	43.05
x_i	43.09	43.13	43.18	43.14	43.36	43.05	43.20	43.08	43.14	43.19
x_i	43.04	43.07	43.01	43.27	43.14	43.19	43.34	43.09	43.25	43.23
x_i	43.08	43.16	43.32	43.24	43.22	43.36	43.24	42.98	43.20	43.23
x_i	43.24	43.24	43.39	43.12	43.23	43.06	43.22	43.13	43.11	43.21
	i	i	i	i	i					
	21	**22**	**23**	**24**	**25**					
x_i	43.15	43.17	43.22	43.18	43.09					
x_i	43.18	43.24	43.32	43.16	43.30					
x_i	43.30	43.18	42.97	43.00	43.15					
x_i	43.08	43.26	43.13	43.18	43.21					
x_i	43.20	43.21	43.20	43.19	43.25					

Values from the processing of descriptive statistics including mean value and range are presented in Tables 7.2 and 7.3).

Tab. 7.2 - Descriptive statistics including mean value and range

VARIABLE	DESCRIPTIVE STATISCIC			
	MEAN	MINIMUM	MAXIMUM	RANGE
SUBGROUP 1	43.26	43.12	43.36	0.24
SUBGROUP 2	43.24	43.18	43.31	0.13
SUBGROUP 3	43.17	42.99	43.32	0.33
SUBGROUP 4	43.19	43.11	43.38	0.27
SUBGROUP 5	43.26	43.16	43.37	0.21
SUBGROUP 6	43.15	43.03	43.28	0.25
SUBGROUP 7	43.25	43.16	43.33	0.17
SUBGROUP 8	43.21	43.11	43.31	0.20
SUBGROUP 9	43.19	43.04	43.29	0.25
SUBGROUP 10	43.23	43.11	43.35	0.24
SUBGROUP 11	43.14	43.04	43.25	0.21
SUBGROUP 12	43.17	43.07	43.24	0.17
SUBGROUP 13	43.22	43.01	43.39	0.38
SUBGROUP 14	43.15	42.99	43.27	0.28
SUBGROUP 15	43.23	43.14	43.36	0.22
SUBGROUP 16	43.17	43.05	43.36	0.31
SUBGROUP 17	43.27	43.20	43.34	0.14
SUBGROUP 18	43.09	42.98	43.18	0.20
SUBGROUP 19	43.21	43.11	43.37	0.26
SUBGROUP 20	43.18	43.05	43.23	0.18
SUBGROUP 21	43.18	43.08	43.30	0.22
SUBGROUP 22	43.21	43.17	43.26	0.09
SUBGROUP 23	43.17	42.97	43.32	0.35
SUBGROUP 24	43.14	43.00	43.19	0.19
SUBGROUP 25	43.20	43.09	43.30	0.21

Tab. 7.3 - Descriptive statistics

VARIABLE	DESCRIPTIVE STATISTICS	
	MEAN OF MEANS	MEAN OF RANGE
MEASURED VALUES	43.20	0.42

In order to define stability of the manufacturing process, it was necessary to compute values of regulation limits according to the standard STN ISO 8258.

7.2.3. Analysis of stability of the manufacturing process

The data measured were analyzed using Palstat software. Its main task is computer aided statistical regulation of a process, monitoring and taking measures of processes, verification of processes and machine capabilities.

It helps determine which remedies are to be implemented in a process in order to achieve its stability and cost reduction through lowering of defectiveness. Values calculated using Palstat software are presented in the Fig. 7.1.

Outputs:

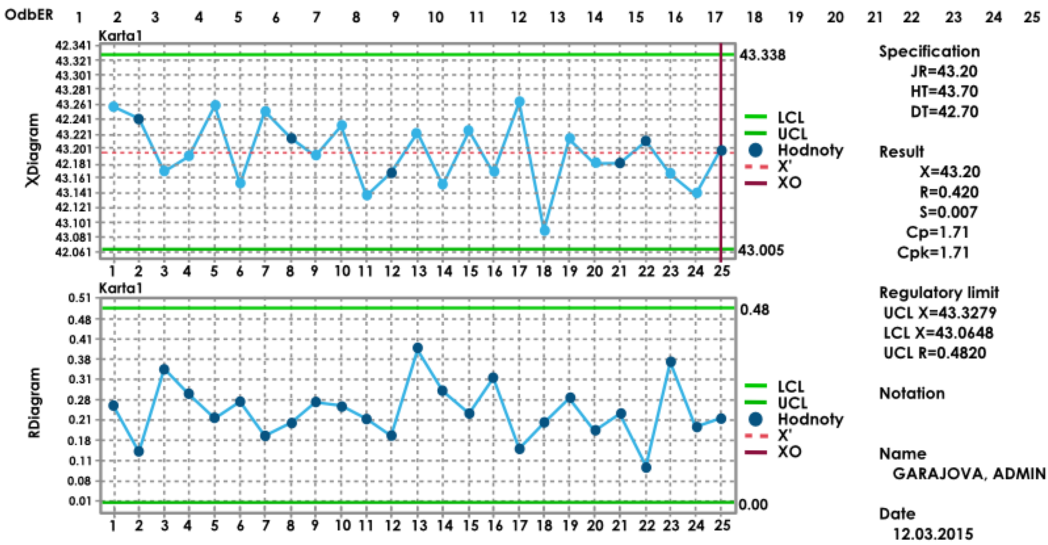

Fig. 7.1 - Regulation diagram for mean and range

The regulation diagram for mean and range shows that the process is statistically ‘in control’. Regulation limits were exceeded in neither case, so the process is stable. We can say that the regulation diagram for this particular process had been properly chosen. Information whether the values of an attribute sufficiently approximate the normal distribution was obtained through an analysis of values plotted onto a probability grid.

The results of the normal distribution test are shown in the figure (Fig. 7.2). The green line shows ideal values and the blue line marks real measured values. The red line shows the difference in significance between the measured values. Resulting values are presented in Fig. 7.3. It follows from the analyses that the process of welding a connector onto a copper line of a carbon brush is stable, so the customer´s requirement has been met; this means that series production can be started.

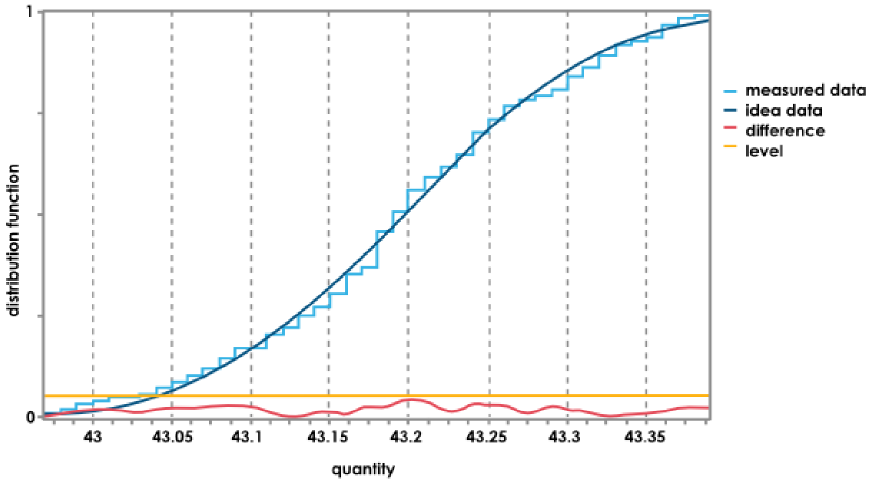

Fig. 7.2 - Normal distribution test

Parametr	Value
X'	43,196
R	0,42
S	0,097
Minimum	42,97
Maximum	43,39
Cp	1,71
Cpk	1,70
Cp	stable process
Cp	1,78
Cpk	1,77
UCL X	43,328
LCL X	43,065
PE	0,000 %
Nad HT	0
Pod DT	0
out of tolerance	0,00 %

Fig. 7.3 - Assessment of SPC analysis

Then we acted upon a check plan. In the next part of the study we focused on the production line, where measurements of the dimensions of pieces cut away are taken with a slide gauge with a digital display, which is considered objectionable in terms of the number of faulty pieces. In addition to improving the manufacturing process through an implementation of the SPC method, we planned to adopt a new measuring method in the production line. As we can see in the table below, we analyzed measurements in three operators, who had taken measures of the cutting angle in ten products with three repetitions. Resulting values are presented in the table (Table 7.4).

Tab. 7.4 - Analysis of measurements operators

	OPERATOR A			OPERATOR B			OPERATOR C		
	1st series	2nd series	3rd series	1st series	2nd series	3rd series	1st series	2nd series	3rd series
1	89.341	89.016	89.825	90.033	90.175	91.133	91.100	89.791	90.525
2	89.692	88.908	89.333	89.691	90.400	89.566	90.300	91.041	90.691
3	88.691	88.891	89.175	89.566	90.358	89.366	89.883	90.441	90.066
4	88.716	90.441	89.066	89.491	90.400	89.858	89.283	89.975	89.991
5	89.491	90.258	89.091	89.375	90.200	90.973	89.033	89.941	89.750
6	89.550	90.083	89.300	90.116	89.725	88.866	90.366	90.025	90.583
7	89.558	89.966	88.883	90.350	89.116	89.750	89.983	90.775	90.558
8	89.575	89.975	89.708	88.800	90.386	89.066	91.008	90.208	90.583
9	88.858	88.608	90.100	90.008	90.073	89.325	90.841	90.200	90.075
10	88.891	89.850	89.916	90.316	90.666	90.483	90.033	90.600	89.966

We used measuring system analysis (MSA) to define the capability of that particular measuring gauge, namely through indicators of repeatability and reproducibility. The analysis of this measuring method is based on tolerance. Acceptable tolerance range of the cutting angle is 91.5 up to 88.5 degrees and a mean required value is 90 degrees. The table below shows the measured values expressed as a variance, or a discrepancy from the mean value as well as characteristics for calculating required indicators. Resulting values are presented in the table (Table 7.5).

Analysis of the process capability was performed based on data obtained from regulation cards filled in with sufficient ranges of values. We drew the above mentioned regulation diagram for a median and range so that we can analyze a particular process. We can see from diagrams, that in the process there are no definable causes and it is statistically in control.

Tab. 7.5 - Table of descriptive statistics

	OPERATOR A									
	1	2	3	4	5	6	7	8	9	10
1 series	-0.659	-0.308	-1.309	-0.284	-0.509	-0.450	-0.442	-0.425	-1.142	-1.109
2 series	-0.984	-1.092	-1.109	0.441	0.258	0.083	-0.034	-0.025	-1.392	-0.150
3 series	-0.175	-0.667	-0.825	-0.934	-0.909	-0.700	-1.117	-0.292	0.100	-0.084
R_A	0.809	0.784	0.484	1.375	1.167	0.783	1.083	0.400	1.492	1.025
R_A	0.940	$\bar{X}_A$	-0.541							
	OPERATOR B									
	1	2	3	4	5	6	7	8	9	10
1 series	0.033	-0.309	-0.434	-0.509	-0.625	0.116	0.350	-1.200	0.008	0.316
2 series	0.175	0.400	0.358	0.400	0.200	-0.275	-0.884	0.383	0.073	0.666
3 series	1.133	-0.434	-0.634	-0.142	0.973	-1.134	-0.250	-0.934	-0.675	0.483
R_B	1.100	0.834	0.992	0.909	1.598	1.250	1.234	1.583	0.748	0.350
R_B	1.060	$\bar{X}_B$	-0.079							
	OPERATOR C									
	1	2	3	4	5	6	7	8	9	10
1 series	1.100	0.300	-0.117	-0.717	-0.967	0.366	-0.017	1.008	0.841	0.033
2 series	-0.209	1.041	0.441	-0.025	-0.059	0.025	0.775	0.208	0.200	0.600
3 series	0.525	0.691	0.066	-0.009	-0.250	0.583	0.558	0.583	0.075	-0.034
R_C	1.309	0.741	0.558	0.708	0.908	0.558	0.792	0.800	0.766	0.634
R_C	0.777	$\bar{X}_C$	0.254							

where:
R – range of values in particular operators,
R – mean of value ranges,
X – mean of measured values.

Thus, it meets the additional requirement of process capability analysis. Analysis through SPC regulation diagrams is shown in the figure (Fig.7. 4).

Based on the same data used in regulation diagrams, we compute a capability index Cp, which expresses what we are able to achieve and Cpk, showing us a fact – what we had achieved and therefore a fact about the process condition. We analyzed the capability of this particular process using Minitab *12* software for Windows and the results are given in the figure (Fig . 7.5).

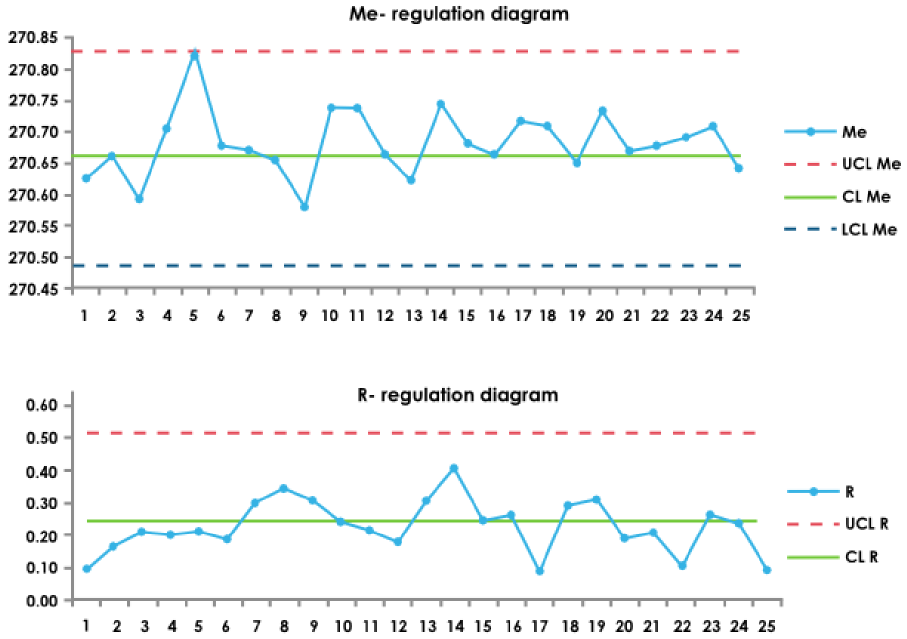

Fig. 7.4 - Analysis through SPC regulation diagrams

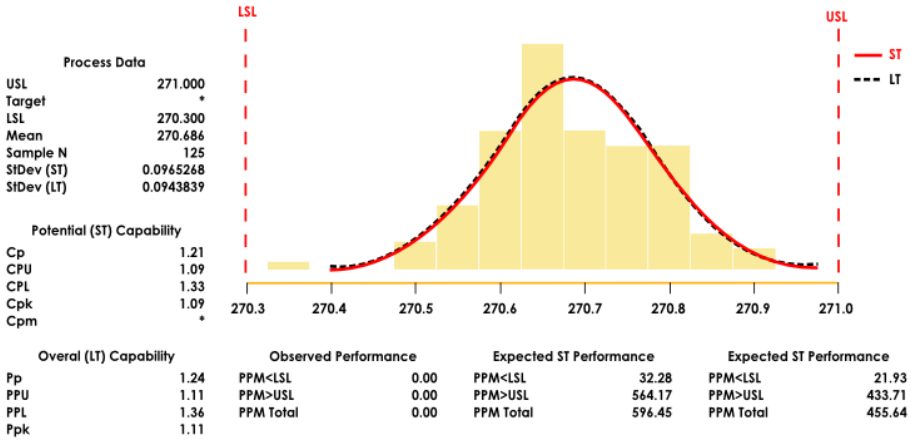

Fig. 7.5 - Assessment of an analysis through a histogram

7.3. The analysis of a process, manufacturing facility and measuring system capability

An important factor determining the quality of products is the quality of processes, through which these products come into being. A suitable criterion to assess their quality is their capability, which can be characterized as the ability of a process to permanently provide products meeting requested criteria of quality. Measures of capability are capability indexes.

The analyses of capabilities of processes are carried out as early as during the planning of product quality. Their results will verify or confirm whether a particular process is able to provide permanent products of desired quality. The obtained information about process capability represents important information for the manufacturer as well as forcustomers, and provides evidence on the fact whether the products are produced in stable manufacturing conditions. Additional information is provided by an assessment of manufacturing facility capability. This capability characterizes the ability of a manufacturing facility to provide products meeting requested quality criteria. Aggregate information allow reviewing of variability rate of a quality indicator being observed determined by a particular manufacturing facility and variability resulting from other sources (e.g. impact of materials, crew, maintenance, etc.) A large amount of data is used in te analysis and therefore it is important to know the features of measurement systems having been used. This information is an essential basis for assessment of the quality of measured data and selection of an appropriate measurement system.

The indexes Cp, C_{pk}, C_m, C_{mk}, C_g, C_{gk}, P_p, and Ppk are used in practice. Their description, importance and calculation are discussed in detail in the practical part, where some of them are being used.

The above mentioned methods were developed in real conditions of a company, which focuses on the production of carbon materials, semi-finished products and finished pieces. It has been active in electrical engineering, mechanical engineering, transport, automotive industry, chemical and metallurgical industry [4].

7.3.1. Verification of the capability of a manufacturing facility

Capacity of a manufacturing facility is characterized by the capability of a machine to provide products, which meet the required criteria of quality.

The capability is defined before the production of a new product begins or before series production starts. Therefore it is imperative that roughly similar conditions of its operation be ensured, such as the same crew, the same material, the same settings of manufacturing equipment etc. so that the features of products being produced are affected wholly by manufacturing equipment. Capability of manufacturing equipment is assessed through C_m and C_{mk} indexes.

The presented analysis of the capability of a manufacturing process was implemented in a company in Slovakia. It operates in automotive industry; it produces and delivers various components on the market, such as headlights, taillights, carbon brushes etc. Before starting an assessment of the capability of a manufacturing facility, we visited a part of the plant, where we chose strategically important production equipment for further analysis.

The measured data are processed through a statistical software interface of the Statistical programme. A working device was set in accordance with requirements defined by the manufacturer. Stranded wires are produced on a working device by a technological procedure. A setter checked the setting of a machine with regards to the requisite tolerance in production of the length of a particular stranded wire 43.20 ± 0.5 [mm]. Subsequently, he had the first pieces measured and checked, to be accepted only by an interoperation supervisor. After the release of the first conforming pieces, he started the welding process of a connector with a stranded wire of a glued carbon brush.

Before assessment, 50 samples of following products were taken and measured. The values measured are given in the table of values for Cm and C_{mk} capability indexes (Table 7.6).

Tab. 7.6 - The measured values for Cmand C_{mk} capability indexes

i	1	2	3	4	5	6	7	8	9	10
X_i	43.20	43.12	43.10	43.09	43.28	43.25	43.18	43.18	43.31	43.24
i	11	12	13	14	15	16	17	18	19	20
X_i	43.34	43.09	43.31	43.07	43.23	43.35	43.29	43.32	43.30	43.36
i	21	22	23	24	25	26	27	28	29	30
X_i	43.20	43.14	43.10	43.23	43.29	43.27	43.11	43.31	43.17	43.34
i	31	32	33	34	35	36	37	38	39	40
X_i	43.34	43.23	43.12	43.29	43.32	43.26	43.26	43.31	43.36	43.28
i	41	42	43	44	45	46	47	48	49	50
X_i	43.39	43.34	43.35	43.19	43.26	43.32	43.19	43.08	43.29	43.13

Then the values were analyzed and particular measured values are represented in the sheet of measured values. A given process was assessed through a regulation chart. The result is presented in the figure (Fig. 7.6).

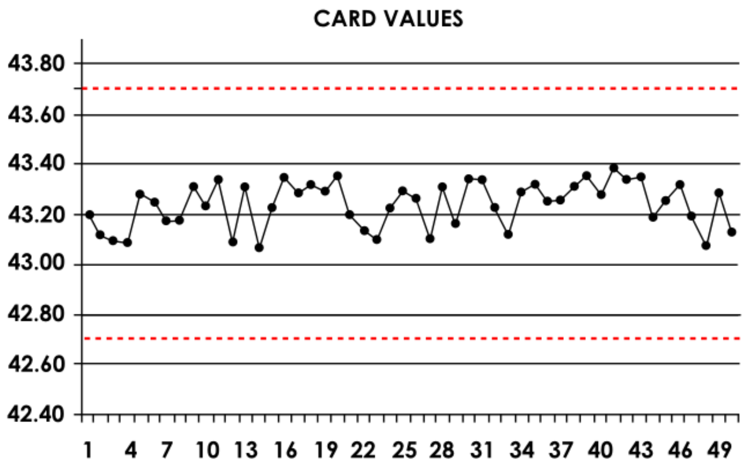

Fig. 7.6 - Sheet of measured values

Then the normality of measured data was verified through a statistic tool, namely a histogram. The result is presented in Figure 7.7.

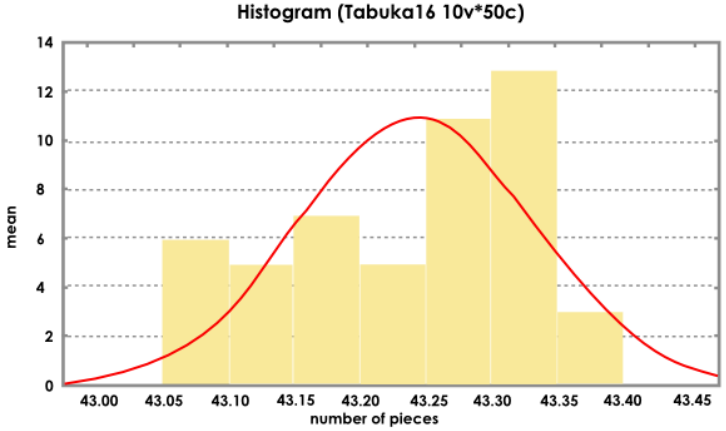

Fig. 7.7 - Histogram

Histogram is of a symmetrical shape with its top point close to its nominal value. This bell-bottomed shape proves a Picture of a normal Gauss distribution. The measured values are verified by a normality test, which proves that the values resulted from a normal distribution for confirmation and for a better visualization of a normal distribution in the figure (Fig. 7.8).

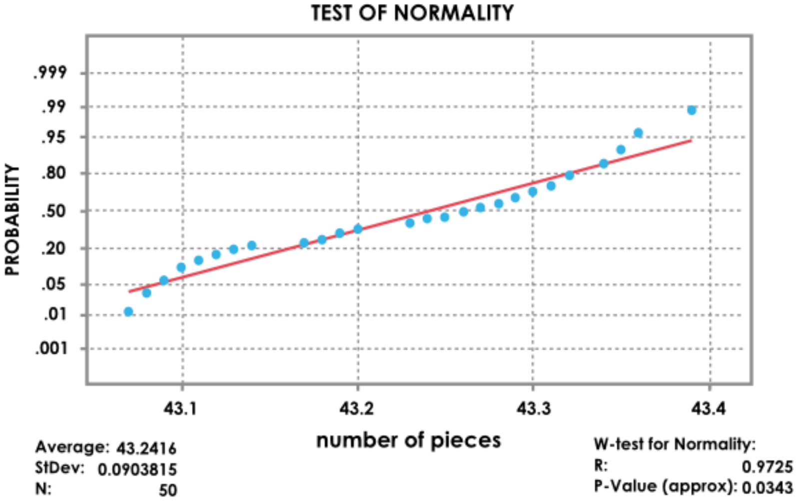

Fig. 7.8 - Normality test

To calculate indexes of capabilities of a manufacturing facility it is necessary to calculate the value of standard deviation:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} \tag{7.1}$$

where: n – a total number of measured values,

$\bar{X}$ - a mean value computed from all measurements [mm],

Resulting values of capability of a manufacturing facility are presented in the figure (Fig. 7. 9). Based on the assessment, the manufacturing facility can be considered as capable if the value of the index $C_m \geq 1.66$ and the value of the index $C_{mk} \geq 1.67$.Based on analysis and after having compared the capability indexes Cm=1.84 and C_{mk}=1.69 we concluded that the capability of the manufacturing facility had been confirmed.

Parameter	Value
X'	43,242 mm
R	0,32 mm
S	0,090 mm
Minimum	43,07 mm
Maximum	43,39 mm
Cm	1,84
Cmk	1,69
UCL X	43,700 mm
LCL X	42,700 mm
PE	0,000 %
PPM	0,00
Nad HT	0
Pod DT	0
out of tolerance	0,00 %

Fig. 7.9 - Resulting values of capability of a manufacturing facility

7.3.2. Verification of the capability of a measuring device

Assessment of the capability of a measuring system is performed before the first use through capability indexes C_g and $C_{gk.}$ These indices compare variability of repeated measures and they determine whether a measurement result lies with the 99.73% probability within a given tolerance range of a measuring device, in which case the measuring system is to be used. The aim is to verify the capability of a measuring device with a deviation gauge and to meet a given requirement for a measuring system precision in a process. These gauges are applied in a significant rate of measures taken in a particular company in a manufacturing process.

Capability of a measuring device refers to:

- a functional capability of a measuring device,
- takes into consideration the range of influence by the crew of a measuring device, its place as well as application.

Tests verifying the capability of a measuring system took place in a metrological laboratory of a particular organization at a given 20°C temperature of measurement. Nominal value was 43.30 mm. Measurement of a glued carbon brush with a connector in a measuring device with a deviation gauge was performed 50 times in short time intervals.

7.4. Defining the possible reasons of unconformable products in a welding process

During the process when a connector is welded on a copper stranded wire of a carbon brush, various defects can occur which are influenced by a human factor, methods, materials, environment and equipment. They may cause an increase in unconformable products in the process. Based on it, the employees received a form in order to record occurring faults and their consequences on product quality upon initiation of a testing pre-series production. The form had been developed by a team assigned to the new project based on a personal discussion with the quality manager together with the chief of production technology, which provided needed information for its development. In the next step, the employees filled in and scored possible reasons that had been divided into main categories by their importance affecting the quality. The score limit was defined in points from 1-5 by requirements defined in advance. 1 point represents the lowest weight assigned to the cause of a defect; whereas 5 points represent the highest weight. The scored forms were then processed and delineated into a so called fishbone diagram (Ishikawa´s diagram). Thereby we gained an overview which of reasons jeopardizing the quality of the product were important and decisive. Then we assessed them by a Pareto analysis [5] shown in the figure (Fig. 7.10, Fig. 7.11).

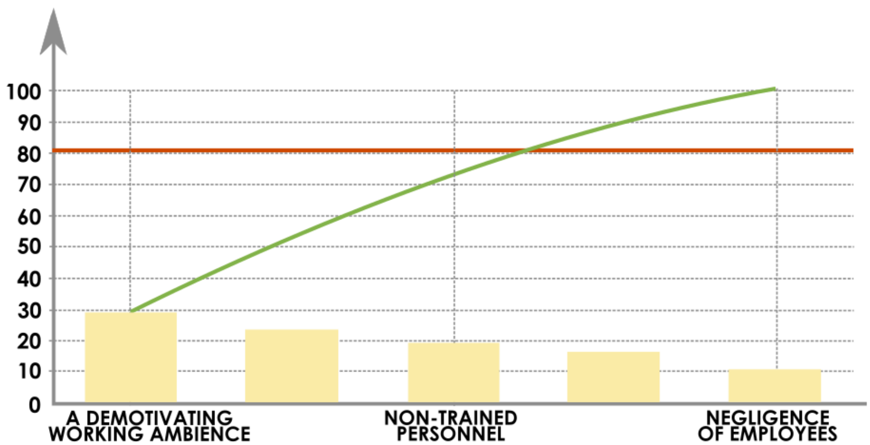

Fig. 7.10 - Pareto diagram for the “Material” category

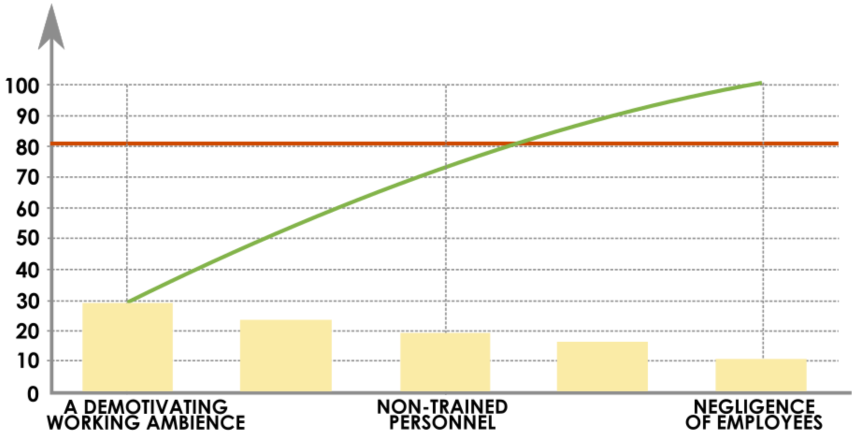

Fig. 7.11 - Pareto diagram for the "People" category

The most significant reasons were chosen from Pareto analyses having the value of percentage share lower or equal to 80%.

- Within the "**Material**" category, there is: damaged material, stolen material, different kind of a connector.
- Within the "**People**" category, there is: a demotivating working ambience, non-trained personnel, negligence of employees.
- Within the "**Methods**" category, there is: violated temperature of a weld seam, violated technological procedure, omitted operation.
- Within the "**Environs**" category, there is noise, unstable temperature, dust nuisance;
- Within the "**Equipment**" category, there is: defect of a device, a jammed container, improper setting.

For the above mentioned assessment, it is possible to use capability indices that compare the standard maximum admissible variability of values defined by tolerance limits with the real variability of a monitored attribute that had been obtained in a process statistically in control. Without appropriate measuring equipment and metrological procedures we are unable to define process capabilities in an adequate way. The measuring system research was aimed at assessing statistically by which rate its repeatability and reproducibility distort the fact being assessed. This paper describes external and internal effects on requisite values using examples of increased accuracy and correctness of measurements and at the same time an application of the capability index of the process being monitored. For a practical interpretation of indices, it is important to choose properly a combination of indices, which means not to compute indices for which the presumptions are not met or to complete them with a graphical presentation of a distribution of the monitored attribute of quality, target values and toleration limits. It results from the preliminary capability of the process that the process meet the criteria requested by the customer, such as indices Pp and Ppk> 1.67. We can thus say that a process is qualitatively capable. The preliminary research of the capability of a welding process is followed by further monitoring of the process when the connector is welded on a copper stranded wire of carbon brushes. It is aimed at securing its stability.

7.5. Possible applications of a regression analysis in a manufacturing process of rotating parts

Our discussion of a problem in the production of rotors has been based on data obtained through measuring of an outer diameter of a rotor after the last phase of production – a turning operation. In addition to a diameter, the measuring equipment assesses additional parameters that will not be evaluated in detail. The tolerance limits for a rotor diameter were defined by a customer and were ranging from 41.56 – 41.63 mm. All produced rotors are subject to control measurements on a measuring device shown in the figure (Fig. 7.12); data are recorded and saved on a computer. Computer screen is presented in Figure 7.13.

Fig. 7.12 - Measuring device taking measures of the rotor parameters

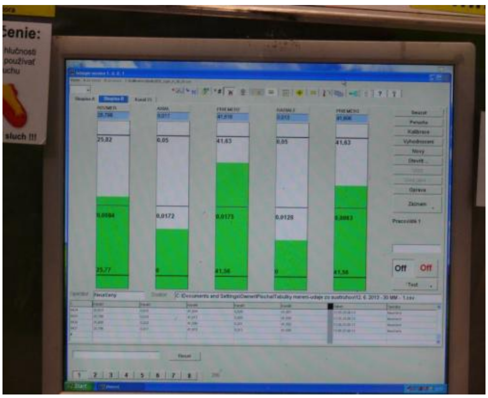

Fig. 7.13 - Computer screen with measured parameters

If a maintenance crew alters machine settings, it means the instrument replacement and calibration is recorded as a line with a non-numerical value “***”. However, identification and the range of the intervention cannot be determined. Replacement of an instrument occurs nowadays in intervals that are not precisely defined; however they are subject to daily inspection. Current solution is not based on a prediction but rather on replacement of instruments during shifts or even upon finding that defective pieces have been produced. The turning operation itself is performed on CNC automatic machines; a work-piece is inserted manually. After the turning operation a rotor is to be cleaned and inserted into a measuring device. KORLOY ® DCGT11T304-AK tool equipped with a plate is used for the turning operation. Material of a surface being lathed is reinforced with glass fiber; an appropriate tool was chosen based on results from empirical testing and it is not the subject of this paper. However, we can assume that it has significant effect on prediction in the moment of tool replacement.

Data about rotor diameters gained in a monitored period can be graphically presented by means of a graph, where the 41.56 and 41.63 values are the limits accepted by the customer. UCL and LCL were computed for each set separately. We use Minitab16 software for computations. Diameter of rotors produced in particular days is shown in the following graphs; for the purpose of illustration, only some graphs have been chosen in the figure (Fig. 7.14).

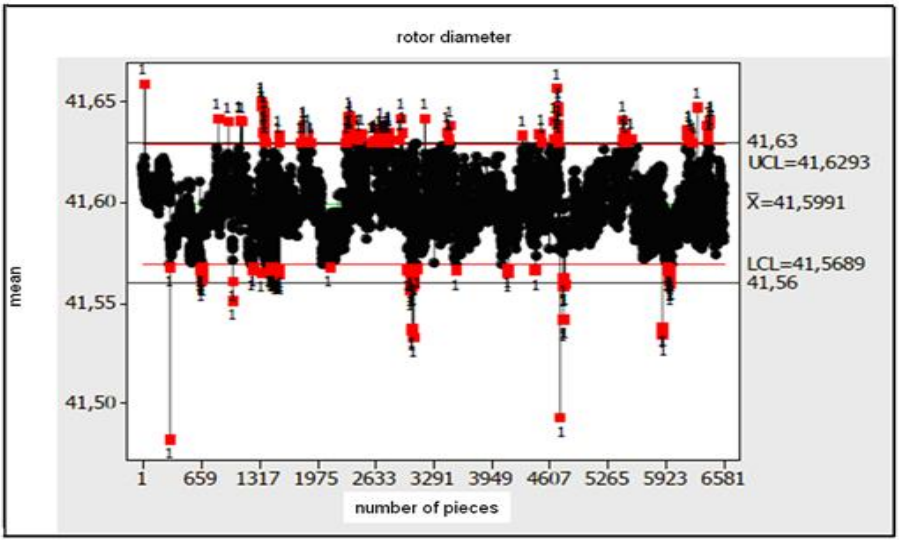

Fig. 7.14 - Diameter of rotors of particular pieces during the whole monitored period

The monitored period covers 5 working days in a two-shift operation, i.e. 10 shifts. Production cannot be considered as evenly spread – particular shifts produced different amounts of rotors – depending on requirements of the customer.

There were produced 6685 rotors during the monitored period, 79 pieces were produced with a larger diameter than requested by a customer – however they were repairable, as well as 22 pieces with a smaller diameter which were irreparable. Inconsistent products represent 1.51%. The irreparable products represent 0.33 % from the total number. In line with the 6σrequirement (representing about 0.227 defective products from the number of 6685 produced pieces) it represents a high level of non-conformity. Measurement of each rotor ensures an early disclosure of a non-conformity that does not reach a customer thanks to such measure. When trying to compare rotors produced in particular shifts or days, the data with low or no predicative values are accumulated. Diameter of rotors produced in particular days are shown in the following graphs; for illustration purposes, only some graphs have been chosen in the Fig. 7.15. The result is shown in the figure (Fig. 7.15).

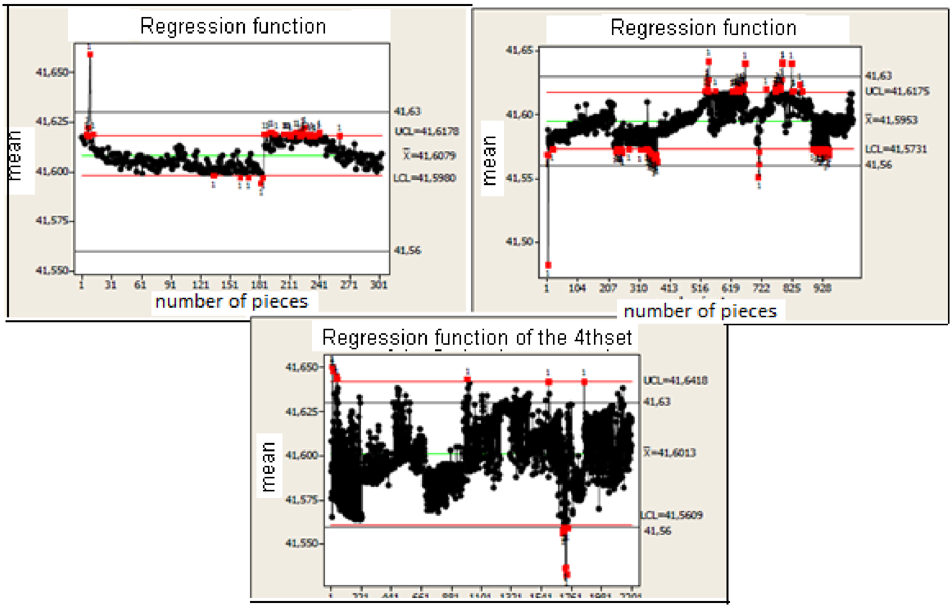

Fig. 7.15 - Diameter of rotors produced from the first until the n-th day

If the data from particular days were combined, the statistical outputs would not be correct. Therefore it is necessary to divide the set by more appropriate classification; in our case, we divide the set into sub-sets by maintenance crew intervention, which is identified by a “****” mark in the record from the measuring device. Some sets designated with this mark contain only several records and therefore can be considered as statistically insignificant. As a rule, it involved a verification of the proper setting of the tool machine. Other sets contain several hundreds of data units concerning the produced rotors. These sets are significant for our analyses. A set of data was divided into 24 sub-sets in a chronological sequence.

In the first phase, during the production of the 1^{st} set, when 184 pieces of rotors were produced, we could formulate the suggestion that after having implemented the new instrument and its correction (at the beginning of the production there were several pieces of rotors above the UCL level, however still within the tolerance range provided by the customer); production course is stable and within limits provided by the customer. The process is stable with an increasing number of rotors produced; the production continues in accordance with the requirements. It should be noted that there were relatively few rotors produced in this set. The result of the histogram – rotors produced as the 1^{st} set, is shown in the figure (Fig. 7.16).

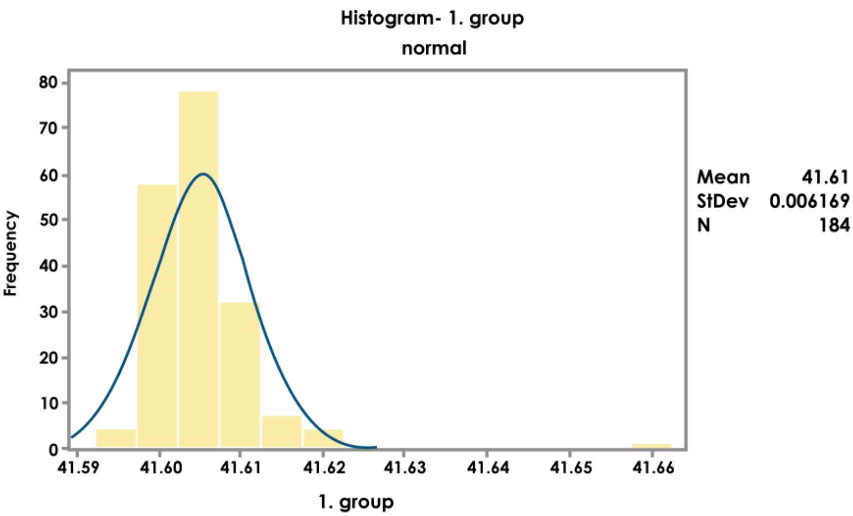

Fig. 7.16 - Histogram – rotors produced as the 1^{st} set

When interpreting a quality control chart (Fig. 7.16) based on data from the 1st set we can consider the manufacturing process as statistically in control; however, there are also values far from the mean value. The rotors with such values were produced in the first phase – we can consider them as "setting" as well as in the last phase of tool lifetime. One rotor was produced which was inconsistent with the requirements of the customer; namely, its diameter was larger – however it is repairable, but it must be subject to a repeated turning operation. With regard to the low number of rotors produced as the 1st set, our further analysis involves sets with a greater number of produced rotors, where we can assume an increase in the number of non-conformities. In the following steps, we will use the method of regression analysis using fundamentals of a trend function.

These sets contain more than 300 produced rotors within the monitored time period, and allegedly they were interrupted by no maintenance intervention. Production of non-conformed products occurred in these sets. Particular sets will be subject to a regression analysis aiming to define a regression function by the method of least squares. We are going to use Minitab and MS Excel software as detection tools. We can obtain outputs through a regression analysis in the table form Table 7.7. A regression function by the previous analysis can be described in the form:

$$y = b_0 + b_1 \cdot x \tag{7.1}$$

In our case, for the linear regression of the 4th set the following is valid:

$$y = 41{,}58 + 0{,}000037 \cdot x \tag{ 7.2}$$

Coefficient y – represents a dependent variable – diameter of the rotor, while x is an independent variable–the sequence of the produced rotor. Locating constant b_0 indicates the size of y at a zero value of x, which does not always have a logical interpretation; in our case, we should consider it as a value, which was previously set on the tool machine. Regression coefficient b_1 gives information about the average change of y, that is by how many measuring units the y value will change if x changes by 1 measuring unit. Importance of parameters is presented in the table (Tab. 7.7).

Table 7.7 - Importance of the parameter and P value – the 4th set

	REGRESSION ANALYSIS	
	t Stat	P val
Locating constant -b0	52367.013	0
Regression coefficient -b1	19.157951	3.9708E-66

If the value of P parameter P<0.05, the model is considered as statistically significant. We can interpret it as follows:

- with 95% confidence, the value of the locating constant will range in the interval from 41.57851556 up to 41.581633,
- with 95% confidence, the value of the regression coefficient will range in the interval from 0.0000335541 up to 0.0004122. We can interpret them as follows in the table (Tab. 7.8).

Table 7.8 - Intervals of confidence -the 4th set

	REGRESSION ANALYSIS	
	lower 95%	upper 95%
Locating constant -b0	41.57851556	41.581633
Regression coefficient -b1	3.35541E-05	4.122E-05

Regression function of the 4th set - polynomial of the 2nd order–square-law function is presented in the figure (Fig. 7.17).

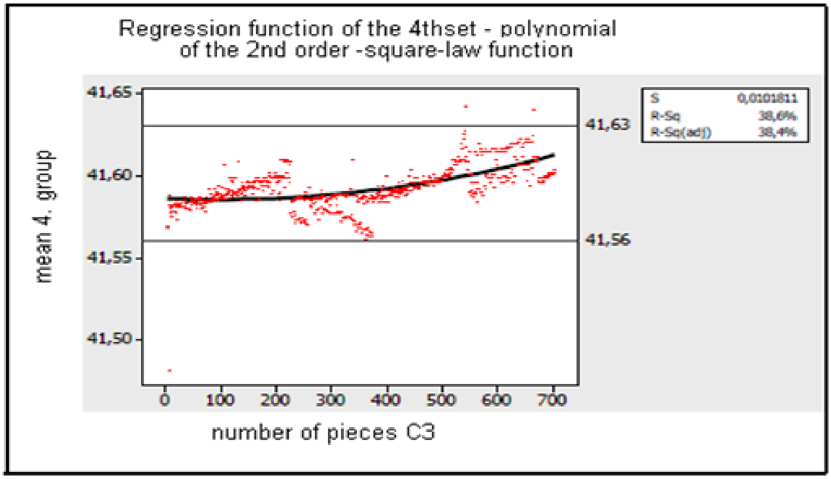

Fig. 7.17 - Regression function of the 4th set - polynomial of the 2nd order - square-law function

Likewise, a regression function is expressed in a square-law form in the figure (Fig. 7.18).

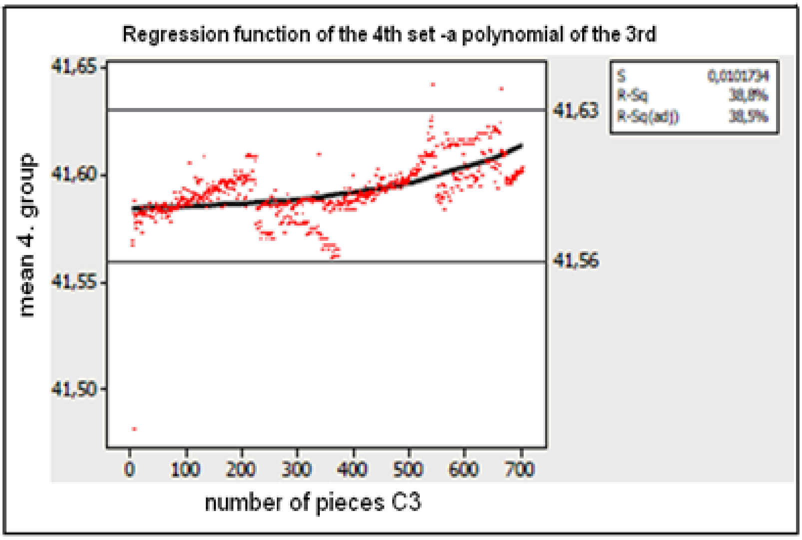

Fig. 7.18 - Regression function of the 4th set -a polynomial of the 3rd degree – a cubic function

A regression line represents in a simple way the relation between dependent and independent variables. The deviations in this relation are important as well. They represent the range in which a future value will probably occur. A confidence interval is an interval, in which a parameter of a basic set inheres. For example, we can predict with 95% certainty that the value of a parameter of a basic set inheres in a particular interval. The width of a particular interval thus represents the proper variability of values in a basic set and it is indirectly proportioned to a sample size, the lower is a range – the wider is an interval. A prediction interval is assigned for individual monitoring; a confidence interval is assigned for values of a regression line.

A prediction interval for a future observation y at a given value of x is:

$$(\hat{y} - ts_{y.x}\sqrt{Q_{2,}}\ \hat{y} + ts_{y.x}\sqrt{Q_2}\ ) \tag{7.3}$$

Q_2 =1+Q_i – Q_i value is degrees of freedom tends to zero, t – critical value of the Student´s distribution with n-2 degrees of freedom determining confidence interval [5]. In our case, we graphically illustrate a confidence interval and a prediction interval for the 4th set in the Fig. 7.19.

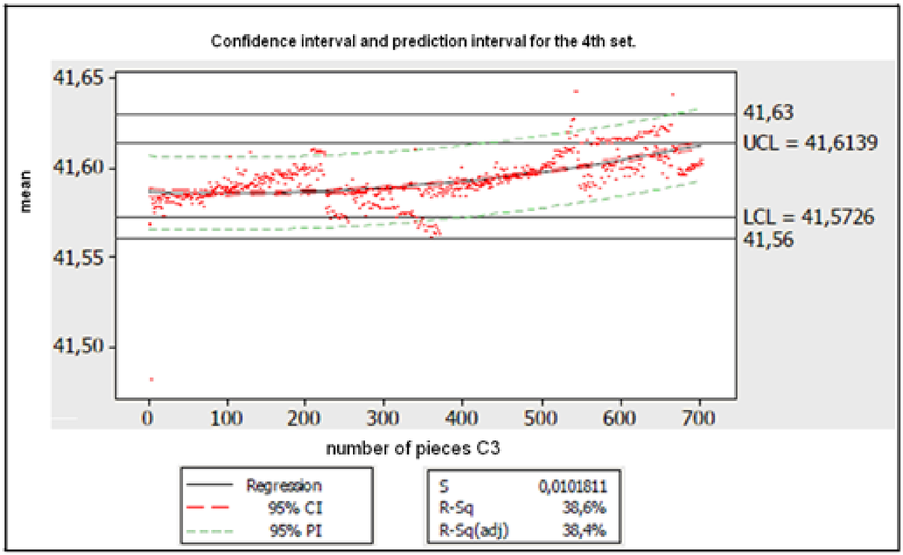

Fig. 7.19 -Confidence interval and prediction interval for the 4th set

When performing the analysis of the presented outputs, we can note that the processes are statistically in control, but a prediction tool is missing which would allow the maintenance crew intervention to correctly influence further development. Statistical processing of data provides us with a basis for an analysis of a present condition, which is a base for predicative measures. Joint application of a regression analysis and a prediction interval together monitoring the data in real time enables the implementation of predictive measures aiming to minimize the production of defective pieces in a given set. Through the application of the proposed solution retroactively on the monitored data, we would have reduced the percentage rate of inconsistent products from 1.51 to 0.69% and the percentage of irreparable rotors from 0.33 to 0.14%. However, the proposed solution needs to be subject to further examination from an economic point of view, which would have a decisive impact on the decision-making process related to its implementation.

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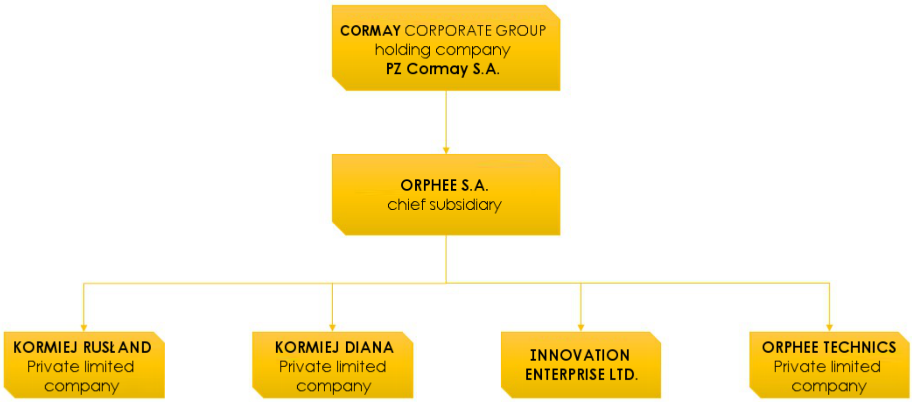
8. Implementation of innovations and an innovation strategy in a corporate group - good practices – Emil Górniak, Michał Łupina

8.1. CORMAY Corporate Group

When writing about good innovation practices, one must first define the background against which the innovations in question were, are being or will be implemented. In this case, the background is the corporate group CORMAY along with its subsidiaries [5], as shown in the figure below (Fig. 8.1).



Rys.8.1 - Diagram showing the structure of the corporate group PZ Cormay plc

CORMAY Group specializes in the production and distribution of reagents and analytical instruments for in vitro laboratory use. Owing to its innovation policy and many years of experience in the industry, the company has become the largest producer of this range of products in Eastern and Central Europe. The company currently supplies several thousand laboratories. It has reached its very good position on the market thanks to the consistent implementation of a strategy based on provision of world class innovative products and services. The current product portfolio allows the company to export chemical reagents to more than 150 countries worldwide. The line of business which CORMAY is involved in is very dynamic and difficult, and demands continuous improvement of company functioning and enhancement of its product offerings. The company places a large, innovation-promoting emphasis on flexibility in customization of products for very diverse markets – the European markets which have advanced expectations and standards, and developing markets, in which the requirements for products, sales activities and widely understood cooperation, are often dictated by legal regulations, which means expectations are defined as they arise and there are few attempts to plan future activities.

All entities in the group have their own, appropriately defined missions which allow them to act in synergy to implement the strategy of the entire group. Apart from PZ CORMAY S.A., which is the initiator of major changes, especially innovation-promoting changes in the whole group, it is worth mentioning here the case of a subsidiary entity, namely Innovation Enterprises Ltd., an Irish manufacturer and distributor of medical diagnostic solutions for use in biochemistry, immunology, cytology and point-of-care testing (POCT), which was bought by PZ CORMAY S.A. and restructured using good practices developed by the group. The methods and mechanisms used in the Polish firm were now used to completely transform a foreign enterprise, leading to very positive changes both in the mentality of employees as well as the functioning of the company.

The main objective of CORMAY Group, as already mentioned, is to achieve full customer satisfaction with the products it offers. In order to meet the requirements of its clients, the company employs specialized personnel, who are open to all suggestions of potential consumers about the products offered. The company derives its knowledge of the market needs of its customers from observations of the broadly understood market and potential competitors, its own research and development activity, and from cooperation with new suppliers and distributors. The knowledge the company has acquired through many years of experience in its line of business, combined with the constant observation and analysis of the development of biotechnology, chemistry, pharmacy, medicine and supporting engineering disciplines, allows its experienced personnel to create new innovative conceptions that bring profit to the company. Representatives of the company take an active part in scientific symposia and conferences devoted to changes in disciplines related to the company's line of business, where new trends are discussed and the ways companies can be steered toward meeting new market needs are presented. Owing to many years of activity and its huge experience, the company is aware that creating a firm's market position and acquiring knowledge largely depends on direct contact with the customer. CORMAY tries to face every challenge posed by the competition and every market need. It is supported in its efforts by experience and its well-established brand, very good relations with customers, attractive product prices, flexibility and quick adaptation to the needs of individual customers.

The earlier-mentioned innovation-promoting approach is no longer the need of the hour. CORMAY recognizes the need for continuous development of the company and the entire group, as the market becomes more and more demanding, not only in terms of growing competition, but also due to the continuous development of medicine and laboratory diagnostics and the growing awareness of potential end-users, raised by the increasing number of media campaigns on prevention and related problems. The specificity of the market in which the company operates, associated with the continuous development of diagnostic technologies makes it necessary to extend the offer with new products and technologies that will reflect the current and future expectations of customers. The progressive development of laboratory diagnostic testing makes the company's market success dependent on its ability to monitor technological change and quickly adapt its products to market expectations. Thus, the possibility of maintaining a competitive advantage, requires constant development and investments in new product lines.

Some of the investments made in the recent years by CORMAY Group concerned research and development and modernization of the production facilities in Poland and Ireland. During that time, the company has expanded its business activity to new markets, including Kazakhstan, Pakistan, Iran, Mexico and some South American countries. The company's development strategy includes further expansion into foreign markets, in particular those of Asian and South American countries.

This short description of CORMAY company clearly shows that it is developing at a quick pace. It currently runs a wide variety of projects, and its primary focus is on innovative solutions in every area related to its business activity. This, as previously mentioned, is dictated by the requirements of the market but also the company's mission, which is to achieve full customer satisfaction with the products the company offers and provide advice and assistance. The key idea here is satisfaction of the customer, who becomes more and more aware and needs new and innovative clinical diagnostic products and solutions for effective testing, in line with the saying that prevention is better than cure.

8.2. Innovation from the point of view of a company

After the brief characterization of CORMAY Group as an innovation-promoting company, and before describing in detail the processes and good practices it uses (Fig. 8.2), it is worth pausing for a moment to answer the question of what innovation is from the perspective of a company.

Fig. 8.2 - Innovation in a company

Now, innovations are novelties introduced in a company or in the market. They may be either tangible or intangible, and are an outcome of an innovative process which encompasses a set of activities that contribute to the creation and first application of a new solution in a given environment. An innovation is any thought, behaviour or thing that is completely new or adds value to already existing forms. Understood in such broad terms, the word innovation can be used to refer to everything, starting with new products and services to technical, technological, organizational and economic changes. It is important to remember, however, that not everything that is innovative to some people, is innovative to others. Each service, process, product, etc., which is innovative in a given market from the point of view of company A, does not necessarily represent something new and better to the competitor. What is important is whether a business entity achieves expected benefits and level of development as a result of implementation of the innovative project. The concept of a new product is not sufficient on its own. A product may be innovative in the general sense following from the definition of innovation, but from the point of view of a company, it only becomes so when it offers real prospects of potential sales revenue.

CORMAY Group, as an innovation-promoting business entity, strives to initiate innovative activities in all possible areas [2, 4]:

- A process innovation is the implementation of changes in the currently used manufacturing and delivery methods. These changes are optimization changes aimed at automating production lines or changing the organization of work. Process innovations may also be a combination of these improvements or a result of the use of new engineering knowledge. The aim of process innovations is to increase the efficiency and flexibility of production and delivery of existing products.
- A product innovation is the improvement of established goods/products resulting in their significantly better performance or the creation of a completely new product using an entirely different, innovative technology.
- An organizational innovation is the most difficult to achieve, from the point of view of a company, as it involves implementation of changes in the company's management paradigm and its approach to policy-making or departure from traditional methods used in a given line of business or market allowing the company to operate differently than the competition.
- A marketing innovation is the implementation of a new marketing method, not previously used by a firm, involving significant changes in product design and packaging, promotion methods, pricing strategies etc., and attempts at developing and implementing new marketing instruments with the objective of opening up new markets.

8.3. Setting targets based on the decision-making model

The idea of innovation in the corporate group CORMAY is based on the desire to obtain in the future a certain capital in the form of money, organizational changes, an increasingly better quality of products, or an increasingly better organization of work. These resources will foster further development and expansion of the group and its new products to new global markets. The company's business activities are all focused on the clearly defined principal objectives of boosting organization and development and achieving a competitive advantage in clearly defined markets, which should ultimately guarantee a very good evaluation of the work of the company's Executive Board and ensure a high dividend for its shareholders. Of course, innovations can also be discussed in empirical terms, but from the point of view of a company, they are meant to bring benefits, most commonly money, and an added value for the organization. The figure below (Fig. 8.3) shows a spiral flow chart that illustrates the process discussed.

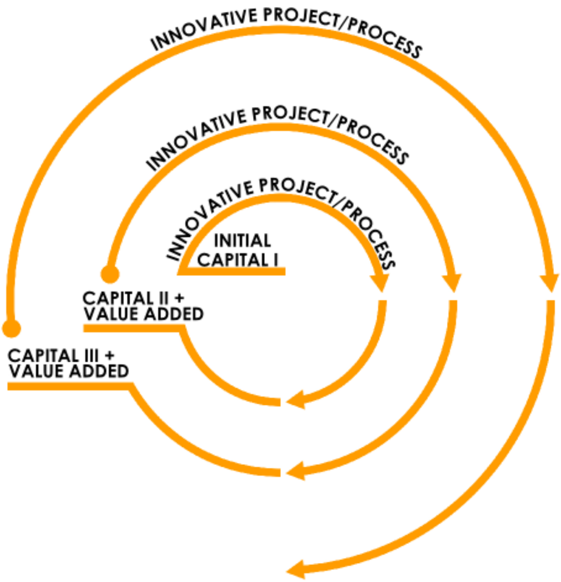


Fig. 8.3 – The relevance and goals of any innovation

A firm always starts from a certain point related to its location in time. Being in possession of a capital, know-how assets, technologies, studies and analyses, knowledge and experience, it steers its innovation-related activities so that they lead the firm from the starting point to the destination, allowing it to realize its main goals along the way. Taking into account the problems of competition, development and strengthening of the firm's market position, CORMAY, to pursue its strategy, must focus on smaller goals contained in shorter time frames, which together make up the company's major goals, as shown in the figure below (Fig. 8.4).

Innovative activities, often defined as a company's successive goals, are designed to lead the company from the starting point to the destination in a cyclic manner, at the same time generating an added value; the destination is the point where the expectations of the board and, most of all, the company's shareholders are met. In the process of completing project tasks aimed at achieving the objectives of a project – a product, a technology, an innovative process, the company acquires new knowledge. It learns from the large amount of data collected during that process, which are analysed and may be used in future projects. By taking such an approach, CORMAY achieves the snowball effect: 'rolling' along a carefully selected path, it increases its resources by gaining valuable data which allow it to increase its capacity and gain speed, creating new and innovative solutions in many areas of organization.

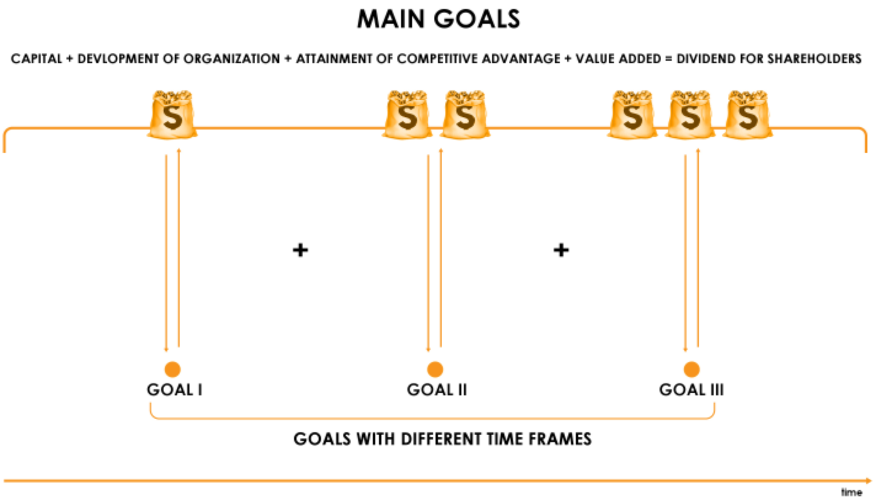


Fig. 8.4 – Goals from the time perspective

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As already mentioned, a company's major goals are often broken down into smaller objectives, the achievement of which, *de facto*, guarantees a degree of stability in the operation of such a complex organism as a manufacturing and trade company. To flourish and strengthen its position in the market, a company has to set and achieve appropriate goals. A wrong choice of goals, or an improperly performed implementation, can destabilize a firm in various ways, and in the long term even lead to serious consequences. The figure below (Fig. 8.5) shows what a goal should be like.

A company is a group of cells interconnected by an organizational structure, which influence each other in some ways. Hence, all goals must be considered in connection with the concept of project, which has to be implemented to achieve the objectives. A project, in general, can have a direct impact on a company's customer or the company's financial results. Unfortunately, projects cannot finance themselves at the very outset, and therefore it is very important to appropriately specify and present the goals and the expected outcomes to the company's top executives. A goal of a project may be to develop a new technology or a new product, to reduce lead times, to improve production efficiency, to limit costs, etc.

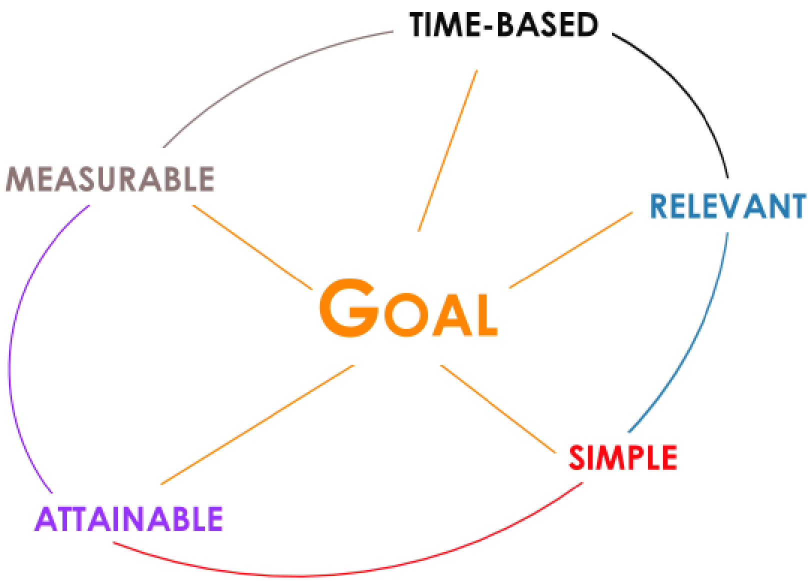

Fig. 8.5. Goal

This means a goal is associated with the company's financial results, and as such must be measurable. The outcomes must be controlled, to determine the impact the project has on the company. Furthermore, in accordance with the idea of SMART goals, a goal should be [3]:

- simple – it should be easy to understand, put in clear words, leaving no room for a loose interpretation,
- measurable,
- attainable – or realistic; goals which are too ambitious undermine faith in the possibility of achieving them and the motivation to attain them,

- relevant – a goal should be an important step forward; at the same time it must represent a specific value to the person who will be trying to reach it,
- time-based – a goal should have a precisely defined time frame in which it is to be achieved.

Sometimes, the very process of establishing a goal may become a goal in itself, because in the absence of proper analysis and with poor knowledge of their own firm, managers/decision makers may overestimate its potential. The most trivial example here is that of a little child who, unaware of his limitations and the consequences of his actions and believing he can do everything, sets himself the goal of opening the hot oven. In this trivial example, it is the role of parents to ensure the safety of their child; in a company this role falls to a team of skilled and experienced employees, who ensure that a SMART goal or goals are established and implemented in the right way. As mentioned earlier, innovations and the innovative projects behind them, which have clearly formulated assumptions, may be related to many aspects of a company's activity, such as products, technologies, organizational changes, marketing, etc. Depending on the nature of a given implementation, the decision-making model presented in Figure 8.6 will assume a variety of forms. The main factor here is which department of the company is engaged in the implementation of a project: for instance, innovative internal optimizations aimed at shortening delivery times do not require the involvement of department X (Fig. 8.6), while the same department may be strongly involved in a project regarding the introduction of a new product on the market. Let us now look at how project goals for a product innovation are established at CORMAY, which is an example of a company that implements numerous projects. Figure 8.6 shows a model of product innovations which provides the basis for the defining of goals at CORMAY.

Three units play a role here, namely the departments responsible for business development, implementation, and sales and marketing. Cooperation between these cells and the market allows the firm to find answers to the basic questions regarding [6]:

- Consumer analysis, i.e. a series of studies which show what product should be placed on the market, what market segmentation should look like, and whether introduction of a product is feasible from the point of view of the company.

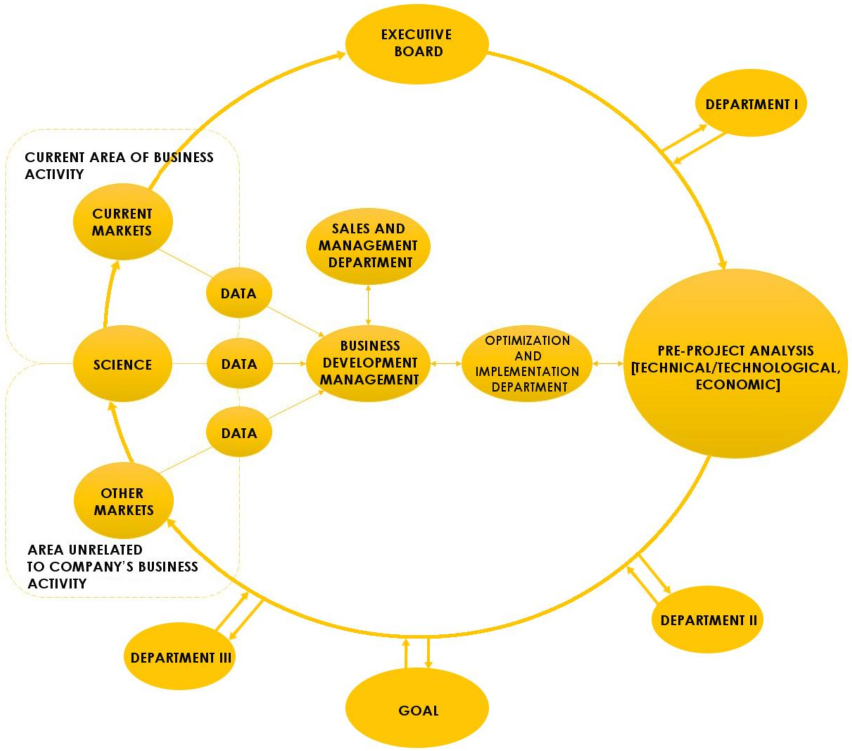

Fig. 8.6 - Decision-making model for projects implemented by CORMAY S.A.

- Market analysis, which describes parameters such as the size of the market, its nature, rate of growth, current segmentation and future trends.
- Competition analysis, particularly with respect to firms with a similar product portfolio: it is worth knowing who your competitors are and what your firm looks like against the background of those firms. This is a very important area in the analysis of the entire project, because it affords a fairly accurate description of the company's position.
- Marketing mix analysis, which focuses on future product, price, place and promotion. It provides information on how the product will compare with other products, how to reach desired segments and through what distribution channels, how the product will be promoted – whether the potential customers will be reached through trade fairs, campaigns or other promoting actions, and what price strategies should

a company choose (is it interested more in the sales volume or the amount of profit?; the criteria for determining prices, etc.).

- Potential analysis, which provides information that allows a company to assess the project against the company's potential related to its resources, technologies, infrastructure, funding, accounting liquidity, knowledge, experience, and so on.
- Economic analysis concerning costs, profitability thresholds, return on invested capital, error estimation, size of the cost buffer relative to the company's resources, and opportunities that successful implementation of the project could bring.

Precise specification of the goal is very important. Even if the above steps of the analysis are very well conducted, they still need to be followed by a revision of the whole. Such a revision is carried out in great detail, which may be time consuming, but, in a broader perspective, allows the company to avoid a wrong decision which would entail a number of doubly unfavourable effects such as financial loss, disorganization of work or loss of time on account of both the ill-prepared project and the fact that during the time of the project the company does not take action in another area, which could bring these benefits. At this point, it is important for company personnel to open their minds and not shut themselves within one area, focusing on a single objective, as it may turn out that the company will not be able to achieve that one objective, but might, in the meantime, during the same process, create another, perhaps even better, conception that will be within its reach. This approach can be taken by companies which develop their personnel and collect information/data not just from one, core area of activity but also through careful observation of what is going on in science. Employees of CORMAY Group take part in various types of conferences, symposiums and fairs, sometimes even reaching for inspiration and novelties into areas completely unrelated to the diagnostic industry.

All these issues are related to pre-project analysis, which is the first and one of the most important steps of innovation. Pre-project analysis is connected with the concept of added value. Because CORMAY treats its development very seriously, it understands the role of pre-project analysis and, with every new attempt at carrying out such an analysis, it becomes better, more calculating, and more efficient, which undoubtedly affects the decision-making process and its accuracy. This illustrates how a company can generate an added value –

sometimes an innovative added value – at the very beginning of an innovative project.

When the project team have all the necessary data, analyses and outcome forecasts and after they have analysed the potential opportunities and threats, they present the objectives of the project and expected outcomes to the board and then wait for the ‘green light’ to start the project. Of course, when the company's top executives have examined all the information provided, they may decide to reject the project if it does not comply with their vision of the company's future, but usually, when the project is estimated to yield satisfactory positive financial results, they allow the project team to start the project.

8.4. Project

This section is devoted to the problems of preparation and implementation of innovative projects. The information provided here, however, has a double significance, because the preparation and implementation of the project discussed was associated with an innovative change in the paradigm of project management at CORMAY, which followed changes in the board of directors. The approach described is a good innovative practice which draws ideas from the theory of constraints and has already been implemented in Polish firms.

The previous chapter described a protocol for specifying the goal or goals of a company. When all the questions related to the selection of goals have been answered, the next step is to determine how goals should be achieved. Using an example from the world of sport, the implementation of a project can be compared to a game of basketball. There is the basketball court which corresponds to the implementation framework, there are the rules of the game, which both the players and the project team members have to obey, and, most importantly, there is the scoreboard which displays the scores of the game/outcomes of the project and time remaining to the end of the game/project. When the goals are properly defined, precise determination of appropriate measures and their control allows the project team to obtain growing approval of the implementation.

The next step in the construction of a project is the appointment of the project manager and the assignment (Fig. 8.7) of appropriate persons to the project team in accordance with the principle that "it does not matter what is to be done, but who will do it".

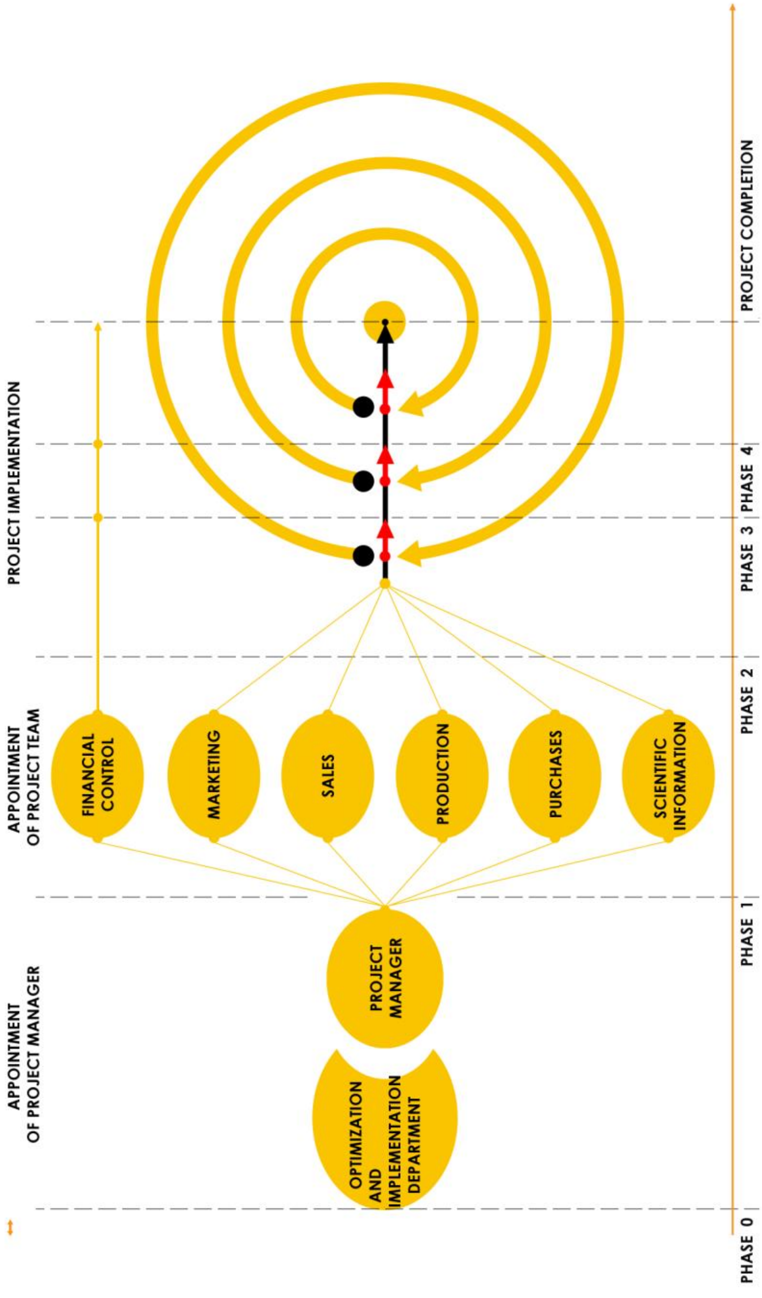

Fig. 8.7 – A model of project implementation at CORMAY plc.

The project manager must be an experienced person who has worked with the company for quite a while, who identifies with it and with its policy, has management, sociological and socio-technical skills, and, above all, understands the relevance and value of the formulated goal [7].

At CORMAY, we have learned from experience that the manager of a project, especially a large scale project that engages most of the company's departments, should be a senior manager because:

- Members of senior management have control over the resources necessary for implementation of a project, especially where one of the resources has to be used in several paths (involving different departments) of the project and it is important to manage it rationally.
- A senior manager also has considerable standing and can give advice, instructions or guidance to the members of the project team when they encounter problems in the implementation of their tasks.
- He/she also has the qualifications necessary to control the entire process and measure the implementation. This enables quick decision-making based on incoming data.

When the project team and the project manager have been selected, it is time to develop the project. As is commonly known or as people commonly think, the biggest enemy of a project is time. Other threats include exceeding the budget and scope seep. Although this is all true, the experience of the many implementations performed at CORMAY has led its employees to form a belief that it is a lack of cooperation that is the biggest threat to timeliness. When considering the problem of a project time frame, it is worth asking the question whether potential delays will affect, in some way, the company's financial results? Let us take here the example of building a new production plant in another country with lower labour costs. Such an undertaking is very complex and requires a huge commitment.

Let us consider it in terms of delays, adopting the following data:

- Estimated monthly costs, after the transfer of business activity to country B = EUR 100,000.
- Estimated monthly sales revenue = EUR 200,000.

Without going into the legal and tax-related matters and assuming this is only a numerical example, we can easily calculate that the profit would be

100,000 EUR. The net profit margin would be 50%, which means that the company earns 50 euro cents to every euro sold. Assuming that the investment is delayed by five months, we can estimate that the delay, in addition to other contractual financial losses, would entail an additional 500 000 euro loss due to the lack of revenue from sales. People involved in a project should be aware of such issues.

As the next stage of project development, the project team work on the organizational aspects of the project. They present and analyse different conceptions of implementation of tasks and establish the sequence of tasks. This can be done using a PERT chart or using sticky notes which are stuck to a large smooth surface. They can be easily peeled off and stuck down in other places until the most optimal and logical sequence of actions has been found. The next step is to assign responsibility for specific tasks to a single person to avoid communication noise, or in situations in which the tasks are very complicated, to break them down into several smaller ones.

Another very important point is to assign critical resources to the individual tasks. In the company, there are people, machinery or equipment with very narrow specializations, who/which must be used in several paths, sometimes, theoretically, at the same time. Hence, their proper allocation at the outset allows the project team to avoid many problems in the future. The ext step is one of the most important steps and to execute it, team members have to change their way of thinking about the project. It involves elimination of safety buffers for each task. You are probably familiar with the following situation: you ask an employee how long it will take him to complete the task, and he replies "About 10 days". The answer sounds odd because you know that this type of task can be performed in less than four days. Such ‘extended’ deadlines are often proposed by suppliers and subcontractors, especially when there is a contractual penalty for failure to meet the deadline. Everyone adds a margin of safety, most often wasting it at the very beginning, because they know that they will carry out their task on time anyway. Such procrastination is popularly called the student syndrome. At CORMAY, we changed our approach to time safety buffers by encouraging people involved in the project to propose the shortest possible deadlines. The members of the project team were informed that there would be no penalties for delays provided that they set aggressive time frames, as shown by the following comparison (Fig. 8.8).

In the classical approach, each task is assigned a safety margin. In the novel approach, the same tasks are assigned the shortest possible deadlines, but a time buffer has been added at the end of the project, which is half as long as the longest sequence of tasks. When someone is late completing his part, time is taken from the buffer.

When someone finishes his/her task ahead of time, time is added to the buffer, which is typically divided into three areas:

- a green area – the project proceeds according to plan,
- a yellow area – some improvements should be worked out to restore the buffer,
- a red area – the project team should think of a shift of resources.

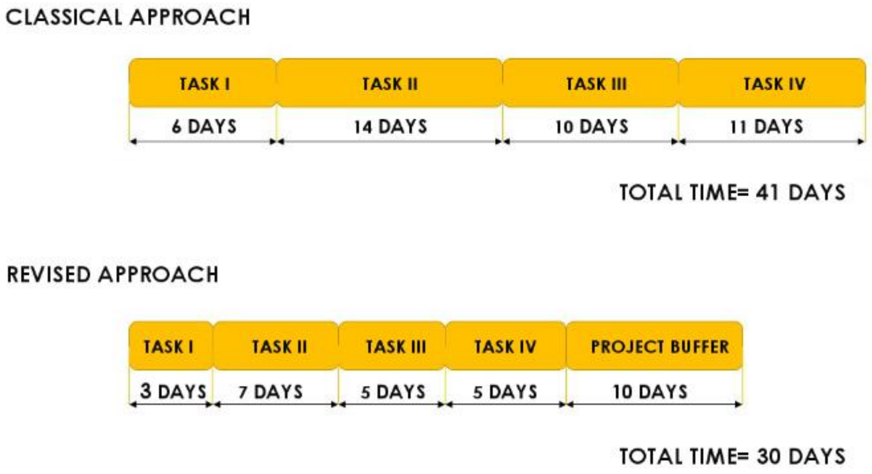

Fig. 8.8 – Comparison of two approaches to project implementation

The last important issue in this step of project development is to set starting dates for the tasks. There are two approaches: ASAP and ALAP. Experience shows that in many cases it is not necessary to start a task as soon as possible. An important factor here is the allocation of resources and capital. A situation in which too many tasks are started too early may disrupt the flow of money due to excessive allocation of funds. A project should be organized so that the financing of its individual steps can be properly planned. Investments should be postponed until they are indispensable. It is always necessary to see whether the savings from postponing the investment offset the probable loss resulting from a potential delay later in the project.

The final aspects of project planning and implementation are reporting and active management. The project manager should know what is going on in the project throughout its duration. He/she cannot lose sight of the big picture of the project, which is often the case when many tasks are started and supervised at the same time (the ASAP and ALAP methods). When the project manager has to perform a large number of activities, he/she not only devotes less time to each individual task, but also makes every effort to meet the deadline, often losing sight of the whole project and relaxing his/her vigilance. Of course, a scenario like this applies to the classical approach. In the revised approach, what matters is when the last task in the project is completed. The times of completion of the individual tasks are not relevant as long as the buffer is not empty. A project manager must receive and collect information about planned task completion times to be able to anticipate where problems may arise, and then concentrate on those tasks only.

In summary, correct performance of the above steps allows the project team to complete the project in the assumed time frame. It is worth mentioning at this point some other important issues which should also be kept in mind:

- When cooperating with external companies, especially during the implementation of projects, the project team should not rely on progress reports delivered by those firms. Instead, they should visit the factories personally in order to avoid delays.
- Delays can also be avoided when reliable suppliers are chosen. It often happens that companies, spending relatively large sums of money on the entire project, look for savings in critical areas of the project. They may, for example, choose an untested supplier, a decision that may initially bring savings but cause significant delays in the long run if the supplier turns out to be unreliable.
- It is also a good idea to remind the employees that the start date of their task is approaching. Reminders should be given 7 days, 3 days and 1 day before the start date. This is very helpful as it allows the employee to organize his/her work better.
- Progress is measured only on the critical chain.

8.5. Good practice

Unfortunately, due to the nature of the business activities carried out by the corporate group CORMAY, a lot of details of this activity cannot be written about because of their confidentiality. Therefore, the information given in the sections below has a general character: we show the good practices used at

CORMAY, but without going into technical, technological or financial details. In Section 1, which gives a description of the companies and their character, we mentioned the Irish company Innovative Enterprise based in Cork. The idea of the good changes and good innovative practices introduced in that company had been conceived in Poland: CORMAY succeeded in instilling its methods and models in a foreign culture, allowing a very badly managed firm to undergo a great transformation and helping it to gradually recover from serious problems. This is why, in the following sections, we would like to discuss what has already been done and what ideas are still being implemented in the Irish company.

8.5.1. Organizational innovations

Below we describe the step-by-step procedure the Polish implementation team used in restructuring the Western company.

Diagnosis

A great analytic effort – this slogan defines well all the activities that took place when the implementation team consisting of Polish employees went for the first time to Ireland. There was little time to think because the frustration of the firm's customers grew with each passing day: orders were not delivered on time, there were a lot of missing products, contact with the customers was disastrous, and, to make matters worse, the computer system had been improperly implemented. The organizational structure existed in name alone, and embraced mainly managerial staff, while all the rank-and-file workers were on the same level of the structure, with no defined responsibilities, scope of duties or assignments. The employees were as ready to accept any changes as they would be to go to the dentist. To sum up those first experiences from the point of view of innovation, one could say that any change that would positively influence the company, would be treated as an outcome of innovation-promoting activities.

The most important thing was to find out why there were undelivered, incomplete, and delayed orders. Because the Polish team did not have good knowledge of the Irish firm, the only way to understand those problems was to observe and analyse the existing processes. The figure below (Fig. 8.9) shows the manner in which the project team worked backward from the problem to identify its root causes [1].

The conclusions drawn from the analysis only confirmed that the whole crew was in for a lot of work. The company was short of raw materials because it had a wide portfolio of products and because its production planner had resigned his position. With the poorly implemented computer system, individuals who were responsible for production at that time could not cope as a result of lack of support. Without a careful analysis, the implementation team would have only been able to identify the symptoms. The problem, however, was a complete lack of communication caused by the fact that employees did not know who they answered to; purchasing specialists did not know who to talk to about money, etc. This gave rise to many misunderstandings and resulted in disorganization, especially disorganization of the production department.

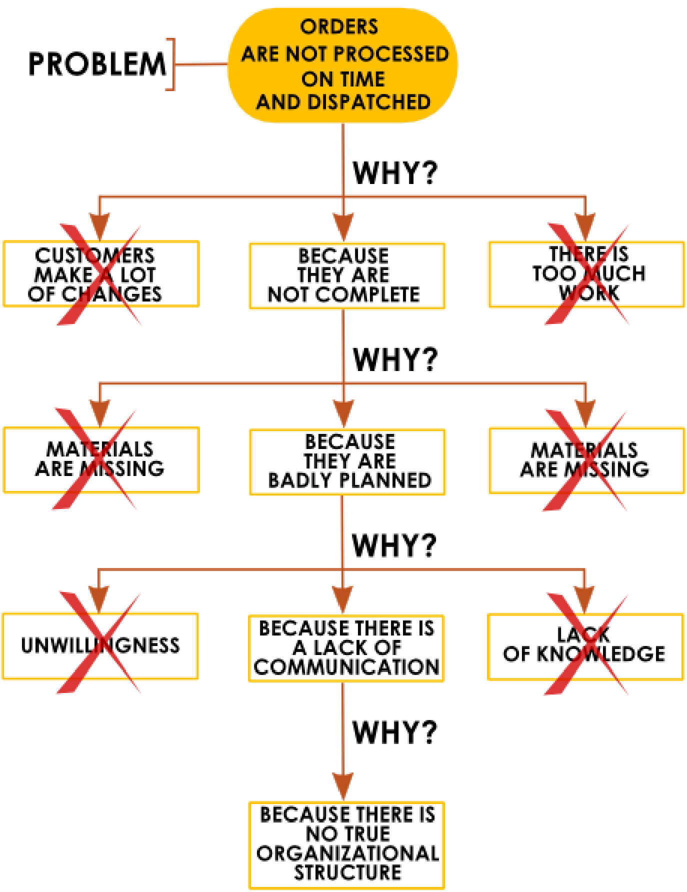

Fig. 8.9 - Problem solving

The ultimate effect was that despite good intentions on the part of the firm's personnel, customers had to wait for their orders and their aggression grew proportionately with waiting time.

Below is a summary of the key points which required addressing:

- Poor communication, both inside and outside the company.
- Lack of a real organizational structure.
- Major shortages of raw materials.
- Lack of production planning.
- Inappropriate preparation of order verifications.
- Large quantities of litter.
- Complete lack of supervision over inventory.
- Broadly understood disorganization.
- A poorly implemented computer system.
- Technology errors.
- Lack of equipment.
- Procedural errors.
- Other important problems which cannot be mentioned for reasons of confidentiality.

Correction of errors and continuous improvement

The first and most important step was to take care of the orders, especially those that had already been waiting to be dispatched for some time. This problem could not wait, and even if it were to cause losses arising e.g. from placing non-standard orders with suppliers, customers had to receive their orders as soon as possible. Customers were sorted by date of order and order size. Each order was assigned a suitable supplier from whom the company had to purchase the missing materials. At that point, all the moves were made possible by the hastily established organizational structure approved by the board, thanks to which everyone knew who he/she should answer to and whose decisions were to be enforced in the first place. To guarantee correct implementation of tasks, two meetings of managerial staff were held each week (Monday and Friday) to verify whether and how the tasks had been completed. There was not much time for preparation of reports, so the meetings had to suffice as a form of controlling task status. At the same time, a plan (Fig. 8.10) was being developed for refreshing the entire management system of the firm.

When the outstanding orders left the factory, attention was focused on planning the next steps. Due to confidentiality, information about preparing the offer, price lists and settlement of liabilities will be omitted. A new order was being introduced in the company. The first change was formal establishment and announcement of the organizational structure. From that time on, every employee knew his/her place in the structure and his/her supervisor, and the communication problem disappeared. The next step was to get rid of unnecessary things. Employees were given red post-it-notes and were asked to move around their work area and stick them on things, machinery, equipment, which in their opinion was unnecessary or had not been used for a long period of time. Then a verification committee composed of managers and the chief operating officer decided what could be disposed of and what could still be useful, assigning items to appropriate categories. As a result of the cleaning, which took more than a month (while normal production was in progress), 4 tons of litter were cleared from the firm's premises.

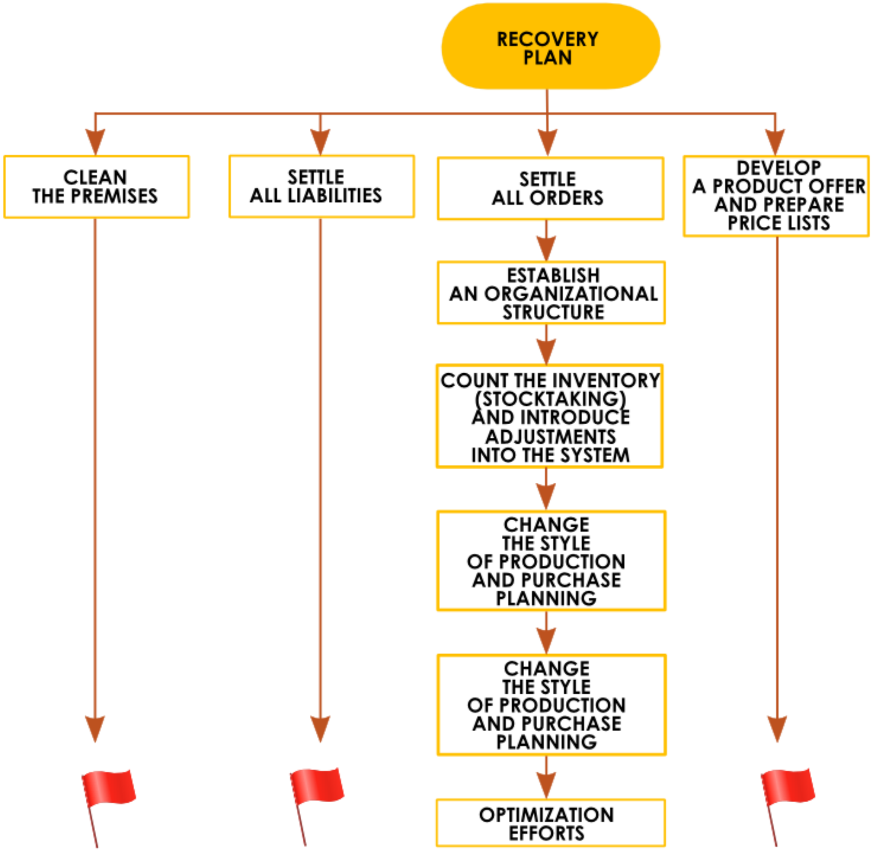

Fig. 8.10 The key points of the improvement plan

Activities related to stocktaking, inventory adjustments and technological corrections prepared the production department for real changes, especially changes in the way of thinking about and understanding the production process, which until that time had been based on the cost approach. Nobody had analysed product flow. At the beginning of each month, the company had taken the cost approach, but what counted at the end of a month was the output, despite overtime and other extra expenses. The only thing that mattered was to fulfill the order. The managers had focused on throughput, forgetting to control the stocks and identify and eliminate bottlenecks.

When the changes began to occur, the most difficult task was to explain to the employees that, from the point of view of the company, their individual work was not as important as the work of the whole team – even if some of them are super-efficient, their efficiency is without significance if there is a bottleneck upstream of them which does not allow workers to process large quantities of products. From the point of view of the company, the most important thing is how quickly it can fulfil the order. An order resembles a project, as previously discussed. It has to be viewed as a whole and not as a combination of the individual stages of work done by the employees. Such a change of approach, coupled with an appropriate transfer of information – prioritization of orders by giving them a tracking number and an estimated date of completion, allowed the company to fulfil their orders much quicker, at the same time improving the morale of the employees and creating a 'no blame culture' in the workplace, with employees being encouraged to find and solve problems rather than look for culprits.

In addition, it should be mentioned that during all these changes, the company developed a large number of tools and optimization projects: projects for the reduction of costs associated with the purchase of raw materials, product range optimization projects, projects related to the temperature monitoring system, projects for the reorganization of the production area aimed at increasing product flow, and projects for standardization of work using the PDCA method. Of course we need to wait to see the outcomes of these projects, if only because of their costliness and complexity.

8.5.2. Product innovations

As described above, the main pillar of the company's business activity is the production of reagents for in-vitro blood testing. The difficult market and the need for development force the company to constantly improve, broaden its knowledge of the products in its portfolio and product groups to which those products belong. The experiences of good implementation practice have allowed the company to conduct project activities in several areas at the same time. In the nearest future, the company plans to launch three completely new in vitro analyzers, innovative in terms of their operating properties and quality. The profits obtained from this undertaking will be used by CORMAY to implement a strategy for the financing of the company's development and to further strenghten its position in the extremely difficult medical diagnostics market. At Cormay, the wheel of continuous improvement keeps turning.

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