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Preface

Primal adaptability ensures the survival of a species. In essence, it concerns the reproduction and adaptation of genetic material passed on to the newly formed organism (system). Adaptability at the level of the genetic code is a phenomenal and unique mechanism. The ability to modify the structure of DNA (deoxyribonucleic acid) guarantees an organism the system of adaptability to ever-changing environmental conditions and the survival of the species as a whole. Secondary adaptability is the ability to adapt to current environmental conditions and to restore internal structures and processes using the self-regulatory mechanisms of each organism. Unlike in living systems, **there is only the possibility of secondary adaptability in an enterprise**, when a company responds to an unbalanced state in order to restore the balance. The basic mechanisms for maintaining equilibrium are the **innovative activity** of stakeholders involved in processes, **targeted optimisation of processes' critical points**, and continuous **measurement and evaluation of processes' performance**.

The assumption that social systems are not balanced raises the question of how to find an optimal internal organisation of a company and to define processes in a way that ensures the business performance goals. If we know the business performance goals, we should ensure the development of processes that lead to its fulfilment. An answer to the question of how to optimally organise a company's management system can be found in the effectiveness of management, which means the ratio of the amount of one's own energy, time, and expenses to achieve the company's objectives and the results represented by the fulfilment of these objectives. An important aspect of a management system is its orientation. The orientation of a management system is determined by defining the structure of the company in which business processes take place. There are three basic types of orientation of a company's management system. The first one is the functional orientation, where the basic structure of management consists of line managers and organisational units entrusted to them. The second type is **process-based management, where the basic structure consists of process**

owners and the company's processes entrusted to them. The third type is based on the process type. It is a project-based management system in which the management structure consists of project managers and unique projects assigned to them.

The answer to the question of why the process-based management system is preferable to the functional one is quite simple. Three basic mechanisms of secondary adaptability (targeted optimisation of processes' critical points, measurement and evaluation of processes' performance by a system of indicators, and the innovative activity of the stakeholders involved in processes) can only be effectively applied if the management system is process-based.

Process-based management is a complex and difficult issue. Establishing such an approach to organisational management requires a very complex change which is impossible to perform at once. It is also impossible to perform it as a single managerial decision with the use of just managerial power. Such a change is a long-term evolutionary process which ought to be carefully managed.

Business Process Management (BPM) can be integrated into a company's management system in two ways. The first alternative is to transform a functionally-based management system into a process-based one; the other alternative is available when setting up a new company, which creates a process-based management system right from the beginning. The process approach is applied in process-based management systems after the integration of process management. This brings about the process-based management of companies. In this case, it is necessary to identify all of the main and supporting processes in order to create an obligatory business process model and to define all its outputs as applied in practice.

Nowadays, the **integration of BPM relies heavily on intelligent technologies. Intelligent technologies are an elementary part of new concept called Industry 4.0.** Developing business processes according to the concept of Industry 4.0, we consider technological and organisational innovations that are based on the informatisation, digitisation, automation, and integration of the business system inside and outside. All intelligent technologies are based on digitisation, computerisation, and automation.

Industry 4.0, referred to as the fourth industrial revolution, is becoming part of business life and fundamentally influences the quality of business processes and products. In particular, intelligent technologies that are indispensable in this revolution play a dominant role. Intelligent technologies as a basic element of Industry 4.0 especially fit in with series and mass production of cyclically repeated processes and material products. There are, however, industries that only manipulate a material product without transforming the product. This is a particular concern of logistic enterprises. There is no definite manual for configuring intelligent technologies for all industries, because their integration always depends on a specific production or logistical system.

The main objective of this scientific monograph is to describe the theoretical aspects of business process management and process performance management and to analyse the utilisation of the business process models and intelligent technologies in business practice. The secondary output of this monograph is a new index for calculating an Industry 4.0 exigency in manufacturing companies.

Our theoretical approaches are **strengthened through several empirical studies** that we conducted in the last few years. The partial results of our empirical research was published in many journals, but we have not yet published them in this comprehensive form. This book links the production processes and intelligent technologies. We focussed on production processes as a part of the value-added activities which are usually under the indirect pressure of customers and suppliers, and for which enterprises primarily use intelligent technologies.

1. Process-based organisation

During the nearly 20 years of this approach's existence, thinking in terms of business processes became a regular part of organisation management practice. Nevertheless, Business Process Reengineering and Process-Based Management means much more than is regarded in ordinary managerial praxis. First of all, it is a real paradigmatic change in the theory of management. The complexity of this shift in paradigm makes putting it into practice not very easy; moreover, it is not easy even to understand the fundamental idea of this approach. Due to these facts, the full implementation of ideas of process-driven management are very rare. Most stories about using process-based thinking accent only marginal aspects of this approach, such as the partial improvement of evidence, reductions in time and costs, automating agendas, etc., without the real fundamental change in doing business, which is the real substance of the idea. On the other hand, there is no business area where the implementation of Process-Based Management cannot bring dramatic improvement. Hammer and Champy (1993) indicated two main characteristics which should be regarded as the essence of the idea of process-orientated management:

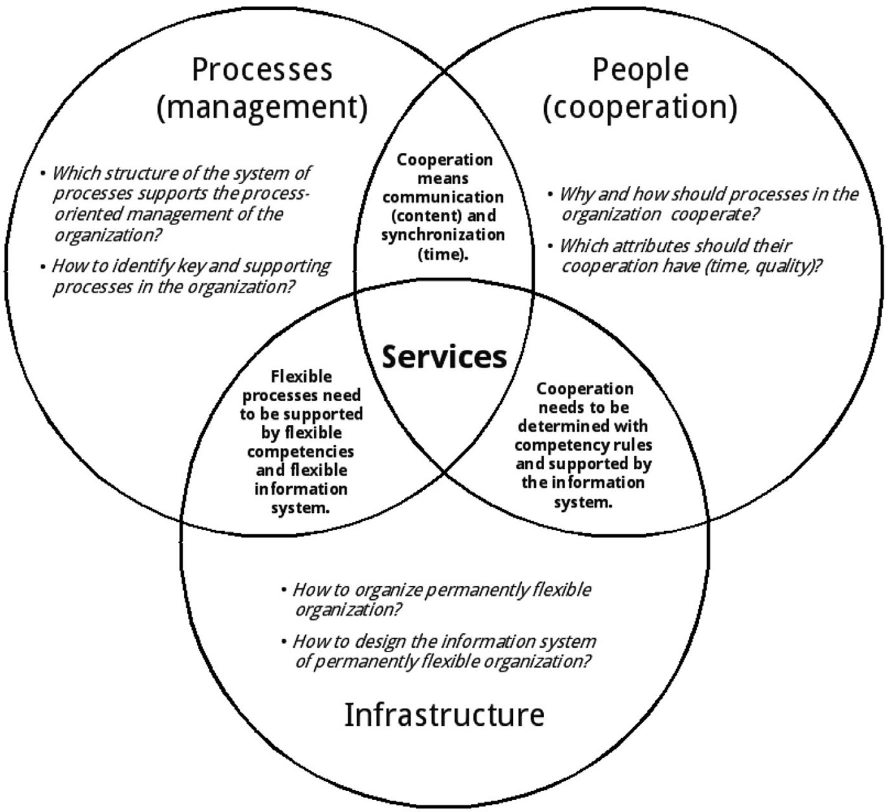
- The main critical reason for this approach is the need to make the organisation flexible enough to be able to change its internal behaviour according to changes in the environment. This may include not only changes in customer preferences and needs, but also in the possibilities of satisfying them, which typically result from the development of technology.
- The main critical consequence of the above-mentioned main reason is the change in the concept of business organisation from a strictly hierarchical one to a collaborative one.

Once this reason is fulfilled and the organisation shifts from a formerly hierarchical to a collaborative style of behaviour, the organisation can be regarded as being managed in the process-orientated manner.

Nevertheless, such a change requires many partial changes in all areas of the life of the organisation, each of which can be regarded as critical. Moreover, the mutual relationships among these areas generate other consequential problems to solve. In the following section we outline and briefly discuss this complexity from the three essential perspectives.

Figure 1.1 shows how the three essential problem areas are connected within a process-based organisation. All three example viewpoints are factored together to address all the substantial parts of the organisation's life: content, technology, and people. Each particular point of view is characterised by typical questions which should be answered by the methodology in that field.

Figure 1.1 **Service as a common denominator of the content, technological, and human aspects of the organisation's management**



Source: Závadský & Řepa (2014)

Process-orientated management represents the basic idea of a process-based organisation, expressed excellently by Hammer and Champy (1993) and originally called 'Business Process Reengineering'. This idea argues for the fact that the organisation has to build its behaviour on an objectively valid structure of its business processes to be able to fully exploit the possibilities offered by the progress of technology. This condition is typically not fulfilled in traditionally managed organisations where a hierarchical organisation prevents managers seeing, as well as managing, the crucial process chains which should be the main subject of changes stemming from the progress of technology. In order to achieve the necessary ability to fully exploit the new technology, the traditional hierarchical way of management should be rejected and substituted with a management style based on the objectively valid model of the organisation's business processes. Realising such an idea nevertheless raises the following questions:

- Which structure of the system of processes supports the process-orientated management of the organisation?
- How can key and supporting processes in the organisation be identified?

In order to make an organisation flexible enough towards the possibilities of progress in technology, one should firstly find the 'right' structure for the system of the organisation's business processes. This means at first identifying the key processes which characterise the organisation, and then according to these processes reorder all necessary supporting activities as supporting processes. The key business process is such a natural process chain that covers all aspects, from the initial need of a customer to the fulfilment of this need with the appropriate product or service. Nevertheless, the above definition does not mean that the key process has to include all the activities necessary to deliver the product/service. It only has to cover all the process, i.e. to manage it using the services of supporting processes to ensure the necessary productive activities/processes on the way to the final delivery. In such a way the key process represents the management side of every business case, whilst the supporting processes represent the production side. In the process of creating the basic structure of internal business processes in an organisation by deciding about the border between the key and supporting processes, the concept of **service** plays the role of a universal separator. It provides the meaning of the border between management and production. This idea of a service-driven technique for creating the basic process structure of an organisation is a key concept of Methodology for Modelling and Analysis of Business Process (MMABP), which was described in more detail by Řepa (2011).

Cooperation is a crucial problem in the process of building the system of processes. Once the basic structure of the processes is decided, the details of their particular relationships should be analysed in order to harmonise the cooperation with the internal structure and the contents of each process. Structural harmony means the synchronisation of the internal process run with the run of the other processes (collaboration between process owners/managers). Content harmony means taking each cooperation point as an act of communication between the two processes. Considering this cooperation point as a service, one can think of them as dimensions in a harmonious whole: service always means delivering the right product in the right time. An analysis of the detailed cooperation of business processes naturally brings up the following questions:

- Why and how should processes in an organisation cooperate?
- How should their cooperation look, in terms of time and quality?

As argued above, the cooperation of processes always means communication between them. The need for cooperation follows primarily from the mutual positions of both processes. According to the above-mentioned MMABP methodology, and consistent with the ideas of process-based management, there are only two correct reasons for the existence of the process:

The purpose of the key process is based on added value creation: it is given by the fact that this process represents the direct way of satisfying a need of a customer, which is the universal mission of any organisation. A key process always represents the direct service to customers.

The purpose of the supporting process is given by the services by which this process supports other processes.

Any cooperation between processes always means providing a service, either directly for the customer or indirectly by supporting other processes. MMABP methodology contains the technique for designing the cooperation structure of processes via 'internal outsourcing' of producing process chains from the key processes. This natural way of providing basic support for processes is created, and cooperation is established along with the basis of the structure of processes in the organisation.

For bringing the system of business processes to life, it is necessary to create the necessary infrastructure. There are two main kinds of infrastructure, representing two main resources in an organisation: technological infrastructure, which represents the aspects of automation, and organisational infrastructure, which represents the people aspects of the organisation's behaviour. As the main goal of the process-based management of the organisation is to make it principally and permanently flexible, its infrastructure also needs to be flexible. Thus, there are two crucial questions to answer regarding the implementation of a process-managed organisation:

- How can a flexible organisation be organised permanently?
- How can the information system of a permanently flexible organisation be designed?

In Řepa (2011), the methodology for designing a process-based organisation was presented. The last step in the procedure, called 'Building resulting infrastructures' is based on the work with the structure of services identified in the previous steps.

Services are identified as a general meaning of the relationships among business processes – their mutual cooperation. The details of every service are described in the form of a Service Level Agreement (SLA) and are used in the last step of the procedure as a common basis for creating all required infrastructure: organisational as well as the information system. The organisational structure of the organisation is then built directly on the structure of competencies derived from the mutual competency relationships of the processes which are defined in their common SLA. Therefore, the rights and responsibilities of managers and regular attendees of both processes directly follow from the needs of the processes. This way, the organisation's structure is flexible and exactly in accordance with the flexibility of the processes.

Similarly, the structure of the information system is derived from the mutual relationships of processes which are defined in their common SLA. The SLA defines all necessary products of the service and specifies their quality and timeline, which is a perfectly sufficient basis for deciding about the necessary functionality of particular parts of the information system. Business processes represent the rules of business behaviour. Each process runs as a workflow with customer specifications. Workflows are the integral parts of an enterprise information system. The workflow management system is thus a basic condition for making the organisation's information system flexible enough in terms of the main principle of a process-based organisation.

The common intersection of all three viewpoints is characterised by the concept of **service**, which represents their universal common meaning. The concept of service, as it is discussed above from all three viewpoints, represents a common denominator of the content, technological, and human aspects of the organisation's management.

1.1. Business process management integration

Business process management (BPM) is a type of management in a process-based organisation. BPM can be integrated into the business management system in two ways. The first alternative is to transform the management system from functional to process-orientated, and the second alternative takes place when a new company is being set up, which will create a process-orientated management system from the beginning. Both alternatives have a fundamentally similar procedure. The integration of BPM represents the implementation of the following stages:

1) identification of existing business processes within functional organisational units in the case of transforming from a functional to a process-orientated management system;
2) selection of business processes included in the process model of the management system/design of business processes included in the process model of a newly established company;

13) categorisation of business processes according to the selected criteria;
14) determination of responsibilities for business processes (process owners);
15) selection of the methodology for analysing and modelling business processes;
16) selection of the technological support for BPM;
17) analysis and modelling of the business processes and their activities and interactions;
18) allocation of resources to business process activities;
19) identification of existing indicators of operational and strategic performance, in the transformation from a functional to a process-orientated management system/design of a group of indicators for the operational performance of business processes in a newly established process-managed company;
10) identification of the relationship between the business process and the strategic goals of the company;
11) identification of interfaces between processes and draft in-house service contracts;
12) creation of a business process model of the management system;
13) definition of the outputs of the process model which are applicable in management practice;
14) approval of the process model and determination of its binding force;
15) use of the business process model in management practice.

The process approach is applied in process-orientated business management systems after the integration of business process management, when we talk about process-driven companies. In such a case, it is necessary to identify all the main and supporting processes, create a binding process model of the company, and define all its outputs applicable in practice. However, there is also the possibility of applying the process approach in isolation and independently of the integration of business process management. It follows that the process approach can be applied to solve specific business problems, related in particular to the detection and optimisation of critical points and the improvement of business processes. An isolated application of the process approach in the control system does not change a functional orientation to a process one, because the boundaries of the control and managed system remain the same. Analysing selected processes is helpful in improving them.

By the integration of business process management, we therefore understand the creation of a process-orientated business management system. An easier alternative is creating a new management system in an emerging company, when the design of business processes is not limited by the existing organisational structure and it is not necessary to take into account the needs of line managers. In companies where business management systems are functionally orientated, transformation is a more demanding process. Cienciala et al. (2011) mentioned several barriers posed by such a transformation, including a lack of will to change, a fear of losing job positions, insufficient communication of the expected effects, and insufficient interest from top management.

The identification of existing business processes within functional organisational units is the first step in transforming a functionally-orientated management system. Process identification is the elaboration of a list of all processes that are carried out in the company, regardless of their boundaries by organisational units.

The next integration step is the **selection and design of business processes** included in the process model of the management system. The process model of the management system contains a description of all business processes and objects and the outputs from the process model can be used in the management practice of the company.

The categorisation of business processes serves to distinguish the importance of a given business process and, according to the criterion of value added, they are usually divided into main and supporting processes.

A fundamental integration step of process management is the **determination of responsibilities** for business processes in the form of process owners. In business practice, we often encounter a combination of functional and process orientation. Business processes are divided into smaller sub-lines, which is not hierarchically contrary to the principles of process management, but their boundaries then copy the boundaries defined by functional organisational units. The benefit is the application of a process approach and of a process model in management, but the complexity of process coordination increases with the number of interfaces, where it is necessary to define agreements on internal services.

The **choice of methodology for analysis and modelling** of business processes and of **technological support for business process management** are methodologically important for the integration of process management. These two stages significantly affect the future process model of the process-orientated business management system.

After selecting a suitable methodology, the business processes are analysed and modelled. **Process modelling** is not considered by many authors to be the main content of implementing process management, although it is the most time-consuming. Košturiak (2010) spoke critically of process modelling as a dominant activity, according to which many companies have spent a huge amount of time and money describing processes and implementing various programmes. The expected results are often not achieved because no process diagram or project management programme has yet been able to improve the internal organisation of the company. At present, information systems have an irreplaceable role in the modelling and analysis of business processes. Informatics is a scientific discipline from which a number of modelling methods and tools have been taken over and developed. The business process is the intersection between the design of an information system that will effectively ensure the information needs of managers and the achievement of business performance.

Management`s and information technology`s views on business processes show Řepa (2006), Polák et al. (2003), and Carda and Kunstová (2003). We consider one of the most significant studies of late to be the comparative analysis by Recker et al. (2009), who compared methods of business process modelling. According to them, process modelling must be used as much as possible in the whole company as a method that draws attention to all or selected business processes as a prerequisite for the decomposition of organisational complexity. When analysing business processes, resources are also allocated to business process activities.

The **allocation of available resources** is a prerequisite for their unambiguous assignment to specific activities of specific processes, from which it is possible to create job descriptions and specifications, or even organisational rules. The allocation of resources (objects) and the determination of their cost also form the basis for the application of an objective calculation of indirect costs using the Activity-Based Costing (ABC) method. Staněk (2003) dealt with the use of a process approach to cost management.

After resources are assigned to process activities comes the creation of a relatively separate part of the model – a set of **performance indicators** that follow the business processes. The **identification of existing operational and strategic performance indicators** is performed to compile a list of all performance indicators that are used in the company to measure operational and strategic performance. After they are identified, a group of indicators of operational performance will be proposed and included in the process model of the management system. Each indicator should have a consistent group of properties defined, which Učeň (2008) called indicator attributes.

An important aspect is the identification of the **relationship between the business process and the strategic goals** of the company. This step is sufficiently described in the literature on the strategic system for measuring and evaluating the performance of companies called the Balanced Scorecard. In the case of integrating process management, it is important to determine which indicators will be used to measure and evaluate the achievement of process goals, whether the implementation of the process also contributes to the fulfilment of strategic goals and which personal goals of employees are derived from the strategy goals.

The identification of interfaces between processes and the drafting of in-house service contracts is a critical step, as these contracts or their equivalents determine the transitions between the interfaces of several business processes. As stated by Řepa (2012), the interface of each of the two processes means a need of outgoing business process and a service delivering of previous business process. Technically, it is the same relationship as the company's relationship with the customer. The general form of the description of the business process is thus an analogy of the SLA, which then defines the clear powers and responsibilities of the individual actors in the process. In this way, each element of the system has a clearly defined role flowing directly from the respective processes and through them with potential changes. The whole system is thus perfectly flexible.

A process model of the management system is created as a result and integration of the previous steps. The process model is a simplified representation of a process-orientated control system, which coincides with the real system in essential properties. The process model, which was created by analysis and modelling of business processes and their properties, becomes a representative of the process orientation of the management system. The correctness of the previous steps is a prerequisite for the successful use of the process model in management.

Defining the outputs of the process model applicable in management practice depends on the needs of the company. The basic outputs include the determination of responsibilities and powers classified as process owners and operators, where the process owner is responsible for the course and compliance with the outputs of the process and the operators are responsible for the performance and outputs of individual activities.

Responsibilities are differentiated according to the activities and processes identified, and from the process model it is possible to (1) create job descriptions, organisational procedures, and guidelines, (2) determine superiority and subordination and to create an organisational and competence order of the company, (3) learn the status of fulfilling strategic and operational objectives, which is indicated by a set of indicators included in the process model so that each process has a clearly assigned performance indicator and possible follow-up to the strategic objective and process model allows reporting on current business performance, and (4) learn the status of implementation and development of ongoing processes.

The real integration of business process management ends by the approval of the process model and the determination of the extent of its commitment to all stakeholders. The last stage of the implementation is the utilisation of the process model in management practice for achieving the strategy and operational goals. Utilisation of the process model in management practice allows to each process owner actively influences employees involved in the process or, when it comes to technical equipment, management processes.

1.2. Business process management maturity

The application of maturity models is sometimes identified with the concept of a process audit (Hammer, 2007). Such a broad understanding of maturity model use is mainly based on the scale, namely how many aspects of a process-based management system we are considering. Maturity models have been reviewed by some authors in detail and their individual criteria have also been compared. Palmberg (2010) compared Goncalves' maturity model, Lockamy and McCormack's model, and Hertz's maturity model. All of them focussed primarily on defining processes, measuring and evaluating performance and improving processes, the organisational structure of company, mutual communication, and information security of processes.

Almost all maturity models are based on the Capability Maturity Model (CMM). Another maturity model which is often cited in the literature is Fischer's model, which integrates five dimensions – strategy, control, processes, people, and information technology. In each of these dimensions the level of process management is defined by the limited expansion in the company, integrated at the tactical management level, managed by company-wide optimisation processes, and part of the intelligent hierarchical network. A set of specific measures is defined in a matrix where the rows and columns meet the dimension and the level of dimension. Indicating the current status (where we are) and the desired state (where we want to get) creates the equivalent of a roadmap specifying the direction of development for process management and business processes.

Závadská (2013) critically reviewed a relatively large number of different maturity models for evaluating business process management and business processes in her paper. She listed a number of models that have been identified in managerial practice:

1. PEMM – Hammer's Process and Enterprise Maturity Model (2007)
2. 8 Omega – a model by the Business Process Transformation Group (2007)
3. CAM-I PBM Assessment – a maturity model of business process management from the International Consortium for Management (2007)
4. BPM Maturity Framework – a model by Gartner Inc. (2006)
5. Rosemann and Bruin's maturity model (2006)
6. Fischer's model of BPM maturity (2004)
7. Lockamy and McCormack's model (2004)
8. Hertz's maturity model (2001)
9. Goncalves's maturity model (2000)

Based on the analysis of the available literature, we can characterise the maturity model according to Michael Hammer, which is most often cited or reviewed by different authors and which we consider to be easily applied. It brings quick results in the improvement of process-based management systems and business processes.

Hammer (2007) stated that organisations need to ensure that their business processes become more mature, i.e. that they are capable of delivering better performance over time. To realise this, organisations need to develop two kinds of characteristics: **Process enablers**, the characteristics of individual processes, and

Enterprise capabilities, the characteristics of the entire organisation. The particular level of maturity of the organisation depends on quality of its processes according to their particular characteristics (Process enablers) together with the characteristics of the enterprise itself (Enterprise capabilities).

Hammer recognised five **process enablers:**

Design – how comprehensively it is specified how the process is to be executed

Performers – people who execute the process with their skills and knowledge

Owner – includes the responsibility of the appropriate proper senior executive for the process and its results

Infrastructure – how well the process is supported by the information and management systems

Metrics – indicators which the company uses to track the process' performance

The **Enterprise capabilities** are as follows:

Leadership – how well the senior executives support the creation of processes

Culture – the values of customer focus, teamwork, personal accountability, and willingness to change

Expertise – includes the methodology for process redesign together with the skills for using it

Governance – addresses the mechanisms for managing complex projects and initiatives

Hammer created the system of evaluating an organisation's maturity level by evaluating the above-mentioned characteristics and taking into the account mainly the fact that the overall quality of the organisation is a complex characteristic where process enablers as well as enterprise capabilities express the necessary conditions for the quality, not the whole quality.

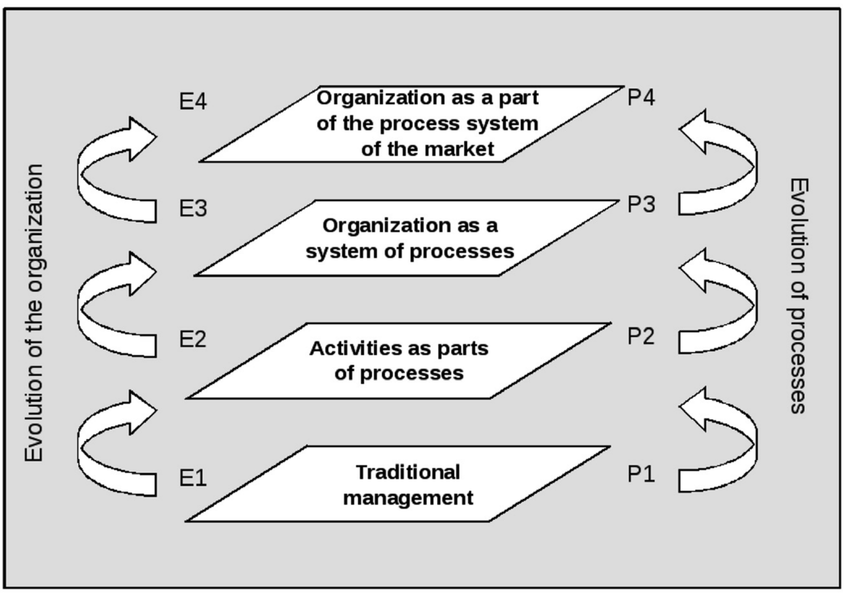
Thus, the particular level of maturity requires the proper quality of all process enablers together with all appropriate capabilities of the enterprise. The maturity of processes therefore should go hand in hand with the enterprise capabilities and vice versa. These levels can be characterised as shown in Figure 1.2:

1. **Traditional management** – At this level the notion of processes already exists in the organisation, but the meaning of the concept of 'process' is still not clear nor commonly accepted. The consequences of this state are that the constructed processes still cover only fragments of the whole business case (i.e. real key process), the actors emphasise only partial/local improvement and their personal contribution in the traditional organizational structures, the infrastructure is still fragmented according to the traditional organizational structure, and the metrics used and their usability are limited by this fragmentation.
2. **Activities as parts of processes –** This level brings the process-orientated view of the organisation's activities. Every particular activity is a part of some process

which expresses its contextual value. The process represents the basic criterion, value, and the common denominator for all definitions, descriptions, behaviour, approaches, and attitudes of the actors, and is the main subject of the organisation of infrastructures and metrics.

3. **Organisation as a system of processes –** At this level every process is principally regarded as just a part of the process system of the organisation. The basic criterion, value, common denominator for all definitions and descriptions, behaviour, approaches, and attitudes of actors, infrastructure allocation and metrics are organized from an enterprise level. All target values and the meanings of all activities are related to the organisation. Particular processes are principally seen in a shared context.
4. **Organisation as a part of the process system of the market –** At the highest level all processes are seen not just in the context of the organisation, but in the context of their target meaning for customers. Thus, all particular decisions principally reach past the boundaries of the organisation towards customers as well as co-operators. Consequently, the structure of processes follows the overall context of customer needs. The behaviour, approaches, and attitudes of actors are targeted at the values provided outside the organisation. Infrastructure is organised to respect the professional and technological standards in order to be principally compatible with the infrastructure of customers and co-operators, including an adequate conception of the metrics used and their permanent link to the strategy.

Figure 1.2. **Model of maturity of an organisation and its processes according to M. Hammer**



Source: Závadský & Řepa (2014)

We propose a unique attribute for process-based organisation (PBOA) that can help organisations to achieve business excellence (BE). The aim of the PBOA is

1) to define the basic terms and concepts of business process management
2) to describe selected maturity models of process-based organisations
3) to define requirements for process-based organisations as the process audit criteria
4) to determine the general procedure for the audit of the process-based management system and issuing and renewing certificates
5) to create conditions for the implementation, maintenance, and development of process management in organisations

This PBOA establishes attributes for the management system and process model of organisation regardless of the content of business processes, their interactions, and outcomes. It serves as a foundation for verification of a process-based management system and for **setting more detailed milestones for its further development** as a basis for maturity management. Maturity management, based on PBOA, has four stages following the acronym **PECA**. Be a **Process-based** organisation in accordance with the PBOA; achieve **Equilibrium** by the three mechanisms of adaptability: (1) innovative activities of the process stakeholders, (2) a process performance management system, and (3) optimisation of the critical points discovered by process analysis; **Check** the BPM maturity according to the PBOA; and **Act** in case the C_{apo} is lower than 90%. We developed C_{apo} as an index representing quantification of the capability to implement, maintain, and innovate a management system based on the process approach.

The PECA steps are integrated to the PBOA as its requirements. Our proposed PBOA contains these sub-attributes:

1. Awareness of the principles of business process management
2. Responsibilities and competences in the business processes
   2.1. Responsibilities and competences of top managers
   2.2. Responsibilities and competences of process owners
   2.3. Responsibilities and competences of workflow managers
   2.4. Responsibilities and competences of process executors
3. Business process model and its content
4. Description of business processes and activities
   4.2. Description of business processes
   4.3. Description of activities
5. Measurement and evaluation of business processes
   5.1. Properly time of the measurement and evaluation of business processes
   5.2. Definition of the relationships among business processes through SLAs
6. Innovation of business processes

6.1. Target optimisation of business processes
6.2. Audit of the business process content
6.3. Innovation of business processes through measurement and evaluation
6.4. Innovative activity of process owners and process executors
6.5. Innovation of process-based management system

17. Change management in a process-based organisation
    7.1. Starting points of process change
    7.2. Project of process change
    7.3. Changes in the business process model
18. Requirements of the information system for a process-based organisation
19. Organisational standards behind the business processes
10. Internal regulations for making the business process management as obligatory

When defining the **requirements for awareness of process management**, we took Hammer's PEMM as a basis and we focussed on how the company is supposed to create conditions for developing process management at all corporate levels. There were two basic groups of employees (process owners and process executors) defined in **the requirements for the competences and responsibilities in business processes**. We also defined their responsibilities and competences in meeting the objectives and outcomes of a given process.

The requirements for the business process model can be defined as all the necessary elements of the process model which the company should include and describe in the model in order that the process management can become obligatory for the company. We identified requirements which set possible requirements for processes and activities in the description of business processes and activities in order to make them understandable to all stakeholders and so that they can be implemented, ensured, and developed based on this description. We took as the basis the well-known information about the measurement and evaluation of performance which is available in the literature on **setting the requirements for measuring and evaluating the performance of business processes**.

We formulated these requirements in the context of a process-based management system. When formulating **the requirements for business process innovation**, we based it on the systems approach to innovative development of a company which is itself based on three innovations: the innovation of processes after the organisational audit, the innovation of processes as a result of measuring and evaluating performance, and the innovation of processes as a result of the innovative activities of stakeholders. The **requirements for change in management in a process-based organisation** are defined as those related to the implementation of specific changes. Although these requirements do not describe specific changes, we state how the company should proceed with their implementation and follow the innovation of business processes.

We propose the **requirements for the information system for a process-based organisation** in terms of developing information technology for the direct and indirect support of process management and business processes. We do not mention specific information systems or application software, we only specify the minimum requirements for their functionality. **The requirements for organisational standards** behind the processes are defined as a way for company to include organisational standards into a process model in order to avoid violating the principle of the unity of management.

The PECA steps are integrated to the PBOA as its requirements mainly because of the sustainability of process management after its introduction into a management system. This way the management system cannot spontaneously modify itself from process-based to functionally-based. This is especially true in cases when the process orientation was achieved through a transformation from the functional orientation.

To check the maturity means to do a process audit according to the PBOA. We propose the C_{apo} index for quantifying an organisation's maturity. The rating assigned to each point is **a combination of the extent of compliance with the requirements** of the PBOA and **the scope of its description** in the process model or organisational standard behind the business process model. There are nine combinations for evaluation which may arise in process audits. They are listed in Table 1.1.

Table 1.1. **Scale for PBOA fulfilment**

Points	Evaluation
10	The requirement is completely fulfilled and is fully described in the process model or in an organisational standard behind the business process model.
8	The requirement is completely fulfilled and is partially described in the process model or in an organisational standard behind the business process model. The requirement is completely fulfilled but is not described in the process model or in an organisational standard behind the business process model.
6	The requirement is partially fulfilled and is fully described in the process model or in an organisational standard behind the business process model. The requirement is partially fulfilled and is partially described in the process model or in an organisational standard behind the business process model.
4	The requirement is partially fulfilled but is not described in the process model or in an organisational standard behind the business process model. The requirement is not fulfilled but is fully described in the process model or in an organisational standard behind the business process model. The requirement is not fulfilled but is partially described in the process model or in an organisational standard behind the business process model.
0	The requirement is not fulfilled or described in the process model or in an organisational standard behind the business process model.

Source: Závadský & Řepa (2014)

The quantitative capability of the organisation to implement, maintain, and innovate a process-based management system is given by the total degree of process orientation C_{apo}. The values of capability are provided in Table 1.2.

Table 1.2. **Values of the degree of process orientation**

C_{apo} [%]	**Verbal evaluation**
90–100	Process-based management system of organisation
60–89	Combination of functionally- and process-based management system of organisation
0–59	Functionally-based management system of organisation

The audit of the process-based management system and evaluation of the scale of fulfilment of requirements and their descriptions, as stated in Table 1.2, serve as foundation for determining the overall level of a process-based management system – C_{apo} – a quantification of the capability to implement, maintain, and innovate a management system based on the process approach according to the formula:

$$C_{apo} = \frac{\sum_{i=1}^{n} C_{apo}^{i}}{n} \ [\%] \qquad (1)$$

in which the C^{i}_{apo} is a partial degree of fulfilment of the selected attribute of PBOA, while $i=1, 2, \ldots n$ and $n \in (1, 10)$. The partial degree of fulfilment of the selected attribute can be calculated using the following formula:

$$C_{apo}^{i} = \frac{C_i}{M_i} 100 \ [\%] \qquad (2)$$

in which C_i is the total number of points scored by evaluating compliance with standards in the i^{th} attribute, and M_i is the maximum number of points that can be achieved through implementation of the i^{th} attribute of the standard.

The audit thus results not only in the determination of the level of process orientation, but also in a detailed identification of specific strengths and weaknesses connected with the identified state. This information should be exploited to focus the further development efforts in terms of the general principles of the organisational maturity model. In this way, the organisation gains a powerful tool for designing sophisticated strategies for further action of organisational development under the rules of the maturity model. At the same time each audit also brings important experience which should be used for the improvement and further development of the standard itself. This ensures that even the standard has the same dynamics as all other aspects of a process-based organisation. In our opinion and according to our experience implementing the ideas of process-based management, there is no danger that we will find our idea of 'maturity-based organisational development' completely wrong.

1.3. Business process model

If a company claims to have implemented a process approach, the proof can often be a developed business process model. A business process model is a managerial system model, which includes all of the company's processes. Every process includes a set of activities; every activity is described by the attributes of the process and every process attribute can be parameterised by its performance indicators. The extent of business process models can vary from company to company.

The development of the process models and their utilisation in the management of companies is interdisciplinary. It is here where Information Management (IM), BPM, and Quality Management (QM) meet. On the one hand, we have the development and the extent of the process model being created, whilst on the other hand we have its utilisation in managerial practice for ensuring its quality.

The extent of the process model depends on the number of elements which can be modelled. It represents the structure of the company's system. The utilisation of the process model in management also depends on the output of the process models which managers use both in operations and strategic management. If the enterprise has created the process model and uses it in management, there must also exist a level of dependence between the extent and the utilisation of the model. In order to identify this dependence, we use correlation analysis, just as it was used by Safari et al. (2012), for example, in their examination of the relationships between people criteria and people results in the EFQM Excellence Model. The diversity of process models has its causes, which we have tried to discover in our research.

The business process model represents the process orientation of the managerial system which can be achieved by applying the process approach. The process approach is a part of the majority of quality management systems.

Gutiérrez et al. (2010) presented different alternatives for quality management implementation, such as the EFQM model, the ISO standards, the Malcolm Baldrige model, or the Six Sigma methodology. The difficulty with implementing each initiative varies from case to case. Saizarbitoria et al. (2011) evaluated the impact of both the ISO 9001 standard and the EFQM model. The process model can be different, if the company developed it during the application of ISO 9001 or EFQM model.

We consider the ISO 9001 standard to be a suitable initiative for creating the process model. This has also been proven by Sampaio et al. (2009), who highlighted the huge importance that ISO 9000 certification has for companies around the globe.

Three disciplines – BPM, QM, and IM – meet in the development and utilisation of the process model. In our survey we focussed on the utilisation of process models from the QM point of view. The process model can increase the effectiveness of the quality management system (QMS) in different areas. The results reported by Wu and Chen (2011) indicate that ISO certification has a significant effect on a company's performance. A well-developed process model can ensure this, and therefore its creation can be one of the internal incentives for ISO 9001 certification. Sampaio et al. (2010) stated that the internal incentives for ISO 9001 certification are related to genuine organisational improvement goals. These include internal communication and process performance. Just as the development of the process model can be a motive for implementing QMS, it can also assist with tearing down the barriers to its implementation. These barriers were described by Hoonakker et al. (2010).

Even a well-developed process model does not necessarily ensure that it will actually be used in practice. This decision lies with the managers. More management involvement in quality efforts and continuous process improvement are the most obvious and valued benefits of certification (Gotzamani, 2010), as well as from following the process model in managerial practice. If the determination of the company's processes is the analogy of the SLA, then the whole QMS is completely flexible. The process model can then clearly define the areas of competence, as well as the responsibilities of managers and of the employees. If the process model is sufficiently used in managerial practice, then the benefits of ISO 9001 certification should not diminish, as stated by Karapetrovic et al. (2010).

The utilization of the process model depends on the way it was created. Business process modelling has become fundamental for modern enterprises due to the increasing rate of organisational change. One major problem associated with the design of business processes is reusability. Reusing business process models has the potential to increase the efficiency and effectiveness of BPM and QMS (Aldin & Cesare, 2011). A comparative analysis of business process modelling was provided by Recker et al. (2009). Business process modelling usually brings a complex view on business processes. We can create many different process models according to the different modelling standards. Process maps as a graphical interpretation does not help in management practice. Managers need more than the static view on business processes. The real business process management allow to manage processes and to achieve the real business goals. We believe that a good process model offers a lot of possibilities for using it in managerial practice.

Developing business process models is obviously part of system design. System design is often overlooked as one of the most important aspects for ensuring that everyone in an organisation understands how they can contribute to its success, and thereby improve their own performance and job satisfaction. Suitable interrelated process diagrams make this easier (Cardwell, 2008). Hung et al. (2007) examined the adaptability of companies in managing core processes related to organisational process alignment, and particularly their potential for generating superior performance. There are even information systems which are able to optimise future executions of the business processes.

Ihaddadene (2008) described the techniques and tools which allow persistent information about the business process model to be extracted from event logs in order to incorporate them in the decision-making system and to optimise future executions of the business processes. It is an IM view of the business process model development. A similar view of the development of process models was offered by Strnadl (2006), Yang and Lin (2008), Blockley (1999), and Nagel et al. (2011). A comprehensive review of BPM and operations management was provided by Ponsignon et al. (2012). They examined whether process design principles derived from best practices are universally applicable to service firms.

Based on a comparative analysis, we can define the business process model as a model of the managerial system, which includes processes, activities, and their interactions in the form of inputs and outputs, organisational boundaries, resources necessary for processes, and a state transition condition related to outputs and inputs. But the use of the process model depends on managers' needs. The process model should enable them to classify processes by their importance, determine the responsibility for processes and activities, limit processes by organisational boundaries, determine the process equipment for each activity in the process model, describe activities directly in the business process model, describe the variability of processes by the 'if-then' rule, determine strategic relationships between strategic goals and business processes directly in the process model, measure process performance after the end of processes by a set of performance indicators in the process model (*ex post* measuring), measure process performance in real time by the set of performance indicators in the process model (measuring the running processes), simulate processes directly in the business process model, and track the processing of individual customer demands (workflow system).

The utilisation of business process models, not only in companies certified to the ISO 9001 standard, can be evaluated by business process maturity models (BPMMs). Various authors have proposed BPMMs to gradually improve maturity and capability (Looy, Backer & Poels, 2011). The application of the maturity models is often identified with the term **process audit** (Hammer, 2007). Palmberg (2010) compared the maturity model created by Goncalves et al. to the one by Hertz.

1.4. Empirical research fucused on utilisation of business process model

We performed an empirical study in companies certified to the ISO 9001 standard. The sample selection was based on the assumption that some certified companies had developed business process models as a representation of their quality management system. This model may have been developed due to the implementation of a quality management system. Our decision to explore the process models was based on the fact that this model is often only declared – that is, companies develop a process model, but it is not fully used by the management. Even if it is used, then the number of actual possibilities for its use varies. According to the Slovak Statistical Office, at the time of our research 16.7% of all registered businesses in Slovakia were certified. The database provided by the certification bodies included 1,012 companies. The questionnaires were filled in electronically and they were publicly accessible. During the research period, 419 questionnaires were returned. Of those respondents, 202 companies stated at the beginning of the questionnaire that they had not developed a process model due to the implementation of their quality management system. Of the remaining 217 questionnaires, 24 were discarded due to incomplete data. The final study sample consisted of 193 enterprises. Expressed as percentages, we can say that the response rate was 41.4%. The business process model was developed in 51.7% of the companies which responded. In order to explore the extent of the business process models, we defined a set of 10 elements (E1–E10) which should be included in the business process model. We used a questionnaire in order to ask the companies whether their business process model includes the following elements:

- business processes [E1]
- flowcharts for each determined process [E2]
- outputs and inputs for each determined process [E3]
- outputs and inputs for each activity included in the given process flowchart [E4]
- a database of the companies' human resources [E5]
- a database of process equipment [E6]
- organisational structure [E7]
- organisational standards created from the business process model [E8]
- a database of external documents [E9]
- a database of performance indicators related to each process [E10]

The first element is the business processes. According to the ISO 9001 standards, a company should define the processes needed for their managerial system. The second element of the process model should be flowcharts defined for each process included in the process model. Although defining the flowcharts is not yet a guarantee that the process will be realised accordingly, it is a supposition of the stability of each process.

No flowchart can fully describe the variability of the process, but it creates a tool for the enforcement of managerial decisions. The third and fourth elements of the process model are the inputs and outputs of processes and activities. Defining these elements is very important in the management of companies. Inputs and outputs are used in order to secure the smooth running of the process. The significance of this factor in management lies in understanding what should be gained through a given activity and process. The output of a company's activity is the partial goal, whilst the output of the process is the main goal. Of course, the set of performance indicators must also be defined.

The determination of inputs and outputs is the foundation for the SLA concept, in order to create a system of internal suppliers and customers. The fifth element which should be included in the process model is the database of human resources. We consider this a key element in terms of managerial practice. A human resources database enables each employee to be assigned the activities of one or more processes. The situation is very similar with the sixth element of the process model on the questionnaire, which is a database of the process equipment. The next element is a database of the organisational units created from the organisational structure of the company. This element is not necessary, but it enables us to sort out the results of the process according to the organisational units. Another important element in the process model is the organisational standards: both the internal and the external ones. In the case of the internal ones, the organisational standards must be created with the process model in mind. In this way duplicity in administration can be avoided.

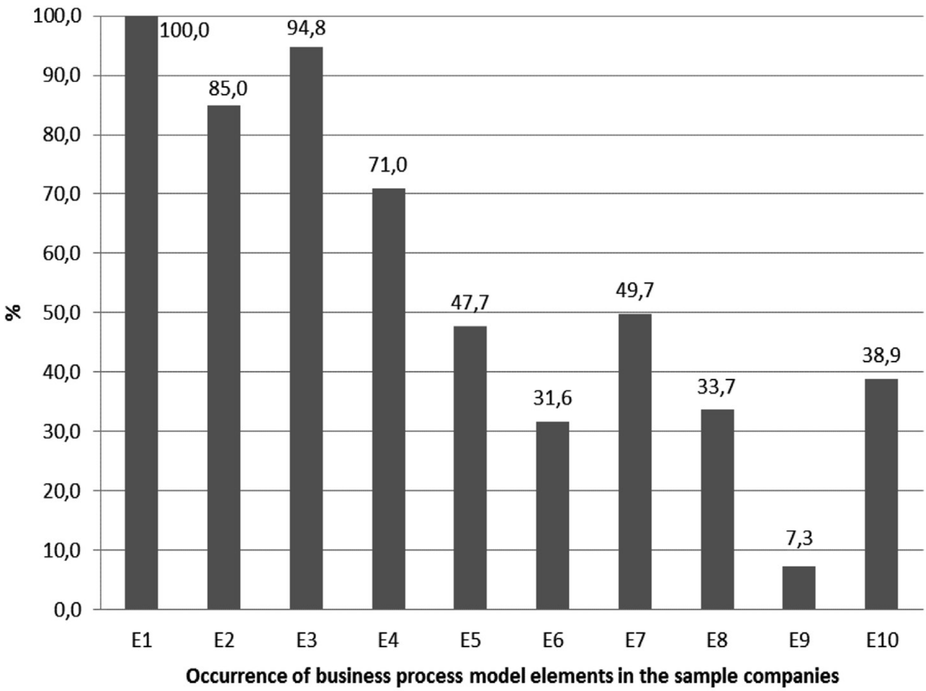
A database of the external documents determining the process should also be included in the company's process model. The last of these minimally required elements of the process model in our research is the set of performance indicators. Every process in the process model should have a performance indicator defined for it. If the process performance indicator also measures a strategic goal, we call it a key performance indicator (KPI).

All of the companies structured according to the number of their employees include the first element in the process model. This result of 100% was expected, since it is one of the requirements for ISO 9001 certification. Similarly, the result of 100% respondents was expected in case of the performance indicators, because indicators are an integral part of process models according to the ISO 9001. On the other hand, the element E10 was declared by only 38.9% of the respondents. Based on this value, we randomly chose 50 companies from the sample file of 193, and we explored whether they monitor and measure their processes.

All 50 companies reported that they do. In the questionnaire we also asked whether the companies have a database of performance indicators in their process model. The result was 38.9%. If we had asked them whether they measure their processes, the result would have been 100%. We focussed on the business process model and its elements, and 61.1% (100% – 38.9%) of all companies monitor their processes by performance indicators outside the process model.

According to the data shown in Figure 1.3, flowcharts for each determined process were created by 85.0% of the companies. Relatively high values were also found for the categories of determining the outputs and inputs of processes (94.8%) and determining the outputs and inputs of activities (71.0%). Approximately half (49.7%) of the business process models contained a database of organisational units; a database of human resources is included in almost half of the business process models researched (47.7%). A database of process equipment was a part of the process model in 31.6% of the companies surveyed. As a reminder, we would like to stress the fact that we did not research companies' fulfilment of the requirements set by the ISO 9001 standard. Every company which was examined has the process equipment because they have to ensure the availability of resources (clause 4.1.e of ISO 9001). We researched the process model and its elements. One third (33.7%) of the business process models we researched contained a database of organisational standards generated from the model, whilst only 7.3% included a database of external documents.

Figure 1.3. **Percentage occurrence of process model elements**



After discovering which elements are included in the business process models of the companies which were surveyed, we also explored their possibilities for the actual utilisation of the business process model in managerial practice. Each of the elements in the model creates a supposition for management. The utilisation of the process model consists of 21 options (U1–U21):

- classify processes by their importance [U1]
- determine the responsibility for processes [U2]
- limit processes by organisational boundaries [U3]
- revise processes in the process model after innovation [U4]
- determine the responsibility for each activity in the process model [U5]
- determine process equipment for each activity in the process model [U6]
- determine the duration of activities in the process model [U7]
- describe activities directly in the business process model, if they are unable to create the description as a flowchart [U8]
- describe the variability of processes by the 'if-then' rule [U9]
- create job descriptions from the business process model [U10]
- create job specifications from the business process model [U11]
- create organisational guidelines from the business process model [U12]
- create norms of material consumption from the business process model [U13]
- create time-related norms from the business process model [U14]
- create other organisational standards [U15]
- determine the strategic relationship between strategic goals and those business processes which are directly in the process model, if such a relationship exists [U16]
- measure process performance after the processes by a set of performance indicators in the process model (*ex post* measuring) [U17]
- measure process performance in real time by a set of performance indicators in the process model (measuring the running processes) [U18]
- simulate processes directly in the business process model [U19]
- track the extent to which the individual customer demands are processed (workflow system) [U20]
- determine the responsibility for the administration of the business process model [U21]

The utilisation of a business process model in managerial practice strongly depends on obligation. Three of the questions in our questionnaire were related to the application of a business process model in managerial practice. Companies could either respond that a business process model as a whole is obligatory for management, partially obligatory, or only informative. If it is obligatory as a whole, then it is applied in managing the company. On the other hand, if it is merely informative, the company does not apply it to manage itself or its processes. In the case of it being partially obligatory, companies have developed a business process model, but some of its parts (some processes) are only informative, whilst other parts of the model are obligatory for management. The business process model was obligatory in managerial practice for 25.4% of the companies and partially obligatory for 29.0% of the companies surveyed. The business process model was of an informative nature in 45.6% of the companies surveyed.

All of the companies had determined the responsibility for their processes, whilst 87.6% of them had classified the processes by their importance. The processes are usually classified by the added value for the customer, depending on whether they play a main or supporting role. It is important for management to recognise the priority processes. Responsibility for the processes was defined in all of the companies which were sampled. It is one of the requirements of the ISO 9001 standard, and our research was conducted in ISO 9001-certified companies, so this result was expected.

Organisational boundaries determined from the database of organisational units were used by 46.1% of companies. We found this not very gratifying result whilst exploring whether companies revise their processes in the process model after innovation. Only 25.4% of them revise the processes in their process model. We looked for the cause of this in a correlation between the process model elements and their utilisation in managerial practice. We found that if the company determines the responsibility for administrating the business process model, then they are able to revise the processes after each innovation. In 72.2% of large companies it is the administrator of the process model who is responsible for its maintenance.

When it comes to determining the responsibility for each activity in the process model, 39.9% of companies do so. We consider this result insufficient, because it is impossible to assign employees from the database to a specific activity, which impacts the management's efficiency. Up to 83.3% of large companies had defined the employees' relationship to the activities; in terms of the element of process equipment, the result was 26.4%. In management it is relevant to assign process equipment to activities even when the company already uses Activity Based Costing. This, together with the allocation of human resources, makes the cost calculation of activities much simpler. The duration of activities had been defined in 19.7% of the companies surveyed, whilst 51.8% of them had described their activities directly in the business process model, if they were unable to create the description as a flowchart. This relatively high value is due to the fact that many companies resort to describing their activities instead of modelling them. In some cases, the variability of the process is so high that using methods other than a detailed description of activities is not possible. A high value was also found in the element regarding the 'if-then' rule: 83.4% of companies use this rule in flowcharts since it enables the process to be branched.

The exploration of creating organisational standards from the business process model was divided by the type of standards. Companies mostly use the process model for creating job descriptions (23.8%), organisational guidelines (30.1%), and time norms (21.2%). Other documents created by companies in this case included job specifications (7.8%), norms of material consumption (4.7%), and other organisational standards (6.2%).

Process performance was measured and evaluated by the majority of the companies which were surveyed. Most of them (52.8%) measured process performance after the end of processes by a set of performance indicators in the process model (*ex post* measuring). Very few enterprises (7.8%) simulated their processes directly in the business process model. About one quarter (26.4%) of the companies determined the strategic relationships between the strategic goals and business processes directly in the process model, if such a relationship existed. Not only is the classification of processes into main and supporting ones important for management, but the determination of their relationship with the strategic goals is also significant. Only then are these processes truly significant for managers. Tracking of the scope of the processing of individual customer demands (workflow system) and measuring of process performance in real time by a set of performance indicators in the process model (measuring the running processes) were each conducted by 11.4% of the enterprises surveyed. We explored which elements are included in the companies' process models (Závadský & Závadská, 2014). Following this, we explored which of the possibilities for utilising the process model in managerial practice are most common. The results revealed that businesses have different elements in their process model, and that they also use this model to manage different situations.

2. Business process performance management system

Every social system in a company is target-orientated. The internal structure and internal processes are ordered for the best fulfilment of the stakeholders' objectives. Every unit and process is managed by a manager, and the managers are part of a management system. The management system serves to coordinate all the business units and processes in order to achieve the business objectives. Based on the internal organisation of the company as a system, we can distinguish three main orientations of the enterprise management system. The first is functional orientation, where the basic structure of management is the line managers and the organisational units entrusted to them. The second type is process orientation, which forms a basic structure of process owners and the business processes entrusted to them. The third type of process emanates from a project-management system, which forms the management structure of project managers and their unique projects. Regardless of the orientation control system, there is always a management subsystem (line managers, process owners, or project managers) and the managed subsystem (employees). The difference is where the structure of the management and core processes take place. All types of orientation management systems have their advantages and disadvantages, and the choice mainly depends on the size of the company, the complexity of core processes, and the degree to which they are automated.

To maintain a balance in the company, as indicated in the introduction, it is necessary to achieve a consistent definition of the company, not only as a whole but also its subsystems. One of the subsystems of the enterprise management system is the performance management system (PMS); a process performance management (PPM) is realised through its PMS.

Consistency of the performance management system was described in the works by Ferreira and Otley (2009) and Flapper et al. (1996). However, we are not looking for a definition of PMS in our monograph – we rather want to set the premises for consistent PMS from the systemic theory point of view. This assumption is based on a homogenous group of attributes of the performance indicator (PI). In this book we want to answer to two basic questions: What are the attributes of the PI and what is the minimum set of attributes of the PI? We sought answers to these questions through empirical research conducted in Slovak companies certified to the ISO 9001 standard.

Flapper et al. (1996) presented a systematic method for designing a consistent performance management system to be used in practice where explicit attention is paid to the relations between the PIs. With a consistent performance management system (PMS), they designed a system that covers all aspects of performance relevant to the existence of an organisation as a whole. Such a system should offer the management quick insight into how well the organisation is performing its tasks and to what extent the organisation's objectives are being achieved. The method consists of three main steps: (1) defining performance indicators, (2) defining relationships between performance indicators, and (3) setting target values or ranges of values for performance indicators. Ferreira and Otley (2009) described the structure and operation of performance management systems (PMSs) in a more holistic manner. Berry et al. (2009) produced a broader literature review of management control publications.

A performance management system can be defined in many different ways, for example as a management control system (Bisbe & Otley, 2004; Chenhall, 2003; Chenhall & Euske, 2007; Otley, 1994). Another point of view is that a PMS is a strategic view, primarily described in the literature by Kaplan and Norton (1996, 2000, 2004). A critical view of their publications was presented by Otley (2008). Chenhall (2005) also referred to the integrative strategic performance measurement system. In the literature we are confronted with three important terms: (1) management control system, (2) performance measurement system, and (3) performance management system. From our point of view, the exact type of system is not important because we can find a performance indicator in each of them. PIs are the subject of our research, especially the attributes of them that need to be defined.

Another aspect of PMS is the excellence models that include requirements for measuring and evaluating performance efficiency. There are a number of these models. Evans et al. (2012) explored how to further improve and achieve higher levels of performance in accordance with the Malcolm Baldridge Award. Abdullah et al. (2012) presented a conceptual framework for the development of a value-based total performance excellence model (VBTPEM) in organisations. This model signifies the core values as a strategic component for an organisation to achieve total performance excellence and this extension integrates the intangible parts of performance measurement that have become a pivotal issue in many organisations.

An interesting work was presented by Doeleman et al. (2012). Their study dealt with the moderating role of leadership in the relation between management control as part of total quality management (TQM) and business excellence in terms of purposive change. Their results also indicate that transformational leadership is the most influential factor in the relation between the management control construct and purposive change. They concluded that organisations are strengthened by using a management control system in combination with an intensive management communication approach in a context of transformational leadership.

Wang (2012) presented a literature review which indicates a lack of an appropriate framework for evaluating organisational performance (OP) during crises. He identified key OP indicators and then developed a multi-dimensional framework for evaluating OP during crises. Alfaro-Saiz et al. (2011) described how to use the information gained from applying the EFQM Excellence Model to analyse the perception that the members of an organisation have of it regarding their business vision. Heras-Saizarbitoria et al. (2012) presented an empirical study of the relationships between the categories of the EFQM model.

There are several views on performance. Again, the starting point of our research is not a description of PMSs. We are dealing with the homogeneity of any of these performance systems whose basic element is the PI.

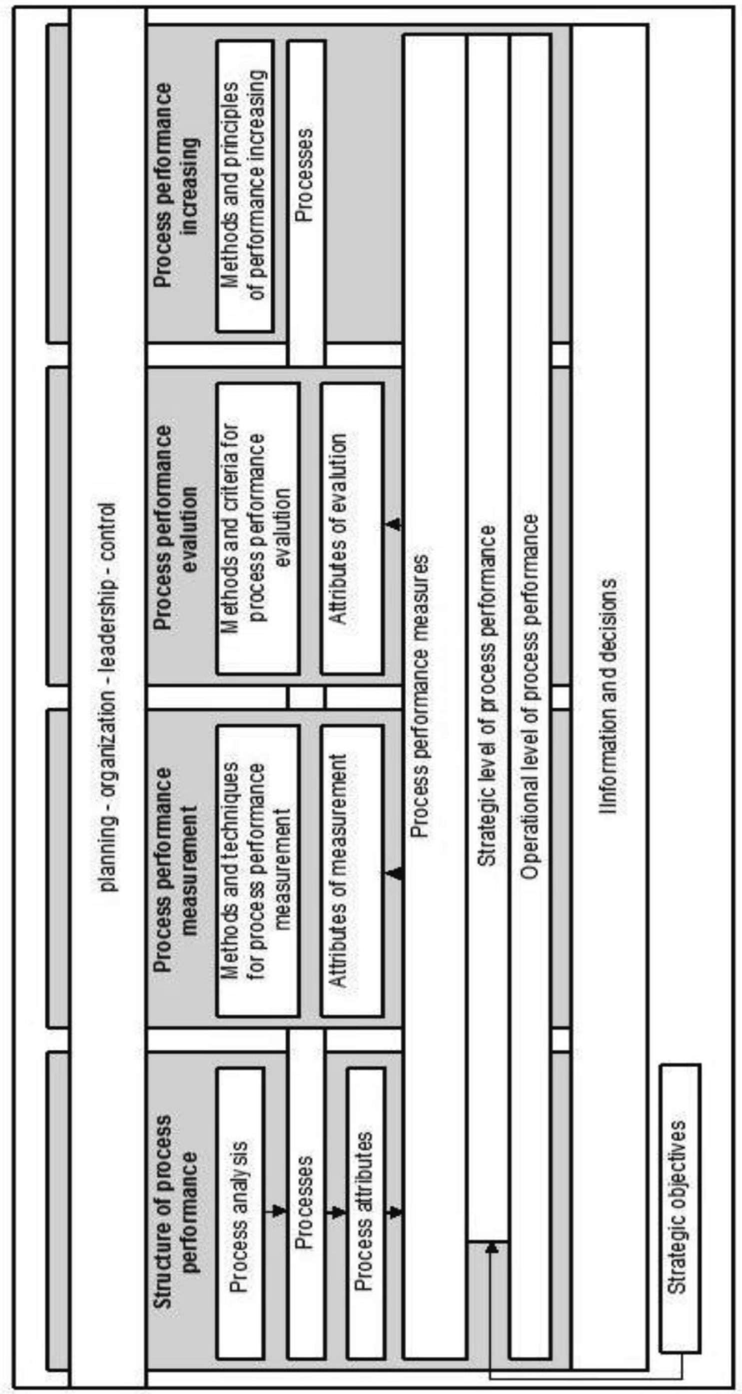
2.1. Static model of business process performance

The subsystem of business process management that is process performance management can be extracted as a separate system of management that keeps integral relations with other subsystems within precisely defined areas. It is not necessary for a manufacturer to apply the philosophy of process management to its fullest extent. If process performance is a priority – at the operational or strategical level – it is enough to implement only a system of process performance management with a strictly determined internal structure. The content of process performance management is as follows:

- generation of a process performance management structure
- measurement of process performance
- evaluation of process performance
- increase in process performance

Each discipline in management, even such a version that is to be applied in a specific, problematic area of business economic life (production management, innovative management, marketing management, etc.), also employs basic management functions: planning, organisation, leadership, and control.

Figure 2.1. **Static model of process performance management**



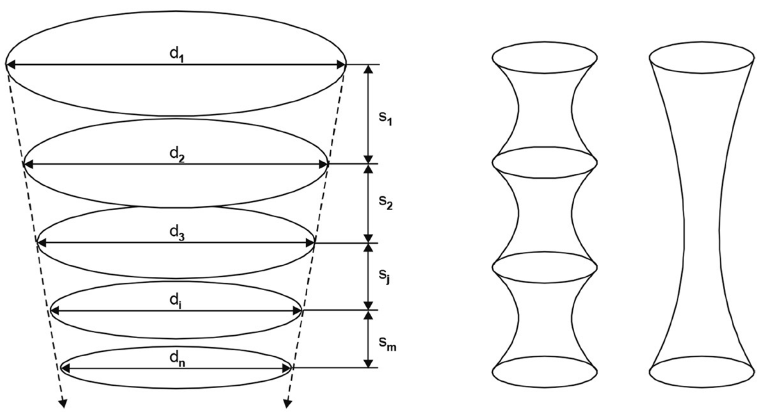
A similar situation can be seen in the case of process performance management, where it is necessary to consider these management functions in each of its parts. Apart from them, cross-sectional fields of management – information management and decision-making – are also established, and they cover all the parts. Figure 2.1 presents the basis for PPM, which can be defined as the management of business processes and their activities with a view to achieving the required performance of an organisation at the strategical and operational levels.

PPM begins at establishing its internal structure – that is process identification – prioritising and generating process attributes along with the indicators that relate to performance at the strategic and operational levels as well. Minimal requirement for process performance management is existence these four aspects: (1) business process, (2) business process attribute for setting up the indicator, (3) performance indicator and (4) performance level (stategic or operational). Process measurement and evaluation has characteristics which must be defined so that the entire system of measurement is consistent.

Each indicator should be described in the same way. After process measurement and evaluation comes the last part of PPM – increasing it. In each of these phases basic management functions are applied along with informatics and decision-making. This represents a model of a process performance management system.

This static model is the basis for a dynamic model of process performance management. It is meant to define PPM so that it is possible to capture changes in the structure of the static model. If the business process system was defined as an open dynamic system, its subsystem – process performance – is also subjected to continuous changes. The basis for process performance change is a change in different factors that influence the process as a whole. Figure 2.2 shows the spiral which represents time changes of business processes.

Figure 2.2. **Business process life cycle**



This spiral form can vary. In general, the diameter *d* of individual spiral levels should be reduced. This phase occurs due to the fact that the duration of a process that is being repeated in two consecutive spiral levels is reduced. It means that the following relation is accepted:

$$d_1 > d_2 > \ldots > d_i > \ldots > d_n \qquad (3)$$

A similar trend can be noticed when the distances *s* between spiral levels are shortened. This is due to the fact that an interval of start of two equal and repeated processes is reduced. Also, the following relation is valid here:

$$s_1 > s_2 > \ldots > s_j > \ldots > s_m \qquad (4)$$

This is not a permanent state, however. Process reduction is determined by different factors. It can be the application of more advanced technologies, rapid innovation transfer, or intense pressure from the competition or customers to speed up business activities. In this situation, the above-mentioned relations are valid. If there is a critical situation in a business, the opposite situation can arise, whereby diameter *d* and distance *s* increase. One possibility when diameter *d* increases and distance *s* decreases, or vice versa, is also acceptable. The spiral form of business processes depends on many factors. The following section presents the characteristics of a static PPM model so that it is possible to identify the basic conditions of changes and at the same time apply PPM principles.

The application of process performance management follows two assumptions: the existence of the content of PPM being reflected in a static model and the existence of changes in PPM being reflected on a dynamic model of process performance. The methodology behind its application integrates both models into a compact procedure. Process performance management involves identifying and prioritising the processes, measuring the performance of the processes, evaluating the performance of the processes, and increasing the performance of the processes.

2.2. Dynamic model of business process performance

The basic structure of the model that results from a static one, yet also describes its dynamic aspect consists of four dimensions:

1) importance of the business process
2) complexity indicator rate
3) fulfilment rate of the required objectives
4) performance level

The importance of the business process determines the ability of the process to add value. This value includes two aspects: value for the owners and value for the customer. From the point of view of value for the customer an operational level of business performance is important, but when value for the owners is being created strategic performance level is more important. Based on the value creation criteria, processes can be divided into core processes and supporting processes.

The criteria of the indicator complexity rate determines two basic groups of indicators. The first one involves process performance indicators concerning attributes of the process; in terms of forming them they are quite simple and it is not difficult to combine them. For example, the indicator of process activity duration is uniquely identifiable and simple. A more complex indicator is one of the proportion of a particular process activity in forming added value for the customer. This indicator is more complex, but is still a process performance indicator because process PIs evaluate performance directly. The second group involves overall performance indicators, but they result from different assumptions of their formation. A good example would be indicators resulting from business results as a whole, e.g. financial indicators. Also, within this group are more and less complex indicators. Overall performance indicators evaluate process performance indirectly, and they cannot be assigned directly to a particular core or supporting process. But some exceptions exist here as well, for example when it is possible to create 'EVA centres' (Staněk, 2003) and evaluate the economic added value of a process by this financial indicator. In this case, performance is evaluated directly in connection with a particular process, which is why such an indicator should be involved in a group of process PIs.

The third dimension of the model is the objective fulfilment rate. There are three basic states of performance: fulfilment, default, and over-fulfilment of a required target value. In which state the particular indicator is found depends on many internal and external factors. Within the description of one indicator it is necessary to determine a target value or an interval where acceptable performance occurs. This interval is limited at both ends by the states of default and over-fulfilment.

The fourth dimension in the model is the process performance level. This refers to what is important for a particular process at a particular moment, whether it is operational or strategic performance. The fourth dimension in the model is described by its integration into the other three dimensions. If a particular indicator is at the strategic level, it means that it represents a measure of a particular strategic goal. If it is at the operational level, it is not allocated to any strategic goal. Also, the philosophy of a balanced scorecard is integrated into the model of process performance.

If an indicator occurs at a strategic level and represents a measure of a strategic goal, then different strategic goals are grouped into specific perspectives. In Figure 2.3 are shown and integrated four perspectives of the Balanced Scorecard approach.

Apart from that, within this fourth dimension of the performance model it is also possible to form chains of causes and consequences, which in the balanced scorecard (BSC) concept are called strategic maps. This strategic map can be applied in a performance map in this model, when it is acceptable to create mutual relations between indicators at the strategic and operational levels. These relations do not represent a system of indicator formation, however, as for example relations in a pyramid system of indicators. In this case we can speak about a mutual influence, which from the point of view of their determination, can have double character relations – identification *ex ante*, when only thanks to intuition and experience are we able to determine the assumed influence between strategic goals or between performance indicators related to the stategic goals, and *ex post* identification, when by means of correlation analysis we may discover the influence from the point of view of different indicators at the time.

First dimension – importance of the business process

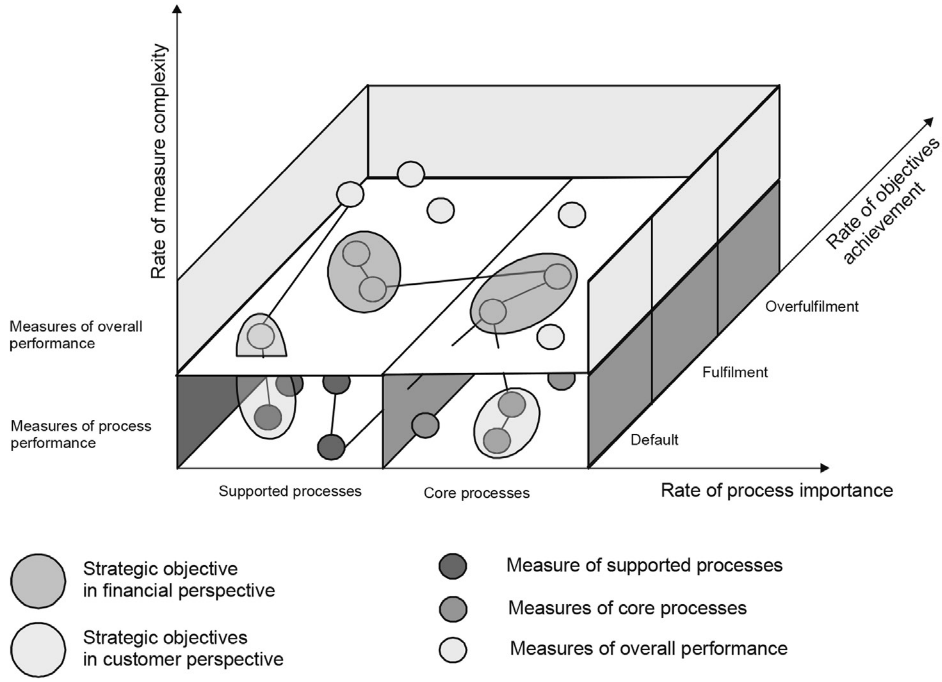
The first dimension in the model (x-axis) is the importance of business processes. Importance of the business processes usually comes from the added value and from the process ability to create added value. For example, by dividing production processes based on the contribution of individual parts of the production process in generating the products, processes can be classified in the following way:

- core processes, which add value and their outputs are products or services;
- supplementary production processes, which complement a core process and do not correspond with the business's main production aim;
- auxiliary production processes, which also add value and bring products which are used directly or indirectly in the main or supplementary processes;
- auxiliary service processes, which are not of a technological nature and which create the conditions necessary to ensure the continuous running of technological processes.

Most frequently we can see the division into main and supporting business processes or processes that add value, those that do not add any value, and processes that decrease value. In the model two categories are located along the x-axis, and they determine the basic scope of the importance of a process from the point of view of creating added value for the customer:

1) core business processes, whose final result is designed for an external customer and which directly participates in creating added value for this particular customer
2) supporting business processes, whose final output is designed for an internal customer and which indirectly participate in creating added value for this customer; an internal customer can be an employee or an organisational unit (process or activity) that takes supporting process outputs and transforms or uses it further within a particular business

Figure 2.3. **The dynamic model of process performance management**



The division into two groups results from a basic categorisation in process management. Also, within one of these two groups more or less important processes can exist. The importance of a process is determined by its position in the model. The more important the process is, the more it is moved to the right along the x-axis. It is the role of identifying and prioritising business processes to create a structure of processes based on their importance. This can be done on the basis of process relation towards other success critical factors, even if it is possible to determine various levels of importance within these factors as well.

The creators of the balanced scorecard concept defined four basic process groups that participate in value creation for owners from a long-term point of view. Theoretically, it is possible to create the above-mentioned groups or another category of processes along the x-axis. Our theoretical dynamic model are divided on the x-axis only to core and support processes regardless four BSC groups. Though the content of individual business processes is always the same, their categorisation may be different. This means that processes introduced in four groups according to BSC cover both core and supporting processes. The following processes are ranked among the basic core processes: marketing process, innovation process, production processes and delivery processes.

The marketing process is placed at the beginning and at the end of the whole business value-creating chain. Its main role is to analyse customers and markets in order to identify where a company can place its products, and to push ahead manufactured products through different forms of promotion. Apart from that, a manufacturer should analyse its competitors and its customers continually; the result is that the marketing process is performed non-stop. The process of innovation especially follows a market analysis or a particular demand for a non-standard product. The output of an innovation process is a prototype of new product or service. Production processes can start when a customer order a particular product or when the innovation process has finished. The output of production processes are a products or services. A process of delivery covers the sale or provision of a product to customer, including the provision of supplementary services associated with the product.

Certainly, these processes can also include sub-processes, such as market research/analysis, contractation, research and development of new products, preparation for production, production, providing services, despatching products, product sales, a marketing promotion, customer satisfaction evaluation or complaints, and customer after-sales service.

Supporting business processes are divided into two subcategories: control processes and service processes. The former includes documentation and data administration, record administration, internal audits, controlling for non-conforming products, corrective measures, preventive measures, setting the mission, vision, and strategy, employee recruitment, employee evaluation, employee training, analysis, property management, financial management, organisational management, human resources management, quality management, etc. The latter includes metrology, inspection and testing, purchasing, supplier evaluation, storage, machinery and equipment maintenance, internal logistics, information technology support, etc. Neither the title of the process nor its content is important, but its importance and priority in relation to other business processes is substantial.

Second dimension – complexity rate of an indicator

The second dimension, which is visible on the y-axis, is the complexity rate for an indicator. As with process importance, two groups of indicators are also specified here:

- process performance indicators, by which process performance is evaluated directly by a particular indicator
- overall performance indicators, by which process performance is evaluated indirectly and accrues from the results of the business as a whole

Process PIs create a relation with the process attributes. It is not necessary to integrate process attributes into the model because they are only complementary in nature, since we are able to bind a particular indicator to a performance area being monitored. Thus, process attributes are areas of performance monitoring. For example, we have business process attribute "quality". This attribute can be measured and evaluated only through defined indicator. So, quality of the process can be measured by percentage of non-conformity products of all products. Concerning the conception of a performance measurement system, a PI is in relation to a critical area of performance that must be measured. We can see that different views of the same problem can be different. A PI in the concept of BSC is in a relation with the strategic goal in a given perspective. A strategic goal can be, for example, within a strategy of internal processes the suppliers' ability to deliver on time; an indicator can simply be the percentage of on-time deliveries. What is important in the y-axis in this model, though, is whether the performance is measured directly or indirectly. The fourth dimension of the model shows whether there is a relation between an indicator and a strategic goal.

Process performance is indirectly evaluated through the indicators of overall performance, where it is not possible to allocate the indicator to a particular process clearly. At first these indicators follow the overall business results, for example from accounting statements. The indicator's complexity rate in this case refers to whether the direction of process performance evaluation is direct or indirect. In both groups indicators other than from the point of view of their actual complexity can also exist. The more complex the indicator within a particular group is, the further it is moved along the y-axis. For example, in a group of process PIs the most complex will be those related with integral attributes because their value is created at the process level and is calculated as a summation of the values of a particular integral attribute indicator according to separate process activities. In this way, the indicator's complexity also expresses a complexity of its formation within a particular group of indicators. In principle, this concerns a system of indicators that form another indicator.

Third dimension – fulfilment rate of goals

The third dimension, presented on the z-axis – is the rate of achieving objectives. There are three basic intervals in this dimension:

- non-fulfilment/default – the required output values have not been achieved
- fulfilment – the required values are within an acceptable interval
- over-fulfilment – the value of a particular indicator showing the performance of a particular process has exceeded the required values, in a positive sense.

In the suggested model it is necessary for each indicator to define an interval of acceptable values within which the defined performance can vary; this state is considered to be ideal. However, there are two basic alternatives that must be taken into consideration:

1. If an indicator exceeds the fulfilment interval and reaches the values of the over-fulfilment interval, it is a positive result because the values are better than those which were planned. An indicator that is allowed to move into the over-fulfilment interval is concerned here. Also, the trend of a given indicator should be considered. In the suggested model, indicators that move into the over-fulfilment interval are improved. The trend of an indicator can be decreasing or increasing. An increasing trend can be seen in an indicator like profit or added value of a process. The highest indicator position is always better and movement of an indicator value which represents process performance, placed further along the z-axis, represents increased performance. The second possibility is that an indicator's value should go down, for example, the costs of activities or a process. If the value of such an indicator goes down, it does not move along the z-axis closer to the x-axis, but it moves further from it because we want its value to go down. Thus, the result is that all values that change positively in relation to a planned interval of acceptable values, regardless of whether their value goes up mathematically (an increasing indicator trend) or down (a decreasing indicator trend) – on the z-axis it reaches the over-fulfilment interval.
2. The second type of indicator is one that cannot move into the over-fulfilment interval. These are indicators where the final value and tolerance limit are specified. In this case, the tolerance limits are equal to the interval of acceptable values and their violation is not acceptable. Typical indicators of this type are indexes of process capacity.

Process capacity stands for a process's ability to meet technical or other requirements. Mostly they are determined by specifying the required minimum value and tolerance limits. If a quality indicator of a manufactured unit is equal to the required value, it is an ideal situation from the point of view of process capacity. However, such a situation for every manufactured unit is almost impossible to achieve in practice. That is why a manufactured unit is considered to conform to the requirements if a monitored quality indicator of this unit lies between the tolerance limits. The specified accuracy is determined by a tolerance where

- USL is the upper specification limit
- LSL is the lower specification limit
- T is the required target value
- MSL is the middle specification limit.

The tolerance interval is defined as (USL, LSL), its range is defined as (USL – LSL), and the centre of the tolerance interval is calculated as follows:

$$MSL = \frac{1}{2}(USL + LSL) \tag{5}$$

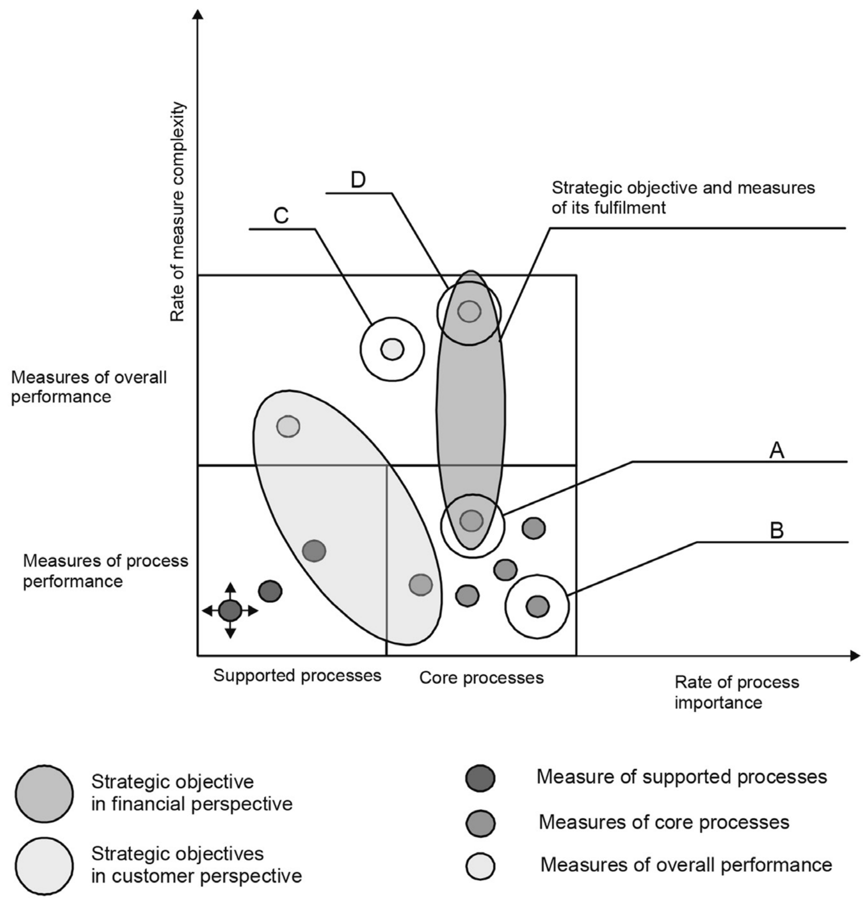
The third dimension of the model represents the rate of an objective's fulfilment, but it is necessary to consider the nature of an indicator, meaning how it can move along the axis of the model.

Fourth dimension – performance level

The fourth level in the model is the level of performance of a given process. This dimension is a part of a three-dimensional description when a performance level does not depend on individual axes (x, y, z), but they represent its limits. The performance monitored by an indicator depends on its relations towards strategic objectives. Figure 2.4 shows a part of the model where the classification of an indicator towards strategic objectives can also be seen. Performance level in this suggested model is divided into two groups:

1) process operative performance
2) process strategic performance.

Figure 2.4 . **Two-dimensional view of the process performance management model (x, y)**



An indicator that is placed on the operational level, meaning that it monitors operational performance, is not classified – is not a measuring instrument of any strategic objective. An indicator that is directly a measure of a strategic objective is placed on the strategic level. Four basic options can arise:

1. A process PI is a measure of a strategic objective and is represented in Figure 2.4, detail A.
2. A process PI is not a measure of any strategic objective (detail B).
3. A process PI is a measure of a strategic objective (detail D).
4. A process PI is not a measure of any strategic objective (detail C).

This model also includes a progressive conception of the BSC system, though not methodically. BSC implementation is a separate and difficult process, and its final state could be taken into consideration in a PPM model. The determination of an indicator as a measure of a strategic objective is only one step of BSC implementation. This process starts by determining strategic objectives and selecting an optimal number of them (20–25 strategic objectives). It continues by building relations between causes and consequences and by targeting strategically important relations. Suitable measures are then selected to monitor strategic objectives and their target values are defined. Finally, strategic activities (measurements) to achieve the targeted performance are defined.

The stage of selecting suitable indicators and assigning them to strategic objectives in BSC determines their relevance to process performance levels. When indicators are assigned to strategic objectives it is possible to use existing measurement instruments or to define new ones that will yield objective statements concerning the achievement of targeted performance and the fulfilment of strategic objectives.

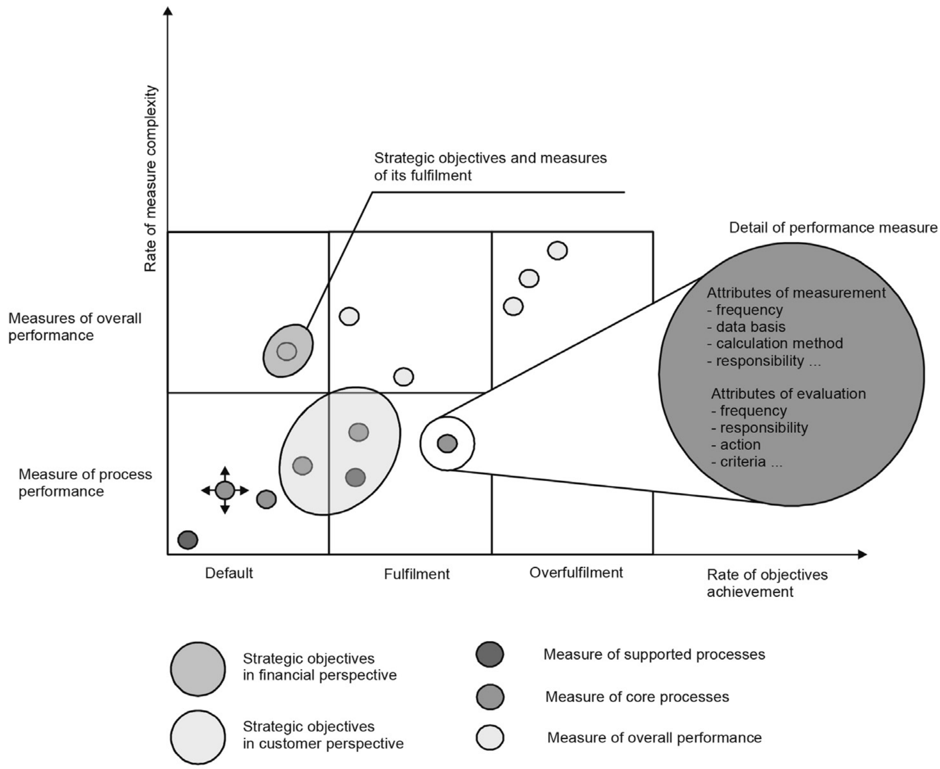
As can be seen in Figure 2.4, strategic objectives can have different indicators to monitor their fulfilment, regardless of their position in the model. One strategic objective can contain a process PI and an indicator of overall performance; it can then be a combination of only overall PIs or only of indicators of process performance.

One strategic objective can contain only one indicator, though. The description of perspectives in the model is coloured, since each colour of a determined objective represents a particular perspective. Thus, four colours have been selected for a model to represent the four perspectives. Ideally, each indicator would be assigned to one strategic objective, but this cannot be always done. To reduce the complexity and ensure correct measurement, the number of indicators should be limited to a maximum of three measuring instruments for each strategic objective. In case more indicators are required, it is suitable to divide the strategic objective.

Each indicator in the model regardless of its position has internal structure expressed through attributes of measurement and evaluation. This structure or describing of indicators is not represented in the model – it is necessary to extract it.

It is represented in Figure 2.5. The basic attributes of measuring and evaluating process performance are defining the responsibility for defining an indicator, the responsibility for defining the indicator's target value, the assumptions based on which a target value is defined, the target value, the unit of measure for the indicator, the time frame for which the defined target value is valid, the responsibility for recording continuous indicator values, the interval between recording values, the place where the values will be recorded, the database from which continuous values will be obtained, the mechanism for calculating values if obtained from several data points, the way of automation for value calculating, the responsibility for evaluating the indicator, the interval for evaluating the indicator, and the procedure for when an indicator value is exceeded. These attributes of measurement and evaluation are characterised in more detail in the following sections of this publication.

Figure 2.5. **Two-dimensional view of the process performance management model (y, z)**



In Figures 2.4 and 2.5 there is an indicator that is demonstrated together with a four-direction abscissa. It is an example abscissa, because indicator movement is allowed in all directions within the model, and in this way it indicates its dynamic features, i.e. the conditions under which its movement can be seen.

We have to consider process performance management as a possible parallel management system which concentrates particularly on process performance. Using activity-based management, the balanced scorecard system, or total quality management sustains performance. But we must remember that processes create value; they are the basic element of conducting business. We can evaluate their performance directly or indirectly, depending on the chosen approach. The areas for measuring and evaluating process performance are determined by the attributes, which are divided into process attributes, activity attributes, and integral attributes. Each group contains process performance measures. It is a basic relation in process performance measurement: process attributes and their measurement. Accepting the progressive business concept of BSC, process attributes and strategic objectives could be the same area for measuring, but at different performance levels. Each process performance measure has its own internal structure for consistent definition. Those basic starting points are integrated into the PPM model. The first part of this model is the static model that determines the content of PPM. It starts with identifying the business processes, moves on to measuring and evaluating process performance, and the last part is process improvement. The model also defines the possibilities for using different methods and techniques at all stages. The second part is the dynamic model. The purpose of this part is to describe and limit the possible change in process performance. The model has four dimensions: the level of process importance, the rate of measurement complexity, the rate of achieving objectives, and the level of performance. The dynamic model describes the causes and assumptions for changes in process performance.

2.3. Attributes of process performance indicators

As can be seen in Figure 2.1, there are two main groups of attributes necessary for PPM. The first group is represented by the attributes of measurement and the second one by the attributes of evaluation. These two groups are divided into four separate sets.

At the beginning, we used an affinity diagram that helped us to clarify and group various attributes of PIs. Affinity diagrams –sometimes called diagrams of relatedness or cluster charts – are a suitable tool for creating and organising information related to a given problem. An affinity diagram helps to sort this information into natural groups and to clarify the structure of problems to be solved. The diagram was created by teamwork and intuitive thinking. The professional composition corresponded with the issues that are being dealt with. The first step consists of defining the problem: What are the attributes of the PI? To focus the team's attention, we wrote down the problem in a visible place.

The task of the team was to use brainstorming to collect the attributes that could help solve the problem. The point was to come up with as many ideas as possible because there is an assumption that the more ideas there are, the higher probability they will be helpful in problem-solving. We wrote down all ideas on cards. A report was created by the coordinator of the brainstorming session, and every attribute was clearly formulated. After the discussion, the cards with the ideas were laid out over a large space. The ideas were then divided into natural groups by their relatedness. This activity was performed by each member of the team individually.

Figure 2.6. **The four groups of attributes of a performance indicator**

F: Formal attributes of the PI
F1: Name of the PI
F2: Relation to the business process (name and sign of the process)
F3: Relation to the strategic goal
F4: Strategic goal (name and sign of the strategic goal)
F5: Responsibility for the PI definition

T: Attributes of the PI's target value
T1: Responsibility for defining the target value
T2: Unit of measure for the PI
T3: Period defined for achieving the target value
T4: Determinants of the target value's definition
T5: Target value (number)

I: Informational attributes of the PI
I1: Responsibility for data recording
I2: Frequency of data recording
I3: Place for data recording (name and destination of database)
I4: Source of data
I5: Formula for calculation
I6: Automation of the calculation (manually/software)

E: Attributes of the PI's evaluation
E1: Responsibility for evaluating the PI
E2: Frequency of evaluating the PI
E3: Visualisation of the performance achieved
E4: Precedure in case of a performance gap
E5: Warning signals for the evaluator

The stage of grouping was finished by the coordinator. The important step was to name the related ideas that could help to characterise each group. At the end we created four groups of attributes of a PI: (1) formal attributes of the PI, (2) attributes of the PI's target value, (3) informational attributes of the PI, and (4) attributes of evaluating the PI. Each group consists of various attributes. Each set of attributes consists of 21 attributes of PIs. In Figure 2.6 the groups and the attributes of PIs is presented.

F: Formal attributes of the performance indicator

F1: Name of the PI

Each indicator should have a specific name which implies an area of performance that is measured by this indicator. To allow the indicator to describe the context, it is advisable to answer the following question: How can we find out whether the level of performance or strategic goal has been reached?

F2: Relation to the business process (name and sign of the process)

This formal attribute refers to the connection between the indicator and a specific business process.

F3: Relation to the strategic goal

It is possible that the indicator is related to the operational or strategic level in a PMS. If the indicator is used for measuring strategic goals, it refers to the measurement and evaluation of strategic performance. Whether the indicator belongs to the first (strategic) or second (operational) level also depends on the utilisation of the BSC system. If this system is used in the company, it is obvious which indicators are part of the strategic set, which are part of the operational level of performance, and what the connections between them are. If this approach is not used by the company, it is advisable to create a primary connection between strategic goals and indicators.

F4: Strategic goal (name and sign of the strategic goal)

If there is a connection to a strategic goal, it is also necessary to name the strategic goal that is measured by the given PI.

F5: Responsibility for defining the PI

If the indicator is at the operational level of performance and it does not measure a strategic goal, then the indicator can be defined by the process owner or the line managers. If the indicator monitors the achievement of strategic goals, it is very important to follow specific principles when defining it. This means that the responsibility for defining the indicator usually lies with the top managers.

T: Attributes of the performance indicator's target value

T1: Responsibility for defining the target value

It is very important to define the responsibility for defining the indicator, and it should be obvious from this definition where the responsibility for defining its target values lies. The target value is critical in terms of performance evaluation, which is why it should be addressed to a specific employee.

T2: Unit of the PI

After creating a suitable indicator and defining the target value, the indicator should be clearly quantified in exact units of measure.

T3: The period defined for achieving the target value

This attribute determines the period for which the goal is set.

T4: The determinants of the target value definition

Each target value should be based on real expectations and there have to exist assumptions how to determine the target value. This usually comes from retrospective analysis and future state forecasting. There are lots of analytical, comparative, and planning methods for determining the target value.

T5: Target value (number)

One of the indicator's attributes is a goal, and without a target value the existence and monitoring of performance would hardly be possible.

I: Informational attributes of the performance indicator

I1: Responsibility for data recording

The next responsibility is determining which employee will record the data necessary for measuring and evaluating performance. This is the third responsibility as an attribute of the PI.

I2: Frequency of data recording

The next informational attribute that deals with the creation and distribution of information in connection to business performance is the frequency of data recording. A dependable employee should clearly identify their responsibilities and the frequency of data recording in order to make the performance measurement realistic. If the data collection is automated, the frequency of data recording is defined by software.

I3: Place for data records (name and destination of data store)

I4: Source of data

If no definite value of an indicator is assigned, it is important to determine the input data from which the final values are calculated. It is characteristic especially of synthetic indicators and relative indicators. If calculation is necessary, it should always be clear what the partial sub-indicators used to calculate the final value are.

I5: Calculation formula

If the value of the PI is calculated from various input values, the mechanism for calculating the final values should be defined (if the calculation is not automated).

In the case of a complex PI, it is recommended to use automated calculation because the evaluation of performance is easier.

I6: Automation of the calculation (manually/software)

In this case, it is important to determine which parts must be automated and which parts need to be calculated manually.

E: Attributes of evaluating the performance indicator

E1: Responsibility for evaluating the PI

The responsibility for evaluation is usually connected with the responsibility for defining the target values. This means that one of the managers is managing 'their' indicators.

E2: Frequency of evaluating the PI

The employee who is responsible for the performance evaluation should know the frequency at which the performance of the selected process should be evaluated by each indicator. If the PMS is automated, it can automatically warn the responsible employee of the need for evaluation and the system can report a deviation.

E3: Visualisation of the performance achieved

An important attribute of the PI that should be determined is a visualisation of the performance results. This is represented by the selection of the method or the way of visualising the results to the evaluator.

E4: Procedure in case of a performance gap

Situations that lead to insufficient performance can have specific causes with specific ways of solving them. For each PI a procedure should be defined in the case that the performance is not in either the 'exceed' or 'failure' interval.

E5: Warning signal for the evaluator

The warning signal is an alert to the person who is evaluating the level of performance achieved.

2.4. Empirical research focused on consistency of business process performance

Consistency is usually defined as agreement, harmony, or compatibility, especially a correspondence or uniformity, among the parts of a complex matter. The importance of consistency in any system guarantees its long-term equilibrium. A consistently defined system minimises externalities leading to the deterioration of the system's balance or even to its demise. A balanced system is thus a prerequisite for sustainability, and consistency is a prerequisite for balance.

Every system can be described using a model which includes those parts whose characteristics are of interest to us. The dynamics of the system are represented by the behaviour of the system. The behaviour of the system can be measured and evaluated using the system's parameters. The parameters then show what the characteristics of the system are. It is similar with a company. In order to describe and observe its characteristics, we need to know its structure (the static aspects) and processes (the dynamic aspects). Parameters to measure its behaviour are then represented by PIs. Each PI is used to observe the behaviour of a particular structure or business process.

The behaviour of a system and the ability to observe it are essential for maintaining its balance. Equilibrium occurs when in the event of deviation from the equilibrium, the system (company) can respond quickly. A rapid response to change ensures the survival of the system. Increasing adaptability to changes ensures a well-established performance management system. A well-designed system is a consistent system.

Perfect consistency is likely impossible for a company to achieve. Furthermore, the current rate of change causes organisations to go from periods of 'near consistency' to periods of 'some consistency.' If the inconsistency is too great, there is an imminent danger of destabilisation (Ramon & Arboledas, 2007).

Závadský (2010), Závadský and Droppa (2013), Závadský and Hiadlovský (2014), and Závadská et al. (2015) have demonstrated how a consistent performance management system could be defined. We know there are many approaches for constituting an effective PMS, but our approach can give managers a quick view of their PMS's consistency as an assumption of the enterprise equilibrium. The level of a system's consistency or inconsistency is one of the system's descriptions. Companies that want to survive need to obey three related laws, say Ramon and Arboledas (2007). According to them, the first is to achieve minimum levels for effectiveness and efficiency; the second is to understand that the degree of effectiveness may decrease if efficiency increases; and the third is to know that the way to increase effectiveness and efficiency together is through consistency. Below we provide some problems that can be solved through consistency.

The first area is environmental or human problems. Tatarkin et al. (2014) proposed a consistent assessment of the status and prospects of institutional and innovative subsurface resource management in the Arctic. In this case, consistency is defined as a uniform and complete development of the institutional framework of the innovative subsurface resource management, which prevents the mineral and resource potential of the Arctic zone being utilised. The object is resource management and the consistency is represented by a uniform institutional framework (regulatory support, project support, and organisational and financial support) of all countries. Holzkämper et al. (2008) developed a consistent framework for integrating knowledge to support integrated catchment management. They claimed that in managing such complex systems, a specific objective can be achieved through different management actions. Likewise, a specific management action can have implications for multiple objectives. Synergies or conflicts between specific objectives and between specific actions are likely to occur, and require careful consideration in order to increase the efficiency of planned management actions. However, such integrated decision-making is a very difficult and highly complex task, which cannot easily be accomplished by either a single planner or group of planners. Integrated modelling tools to facilitate and enhance communication within a group of decision-makers and to create a more objective and evidence-based, multi-criteria decision-making process are required. Holzkämper et al. (2008) described a consistent framework for the integration of knowledge and information about environmental, social, and economic processes and process interactions which are affected by management actions and which impact multiple management objectives. Consistency was also addressed by Hrdinová et al. (2014) in their paper focussing on sustainable development and environmental effects. Healthcare services can also be consistent. Ellis et al. (2007) asked whether the pain management practices for lumbar punctures are consistent. Lu et al. (2008) solved another human problem: they carried out a study on a consistent and integrated traffic management model and emphasised that that model must have consistency criteria.

The next area where consistency should be the standard is software engineering and mathematical modelling. Papendieck and Schulze (2014) presented concepts for consistent variant-management tool integrations. Antonacci et al. (2013) described consistent and efficient output stream management in optimistic simulation platforms and in software engineering. Ishikawa (2010) expected a consistent integration of selection and replacement methods under different expectations in the service composition and partner management life cycle. Stender (2009) stated that setting up backup infrastructures for large-scale data management systems that can be operated cheaply and accessed with low latency has emerged as a practical problem. As a solution, he presented a highly scalable and cost-efficient architecture for backup management in a distributed file system. He described techniques for the creation of consistent backups at runtime, as well as approaches to resource management in connection with an integrated backup architecture. Magnier-Watanabe and Senoo (2007) explored the effect of consistent knowledge management behaviours on competitive advantage. Consistency is very often connected with data management. Awerbuch and Scheideler (2004) described it in their study of consistent and compact data management in distributed storage systems.

Financial management based on quantitative methods is the next area which usually requires consistency. Ma et al. (2013) showed the optimal time-consistent investment strategies in multi-period asset-liability management problems under mean-variance criterion. Time consistency is presented as a mathematical model. Likewise, Ekeland et al. (2012) discussed time-consistent portfolio management. Weißenberger and Angelkort (2011) did not identify a significant effect of the technical aspects of integrating a management accounting system, but report a fully mediating influence of a consistent financial language on controllership effectiveness. Their results imply that consistency with financial reporting is an important property of management accounting system design from the point of view of management.

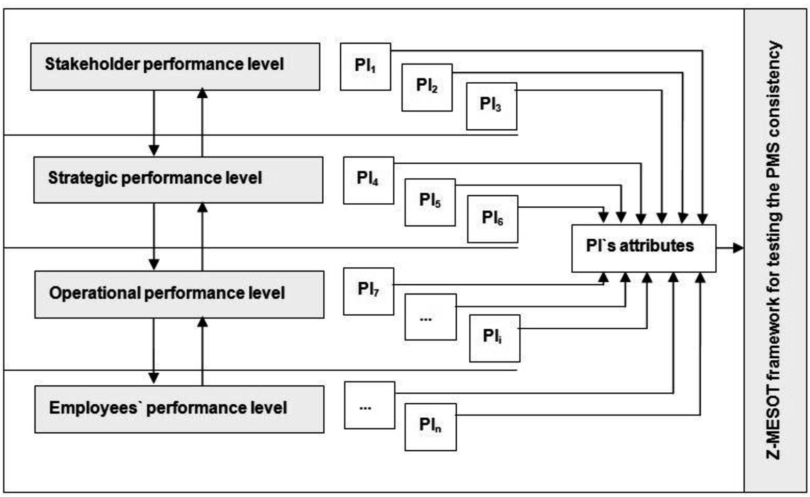
A consistent definition can be used for other company subsystems as well as for PMS. Augestein et al. (2012) proposed consistent logistics service management. Their central idea was to integrate different specialised service models and to construct a comprehensive model which supports the direct implementation of services as concrete logistics tasks. Hermansson (2005) even talked about consistent risk management and introduced three models for understanding the demand for it.

The use of mathematical models was a good basis for creating the Z-MESOT framework, as other authors do using modelling. The model represents a system. The parameters included in the model describe its behaviour, and the structure of the parameters can be consistent or inconsistent. The level of PMS inconsistency should be calculated and should be able to illustrate the enterprise's real PMS.

Z-MESOT framework for testing the consistency of a performance management system

Figure 2.7 shows at what performance level PIs can be defined. The main idea of the Z-MESOT framework, however, is not to define specific PIs for each level of performance. For the application of the Z-MESOT framework, it is necessary to define the same set of attributes for all PIs at all levels of performance.

Figure 2.7. **Basis for the Z-MESOT framework application**



In order to evaluate consistency, we use the Z-MESOT framework (Measuring and Evaluating Strategic and Operational Targets). The consistency of a performance management system is clearly described by the Z-MESOT framework application in the specific business conditions and in accordance with the analysis of performance indicators. In this book we focus on performance indicators through selected key PIs. In the Z-MESOT framework there must always be more than two indicators in order to correctly identify a performance management system's consistency. Figure 2.8 outlines this framework and shows all attributes of performance indicators (21) in the first column of the framework and more than two real indicators in the first row. The rows of the Z-MESOT framework provide information about all attributes of the PI A_j. In total there are 21 of them. Therefore, $j = 21$. The data in the columns describe specific performance indicators PI_i, where $i = 1, 2, \dots n$. In order to evaluate the total consistency of a PMS, all indicators used in the company should be included, especially those used in all performance-level evaluation, as shown in Figure 2.8.

We can assess whether a PMS is partially consistent according to the sum of values in the corresponding lines. The framework consists of values 1 or 0, depending on whether an indicator PI_i in the corresponding column has a defined attribute A_j or not, whilst *Aj* Î {*F1, F5; T1, T5; I1, I6; E1, E5*}. If the attribute is defined, a value of 1 is entered; if the attribute is not defined, 0 is the value.

If a given attribute A_j has reached a value equal to the number of indicators *n*, we consider it a positive, partially consistent definition of all the indicators included in the analysis using the Z-MESOT framework. If the attribute has a value of 0, there is also a partially consistent definition, but negative. All values between 0 and 21 indicate inconsistent definitions of the characteristics. Mathematically, we can describe partial consistency as follows:

If $\sum_{i=1,j=21}^{n} A_{ij}$ 1, F5; T1, T5; I1, I6; E1, E5} → negative partial consistency (6)

If $\sum_{i=1,j=21}^{n} A_{ij}$ 1, F5; T1, T5; I1, I6; E1, E5} → positive partial consistency (7)

If $\sum_{i=1,j=21}^{n} A_{ij}$ $_i$Î{F1, F5; T1, T5; I1, I6; E1, E5 → partial inconsistency (8)

Figure 2.8. **Z-MESOT framework**

			1	...	i	...	n	
			Performance indicator PI_1	...	Performance indicator PI_i	...	Performance indicator PI_n	ΣA_{ij}
F1	A_1	Name of the PI	$A_{1,1} = 1 \vee 0$	...	$A_{1,i} = 1 \vee 0$	...	$A_{1,n} = 1 \vee 0$	<0,n>
F2	A_2	Relationship to the business process	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
F3	A_3	Relationship to the strategic goal	$1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
F4	A_4	Strategic goal (name and mark of the strategic goal)	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
F5	...	Responsibility for defining the PI	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
T1	...	Responsibility for defining the target value	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
T2	...	Unit of measure of the PI	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
T3	...	Period defined for achieving the target value	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
T4	A_j	Determinants of the target value's definition	$A_{j,1} = 1 \vee 0$	...	$A_{j,i} = 1 \vee 0$	...	$A_{j,n} = 1 \vee 0$	<0,n>
T5	...	Target value (number)	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
I1	...	Responsibility for data recording	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
I2	...	Frequency of data recording	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
I3	...	Place for data recording	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
I4	...	Source of data	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
I5	...	Calculation formula	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
I6	...	Automation of the calculation (manually/ software)	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
E1	...	Responsibility for evaluating the PI	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
E2	...	Frequency of the PI evaluation	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
E3	...	Visualisation of the performance achieved	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
E4	...	Procedure in case of a performance gap	... $1 \vee 0$	...	... $1 \vee 0$	...	... $1 \vee 0$	<0,n>
E5	A_{21}	Warning signal for the evaluator	$A_{21,1} = 1 \vee 0$	...	$A_{21,i} = 1 \vee 0$	...	$A_{21,n} = 1 \vee 0$	<0,n>
		ΣA_i	<0,21>		<0,21>		<0,21>	

Inconsistencies in the Z-MESOT framework are featured in the last column in red; negative partial consistency is depicted in yellow; and partial positive consistency is depicted in green. In regards to the total consistency of the PMS, then all the attributes in all the rows have values equal to the number of analysed parameters *n*, then:

$$\text{If } \sum_{i=1,j=1}^{n,21} A_{i,j} = n \text{ Ù } j = \langle 1, 21 \rangle \rightarrow \text{whole PMS consistency} \tag{9}$$

The sum of the individual columns can have a value between 0 and 21. The more attributes are defined for performance indicators, the more measurements and evaluations are systematic, and the more a systemic approach is in use.

Empirical research focused on application of the Z-MESOT framework in a selected manufacturing company

The application of the Z-MESOT framework is shown in Figure 2.8. This application is used to verify the consistency of PMS in the selected manufacturing company. Twelve performance indicators were included in the testing:

1(1) PI_1: Marketing Return on Investment (MROI)
1(2) PI_2: Inventory Turnover (ITO)
1(3) PI_3: Debt-to-Equity Ratio (DER)
1(4) PI_4: Return on Equity (ROE)
1(5) PI_5: Net Profit Margin (NPM)
1(6) PI_6: Average Cycle Time (ACT)
1(7) PI_7: Units On Time (UOT)
1(8) PI_8: DIFOT – Delivery In Full On Time (DIFT)
1(9) PI_9: TSMC – Total Supply Management Costs (TSMC)
(10) PI_{10}: Overall Equipment Effectiveness (OEE)
(11) PI_{11}: Number of Customer Complaints (NCC)
(12) PI_{12}: Customer Satisfaction Index (CSI).

In this book we do not analyse whether the indicators are suitable for measuring overall performance. We analyse their consistency through the Z-MESOT framework. Based on the analysis in the selected company, we enter values 1 or 0 into the framework matrix, depending on whether the attribute has been defined for that variable. We conducted an analysis of the controlling system, reviewed reports, and conducted structured interviews with managers of the selected company. Figure 2.9 shows the results of this analysis with the Z-MESOT framework. The company uses 12 key performance indicators form PI_1 to PI_{12}; in this case $i = 12$. The number of attributes of the performance indicator is unchanged, i.e. $j = 21$.

Figure 2.9. **Testing the consistent definition of a PMS using the Z-MESOT framework**

		1	2	3	4	5	6	7	8	9	10	11	12	
		MROI	**ITO**	**DER**	**ROE**	**NPM**	**ACT**	**UOT**	**DIFT**	**TSMC**	**OEE**	**NCC**	**CSI**	ΣA_{ij}
F1	Name of the PI	1	1	1	1	1	1	1	1	1	1	1	1	**12**
F2	Relationship to the business process	1	1	1	1	1	1	1	1	1	1	1	1	**12**
F3	Relationship to the strategic goal	1	1	1	1	1	1	0	0	0	0	0	0	**6**
F4	Strategic goal (name and mark of the strategic goal)	0	0	0	0	0	0	0	0	0	0	0	0	**0**
F5	Responsibility for defining the PI	1	0	0	1	1	0	0	1	1	1	1	0	**7**
T1	Responsibility for defining the target value	1	1	1	1	1	1	0	0	0	0	0	1	**7**
T2	Unit of measure of the PI	1	1	1	1	1	1	1	1	1	1	1	1	**12**
T3	Period defined for the target value	1	1	1	1	1	1	1	1	1	1	1	1	**12**
T4	Determinants of the target value's definition	0	0	0	0	0	1	1	0	0	0	0	0	**2**
T5	Target value (number)	1	1	1	1	1	1	1	1	1	1	1	1	**12**
I1	Responsibility for data recording	1	1	1	1	1	0	0	0	0	1	1	1	**8**
I2	Frequency of data recording	1	1	1	1	0	0	0	1	1	0	0	1	**7**
I3	Place for data recording	1	1	1	1	1	1	0	0	0	1	1	0	**8**
I4	Source of data	1	1	1	1	1	1	1	1	1	1	1	1	**12**
I5	Calculation formula	1	1	1	1	1	1	1	1	1	1	1	1	**12**
I6	Automation of the calculation (manually/software)	1	1	1	1	1	1	1	1	1	1	1	1	**12**
E1	Responsibility for evaluating the PI	1	1	1	0	0	0	0	1	1	1	0	0	**6**
E2	Frequency of the PI evaluation	1	1	1	0	1	0	0	0	0	0	0	0	**4**
E3	Visualisation of the performance achieved	1	1	1	1	1	1	0	0	0	0	0	0	**6**
E4	Procedure in case of a performance gap	1	1	1	1	0	0	0	0	0	0	0	0	**4**
E5	Warning signal for the evaluator	1	1	1	1	0	0	0	0	0	0	0	0	**4**
	ΣA_j	**19**	**18**	**18**	**17**	**15**	**13**	**9**	**11**	**11**	**12**	11	11	

Firstly, we investigated the existence of a partial positive or negative consistency. As shown in Figure 2.9, the positive consistent partial definition applies to all KPIs in the following attributes: F1, F2, T2, T3, T5, I4, I5, and I6. This means that the key performance indicators used to evaluate the company's performance have not specified all the PIs' attributes (*j ≠ 21*), but selected attributes are specified overall in these KPIs. This represents partial positive consistency of the PMS. These KPIs have a consistent definition, but the whole PMS is inconsistent. If any of the following performance indicators had all other attributes defined, the PMS would have been completely consistent. Our analysis, however, revealed that some indicators also have other attributes defined and that several do not. Thus, the sum of the last column shall be neither 0 nor 12.

In the case of the company under study, we can therefore describe it as having an inconsistent PMS. One solution would be either to define attributes – F1, F2, T2, T3, T5, I4, I5, and I6 – for the other indicators or to omit the attributes which are defined only for certain parameters, with the last column of this attribute acquiring the sum of 0. The set of all attributes reaches a value of 21. In the last line we can see the degree of a systemic approach in measuring and assessing a company's performance. A systematic approach is applied when the last line in each field has a value of 21, representing a definition of all attributes for all indicators.

The presented Z-MESOT framework can serve managers not only in testing for consistency, but also in defining the responsibility for measuring and evaluating business performance if individual indicators have specified various attributes.

3. Increasing business process performance using intelligent technologies

In many European Union member countries, the integration of Industry 4.0 has become a priority at the government level. Not all enterprises and business processes are suitable for Industry 4.0 integration, however. Intelligent technologies as a basic element of Industry 4.0 especially fit in with serial and mass production of cyclically repeated processes and material products. There are, however, industries that only manipulate a material product without transforming it. This particularly concerns logistics companies. There is no definite manual for configuring intelligent technologies for all industries, because their integration always depends on a specific production or logistical system.

This chapter deals with increasing business process performance through the Industry 4.0 concept. We do not describe the economic benefits from introducing Industry 4.0. Each company is different due to its production system, which is why deploying this concept is always dependent on a specific company's conditions and it is impossible to generalise. If we integrate a specific intelligent technology to a selected business process, e.g. smart gloves in dispatching and manipulation, then quantifying the savings which an enterprise gains will depend on a number of components, operating zones, the way information is collected and processed, consequential operational factors, and the product itself. An analysis of the savings resulting from Industry 4.0 deployment must include an analysis of requirements concerning the performance of individual production processes before and after the integration of specific technologies. We must state that not every enterprise must necessarily apply the principles of Industry 4.0. There are some companies which do not have to apply the concept because the nature of their products does not allow it.

3.1. Industry 4.0 as an assumption of business process performance

The growth of a new digital industrial paradigm known as Industry 4.0, supported by a few technologies, such as collaborative robots, autonomous vehicles, and the Internet of things, is considered to be a key factor for the fourth industrial revolution. It is also designated as digital production. Ferreira et al. (2016) claimed that there are some more challenges related to the effective adaptation of these technologies and the interoperability of individual company levels so that the whole production system can work. Likewise, Wang et al. (2016) and Yao and Lin (2015) mentioned Industry 4.0 as an oncoming industrial revolution. The term Industry 4.0 was used for the first time in Germany in 2011 as Industrie 4.0. It describes and incorporates a set of technological changes in production and determines priorities that aim to preserve the global competitiveness of German industry (Qin, Liu, & Grosvenor, 2016). Digitalisation of the whole value-creating chain and continual access to information in the form of virtual models enabled the fourth industrial revolution (Moller, 2016). Industry 4.0 applies the principles of cyber–physical systems (CPS), technologies orientated towards the Internet and intelligent devices with interaction between man and machine. As several authors have stated (Lasi et al., 2014; Posada et al., 2015; Valdez, Brauner, Schaar, Holzinger & Ziefle, 2015), it enables communication among all the entities in a production system in real time. Industry 4.0 is qualified by three dimensions of integration (Almada-Lobo, 2015; Stock & Selinger, 2016):

- horizontal integration within the whole chain of value creation
- end-to-end engineering during the whole product life cycle
- vertical integration and net production systems.

Nowadays, companies face problems processing the huge amount of data coming from information systems and smart devices. Many production systems cannot manage these huge amounts since they are not integrated into a single system that could be used for autonomous management and optimisation of the production system (Lee, Kao & Yang 2014). According to some authors (Brettel, Friederichsen, Keller & Rosenberg, 2014; Almada-Lobo, 2015), the oncoming industrial revolution is based on Internet functions, which allows communication between people as well as between machines in CPSs. According to Kagermann et al. (2013), the Industry 4.0 concept is based on CPS, which he designated as a fusion of the physical and virtual worlds. In his opinion, the Internet of things enables the whole enterprise to be connected into the virtual environment. Intelligent machines develop digitally and warehousing systems and production facilities enable the integration of information and communication systems across the entire supply chain. The term Industry 4.0 refers to a wide range of actual concepts whose clear classification related to Industry 4.0

does not exist. The following fundamental concepts have been mentioned by a fewauthors (Lucke et al., 2008; Lasi, et al., 2014): (1) smart factories – manufacturing will be completely equipped with sensors, actors, and autonomous systems; (2) cyber–physical systems – the physical and the digital level merge, which if it covers the level of production as well as that of products, systems can emerge whose physical and digital forms cannot be differentiated in a reasonable way anymore; (3) self-organisation – existing manufacturing systems become increasingly decentralised, which comes along with a decomposition of the classic production hierarchy and a change towards decentralised self-organisation; (4) new systems in the distribution, procurement, and development of products and services – this will increasingly be individualised; (5) adaptation to human needs – new manufacturing systems should be designed to follow human needs instead of the reverse. Kane, Palmer, Phillips & Kiron (2015) stated that some kinds of jobs may completely cease to exist after Industry 4.0 deployment, but at the same time the increased productivity achieved through the use of smart technologies can ensure new jobs and can increase consumer demand. Weber (2015) claimed that if the number of jobs does not decline, their profiles will be changed. This means that in the area of employee education, adaptation measures will be required.

3.2. Intelligent technologies and main value-added business processes

The integration of intelligent technologies is the basis of Industry 4.0, and it simultaneously presents an important organisational and technological innovation. Crossan and Apaydin (2010) systematised organisational innovations with a comparative analysis of the literature from the past thirty years. They synthesised various perspectives concerning the theory and consequences of organisational innovations and suggest indicators and determinants of organisational innovations and their consequences for managerial practice. Similarly, Damanpour and Aravind (2012) also pointed out the impact of organisational innovations on management practice. Their publications, independent from Industry 4.0, expanded the theory of organisational innovations, which is not based only on technological and product innovations. Damanpour et al. (2009) conducted a study aimed at technological and organisational companies in non-industrial industries, particularly among a sample of 428 public service organisations in Great Britain over four years. One of their findings was that technological and organisational innovations based on intelligent technologies have an impact on performance even in non-production organisations. Adams et al. (2006) focussed on measuring technological and organisational innovations in enterprises. They proposed a complex framework to measure and assess innovations. In regards to the development of production quality according to Industry 4.0, though, we think of technological and organisational innovations which result from informatisation, digitalisation, and automation. All intelligent technologies are based on digital information and automation. Some authors also grouped Big Data and cloud solutions under Industry 4.0. We can see the arrival of nanotechnologies and new communication solutions such as high-speed networking, as well, but these were not included into our set of intelligent devices.

A description of a practical demonstration which utilises technologies of the Internet of things, wearable technologies, virtual reality, and cloud technologies for supporting production systems was presented by Hao and Helo (2017). Maly et al. (2017) described the implementation of augmented reality through intelligent glasses with gestures in a production cell containing an industrial robot and claim that users of smart glasses are able to make products without previous knowledge or any other assistance due to the fact that smart glasses project information into the physical work space of their user. Kolberg and Zühlke (2015) dealt with the utilisation of smart watches in flexible production planning supported by the Kanban conception of what really underlines their rich application. Vernim and Reinhart (2016) presented a study which compared two mobile devices used as assistance systems. The goal of their study was to identify the possibilities of using smart phones and tablets in an unknown assembling task. Their findings demonstrate that in contrast to the classic forms of working instructions, these devices also bring better results in the execution of an assembly task. As Mo et al. (2016) stated, radio-frequency identification technology could also be used locally in production companies to monitor assembly. Ji et al. (2016) described the technology of production process management for producing components based on bar codes.

Autonomous vehicles, drones, and GPS systems are examples of navigation and localisation technologies. Autonomous mobility presents an important element towards the integration of intelligent technologies based on localisation systems. It is divided into autonomous mobility used in road-traffic infrastructure and internal company logistics. For example, BMW transports components using a fleet of ten autonomous intelligent robots called Smart Transport Robots. One of the integral parts of Industry 4.0 in production companies is a manufacturing execution system (MES). Nowadays, a detailed exchange of data between MES and ERP systems is inevitable, since these systems are necessary for the effective and faultless planning and operation of devices and production processes. According to Fallaha (2015), the need for information technologies is growing and is led by computer-integrated production. The disadvantage, as the author said, is insufficient flexibility and rigid hierarchical managerial architectures. With the aim of overcoming these restrictions within Industry 4.0, MES systems should be integrated. Kletti (2015) stated that a key to ensuring the success of production information is a fully integrated MES solution which is used as a central information data system. In his publication, Kletti (2015) described how an integrated MES helps improve production effectiveness and success with Industry 4.0 technology, which from the point of view of Industry 4.0 is considered to be as important as 3D printing. Chen & Lin (2017) stated that 3D printing is an important factor that enables the development of production quality in accordance with Industry 4.0. In their study, they directly analysed the barriers which prevent this technology being deployed. Another technology which forms Industry 4.0 in practice is virtual reality. For example, Turner et al. (2016) examined the possibilities of using virtual reality in industrial enterprises, particularly in simulating discrete events.

In a smart factory, it is not possible to avoid the use of collaborative robots (Murashov, Hearl & Howard, 2016). Collaborative robotics is a new trend in the area of industrial robotics, and it creates new opportunities in the cooperation between people and machines. Workers share their workstation with a robot, which helps them with non-ergonomic, repetitive, uncomfortable, or dangerous operations. The robot monitors its movement with advanced sensors so that it does not restrict – and more importantly does not endanger – its colleagues, the production operators (Vysocky & Novak, 2016).

The main value-added business processes are production processes. We focus on manufacturing companies where intelligent technologies are used the most. Each manufacturing company has production management as an integral part of the industrial enterprise management system. It creates the core of the value-added process through core and support manufacturing processes. Production management is a specialised discipline of management orientated towards production planning, the organisation of production operations and activities, the management of production operators and other employees allocated to production processes, and control activities related to the production process. These management processes are ensured by manufacturing managers, shift managers, and other management staff, organisationally associated with manufacturing processes regardless of the management system, which may be function- or process-orientated. Manufacturing operations are provided by manufacturing operators.

If we consider production management as a subsystem of the company's management system, its function is mainly to create a manufacturing and product programme, technical preparation, technological preparation of production, organisational preparation of production connected with time, space, layout, and capacity planning, production run, production start, planning and organisation of the main production processes, planning and organisation of service production processes, checking the quality of inputs and outputs of production processes, controlling non-conforming products, and changing procedures. The function of production management is also to ensure the integrity, flexibility, and continuity of production processes by using production management methods and tools and operational analysis. The basic goal of production management is to produce products in the amount and quality required by stakeholders in order to optimally secure all production management functions.

The content of the production management system is determined by its functions, objectives, and outputs of production processes. The development of production management mainly influences technological and organisational innovations associated with the digitisation, computerisation, and automation of production processes. The rapid technological development in external technologies entering production processes was also signalled by the creation of the Industry 4.0 concept. All social and technological elements of production system are conected via the Internet or an intranet. The social element consists of production managers and production operators or other employees involved in production processes. However, such connection can be only secondary to another technological device; there is no direct connection between humans and machines in Industry 4.0. Besides interconnectivity, this concept contemplates the massive deployment of collaborative robots to replace human resources and the deployment of information systems based on the mass collection of all data as a result of the interconnectedness of a factory's management system elements.

Pre-production processes

The objective of the survey is to classify production processes and the subjects of the survey were selected industrial enterprises. Not all manufacturing concepts are applicable separately, as they have to be integrated into an existing production system in which production and logistics processes are implemented. Therefore, in the next part, we focus on defining the content of the individual processes that form the basis of our literature review. The first group is the pre-production processes listed in Table 3.1.

Table 3.1. **Pre-production processes**

Process	Process outputs
Forecasting	production prognosis, production programme, long-term production plan, development plan
Product development	prototype design, construction, and technological documentation
Prototype production and evaluation	real prototype, approval documentation (suppliers, customers, construction, technology, and economy)
Commercial prototype production planning	design of production system layout, design of production processes, drafting of norms (material, energy, and time), allocation of human resources
Commercial prototype production and evaluation	real production system, production run, start of production, production system typing
Demand management	product price, marketing communication plan, contract

The importance of pre-production processes lies in the generation of future production based on forecasts on the design and development of new products, together with the production and approval of the prototype, the technical preparation of production, and the planning of the corresponding production system. Pre-production processes begin by forecasting and creating a business programme.

Production processes

An essential part of the production system is the production process, where organisational and technological innovations are primarily implemented to ensure that it fulfils its strategic and operational performance. Table 3.2 shows the manufacturing processes that we consider to be the basis for further investigation, not only theoretical but also empirical research in the selected industrial plants. This research is not described in our monograph.

According to Kupkovič (2003, p. 258), production is a part of the transformation process, specifically the conversion of production factors (inputs) into products (outputs). This transformation takes place as a production process that consists of a whole range of working, automated, and natural processes and is limited by the time interval in which the inputs are converted to the product.

Table 3.2. **Production processes**

Process	Process outputs
Tool management	need for tools, new tools, repaired tools, tool warehouse
Material management	material requirements according to bill of materials and consumption norms, stock material, material flow, waste material
Scheduling	layout of the production system, allocation of resources to workplaces, plan of technological operations
Manufacturing planning and control	daily and change-over production plans, operational re-allocation of production operators, time, rhythm and continuity of production
Manufacturing	production batches, assembly, assembly, performance of production operations, intermediate stocks, finished products
Converting manufacturing processes	plan for reconfiguring the production system, changing the layout of the workplaces
Non-conformity management	identification of inappropriate product, marking non-conformities, stock of non-conforming products, repairing, releasing, recycling or disposing of non-conformities

Tomek and Vávrová (2014) defined production as the decisive part of the value-creation chain, which uses combination of factors to secure the satisfaction of the customers' needs by creating goods and services. Implementation takes place through the enterprise production system. Keřkovský and Valsa (2012) described production as a transformation of production factors into economic goods and services that are subsequently consumed. Production is a crucial part of the value chain. Value is added throuhg production process which can be characterised as the result of a purposeful human behaviour which, using input factors, ensures the given transformation process with the result of the most valuable output.

Rudy et al. (2012, p. 6) stated that the essence of production is the input of the input factor into the transformation process, at the end of which output is generated. To realise these changes, it is necessary to mobilise labour and means of production. The authors attribute an important role to the production technology used as well, indicating how the work force and working refer to work on raw materials, materials, and semi-finished products when they are transformed into the desired product or service.

Kupkovič (2003, p. 258) characterised the production process as a 'creative process whose function is the creation of utility values and it represents the main activity of the enterprise.' According to him, the main aspects of the division of the production process are as follows:

- the production programme – the main manufacturing process, the auxiliary production process, the by-product manufacturing process, and the associated manufacturing process;
- complexity of products – simple manufacturing processes and complex (medium complex products, complex and very complex products) production processes;
- participation of nature, man, and technology – natural, working, and automated processes;
- technology used – extraction technological processes, mechanical technological processes, chemical technological processes, biochemical processes and energy technological processes;
- the composition of the products;
- method and rate of the repeatability of production – a continuous, cyclical, and non-cyclical process.

Post-production and cross-production processes

Post-production and cross-production processes are shown in Table 3.3. We joined this group into one table where we try to briefly characterise the basic attributes of these processes.

Table 3.3. **Post-production and cross-production processes**

Process	Process outputs
Continuous improvement	incremental process changes
Reporting	reports according to the requirements of the production managers
Maintenance	the technological equipment being maintained
Quality Control	input, intermediate, and output control
Visual management	visualisation of results, instructions, and security zone
Waste management	waste sorting, low environmental burden, recycling of usable materials
Change management	integrating changes in product requirements into production systems and production processes

Continuous improvement of production processes is based on gradual incremental changes. Continuous improvement as a philosophy was described by Freiesleben (2005), Perdomo-Oritz, Gonzales-Benito and Galende (2009), Kosturiak et al. (2006), and Košturiak (2013). Similarly, Řepa (2006, p. 13) noted that it is necessary to improve production processes and states that several approaches have been created to improve processes and introduce incremental changes, following the crisis of reinvigoration as a radical change of processes.

Reporting is one of the post-production processes. Today it is often referred to as reporting and is significantly linked to the existing enterprise information system and its database. According to Fibírová (2003), reporting should create a relatively comprehensive system of indicators and information that should evaluate not only the development of the whole enterprise but also provide partial views – including those from production processes – which are decisive in terms of management. Reports should therefore be structured in line with their real users' needs. Reporting thus represents the process of creating internally structured information groups for production managers at regular intervals or upon request.

An important cross-production process is maintenance. This process is often also included in the manufacturing process and represents the care of technological equipment that ensures their operational reliability and sustainability. Usually we include the regular repair of machines and equipment during operation and all types of planned and unscheduled repairs in order to eliminate the consequences of fatigue of the machines and equipment. Today, maintenance in businesses has evolved into the Total Productive Maintenance (TPM) concept. This concept was written/described by Chong et al. (2012), Jeon et al. (2011), Jirarat et al. (2011), Sivaram et al. (2013), and Leflar (2001). Boledovič (2013) stated that a fully productive maintenance system of a company consists of five elements. The system of total productive maintenance aims to change the organisational culture in the enterprise to maximise the overall efficiency of the production system. TPM takes a thorough look at the entire business system to prevent all types of losses in the workplace or of the equipment. TPM is not only in the production system and cooperative departments, but it is a company-wide concept. The implementation and functioning of TPM entails the activities of all employees in the company and strives for zero losses through activities in small autonomous teams.

Quality control is a part of quality management. Like the management of innovation, this is also a separate management discipline. Specifically, and in connection with the quality control of production processes, Ghinato addressed this issue (1998). In principle, various measuring and diagnostic equipment is used for quality control, so quality control is closely related to the discipline of metrology. Quality control, in our opinion, is one of the processes where it is possible to deploy some innovative and intelligent technologies very quickly and efficiently.

Visual management is based on the principle of visualising as many elements of the production system as possible. Visualisation is based on the claim that visual perception facilitates adaptation and performance. Visualisation includes the creation of horizontal and vertical boundaries around devices and workplaces, the visualisation of the current state of work in progress in the form of screens, the visualisation of supremacy and subordination in the form of clothing, the visualisation of performance results, and the visualisation of work operations in the form of pictograms.

Waste management is often governed by legislation, where the relevant statutory regulations have to be met. With regard to waste management, companies are given the opportunity to use resources efficiently.

The next cross-sectional production process is change management. In this case, it is not the management of changes in management considerations. In this case, it is about implementing changes that are triggered by stakeholders and that affect the production system or production processes, consequently affecting the final product. It is, for example, a change in customer requirements at a certain phase of production sprawl, a requirement for a change in material or construction, or a requirement to implement a change in product safety. Changes can thus be divided into those that relate to a specific customer's product or a change that affects all other manufactured products, regardless of the customer.

3.3. Empirical research focused on utilisation of intelligent technologies in production processes

Our empirical research was conducted in a few phases, the most important of them being the determination of a set of 26 manufacturing and logistics processes in four groups and four smart devices, the creation of a research matrix, the determination of basic and a selected set of industrial enterprises, distribution of the questionarie as a research matrix, data collection from surveys filled in by quality managers, processing of research data representing current application of intelligent technologies in the sample, the expectations of quality managers, and the identification of the potential for growth in intelligent technologies.

The basic method for the research was a sociological enquiry in the form of a questionnaire – in our case the questionnaire shown in Table 3.4. Questionnaires were sent to quality and production managers, and data collection was carried out from November 2018 to March 2019.

Table 3.4. **Percentage of smart device utilisation in production processes** [%]

Manufacturing processes	Smart Glasses	Smart Gloves	Smart Watches	Smart Phones/ Tablets
Forecasting	0	0	0	80
Product development	7	0	5	80
Prototype production and evaluation	7	0	0	80
Commercial prototype production planning	7	0	0	80
Commercial prototype production and evaluation	7	0	0	80
Demand management	0	0	11	80
Tool management	9	0	0	80
Material management	9	0	11	80
Scheduling	0	0	0	80
Manufacturing planning and control	7	0	18	80
Manufacturing	20	9	18	80
Converting manufacturing processes	0	0	0	77
Nonconformity management	27	2	50	98
Continuous improvement	0	0	0	80
Reporting	2	0	39	80
Maintenance	9	0	7	80
Quality Control	23	2	57	98
Visual management	20	0	30	98
Waste management	0	0	0	80
Change management	23	2	59	80
Purchasing	11	0	23	98
Warehousing	27	2	25	98
Dispatching	36	16	16	98
Transportation	7	0	14	98
Manipulation	25	2	7	98
Delivering	11	0	39	98

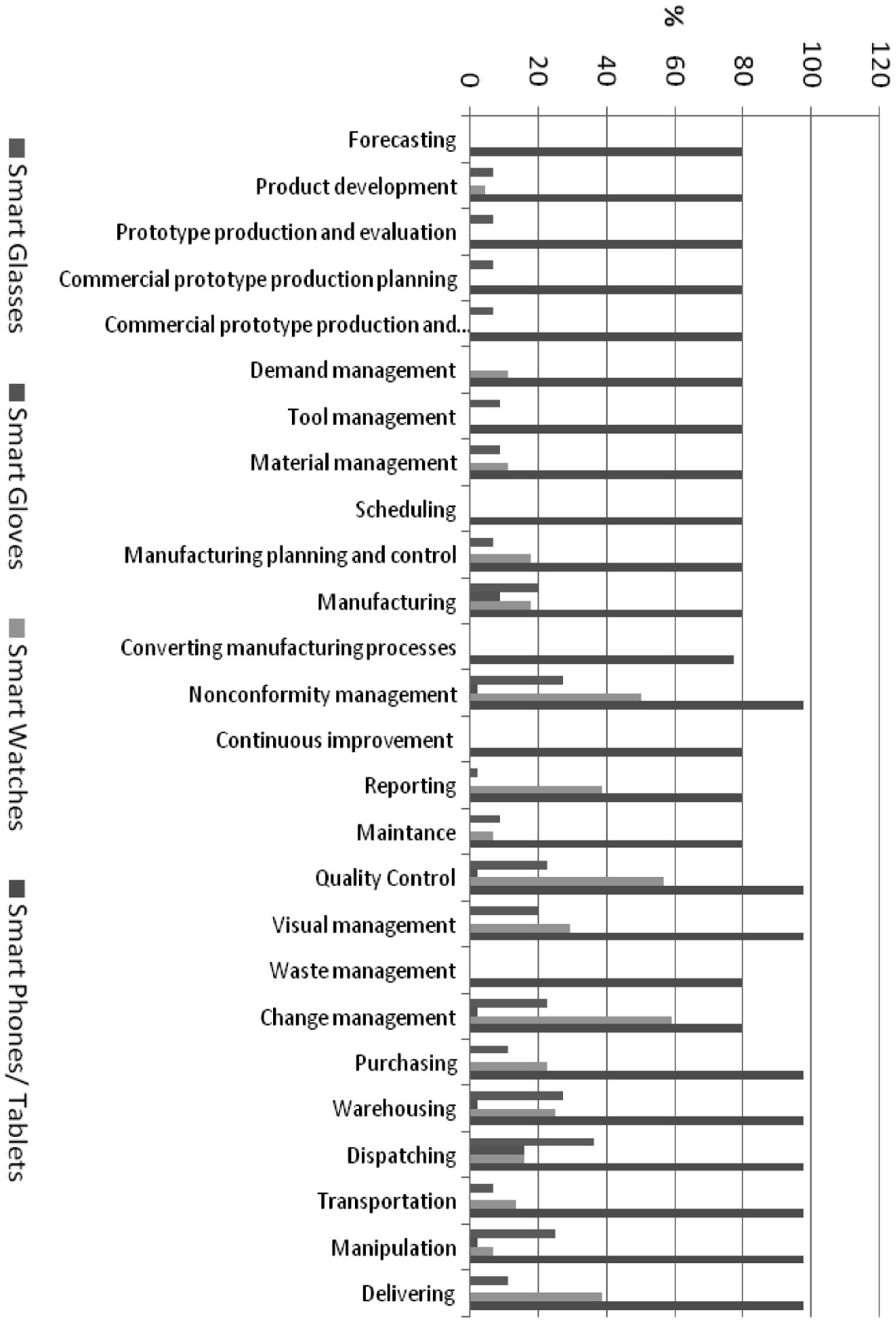
The study group consisted of large enterprises employing more than 249 employees. According to the Slovak Statistical Classification of Economic Activities in the European Community (SK NACE), the total number of registered large enterprises in December 2016 was 907. The basic set of 251 enterprises met these selection criteria:

- to have more than 249 employees,
- to be located in Slovakia,
- to have manufacturing or logistics processes,
- to have products clearly identifiable.

Table 3.5. **Industrial enterprises**

Industrial enterprises	No.	%
CA – Manufacture of food, beverages, and tobacco products	23	9.16
CE – Manufacture of chemicals and chemical products	5	1.99
CF – Manufacture of pharmaceuticals and medicinal chemical and botanical products	3	1.20
CG – Manufacture of rubber and plastic products and other non-metallic mineral products	40	15.94
CH – Manufacture of basic metals and fabricated metal products, except machinery and equipment	29	11.55
CI – Manufacture of computer, electronic, and optical products	11	4.38
CJ – Manufacture of electrical equipment	29	11.55
CL – Manufacture of transport equipment	52	20.72
F – Construction	11	4.38
H – Transportation and storage	48	19.12
Total	251	100.00

Figure 3.1. **Current utilisation of smart devices in manufacturing processes**



The industries which are shown in Table 3.5 were classified as the basic set of enterprises. The largest group in the basic set (n=52) is represented by those companies doing business in the automotive industry. The second largest group is those enterprises from the area of transport and warehousing. This fact is not very surprising since the automobile industry plays an essential role in the Slovak economy.

The selected set consisted of 44 companies. Tablets and smart phone are most often used among smart devices. In none of the defined set of production and logistic processes was the percentage of their use lower than 77%. The second most often used smart devices were smart watches, which are classified as wearable intelligent technologies. Intelligent watches were most used in processes such as non-conformity management (50%) and in reporting, quality control, and change management. The least utilised intelligent device in the selected set of enterprises was smart gloves. They were mentioned in only six processes. The gloves are most intelligent in dispatching, where they were used by 16% of the surveyed companies' processes. Smart glasses were most often used in manufacturing, non-conformity management, quality control, visual management, change management, purchasing, warehousing, dispatching, transportation, manipulation, and delivering. The process with the highest level of usage was dispatching, with a value of 27%.

An analysis of the current utilisation of smart technologies was the one of the main goals. This topic is closely connected with business performance. Innovations based on utilising new technologies which are a part of Industry 4.0 is a concept understood under the term quality development. They can also be discussed separately, because, for example, intelligent devices are used in almost every company but they do not have to apply Industry 4.0 as a complex of technologies. It should be remembered that not every enterprise has to apply all technologies in the set of our empirical research. The deployment of complex technologies is especially determined by the following factors:

- the industry
- the number of pre-manufacturing, manufacturing, post-manufacturing and cross-manufacturing processes
- the scope of individual processes
- the actual rate of data, digitalisation, and automation of processes
- the actual state of production system integration
- the actual state and number of smart technologies
- the requirements of concerned parties concerning the utilisation of smart technologies (especially suppliers and customers).

The most important conclusion resulting from the empirical research is that the high degree of variability in smart technology usage is dependent on the industry. For example, the automotive industry used these technologies at the highest level among all industries, and in contrast the lowest level of using new technologies is in the building trades. Thus, there is a relatively large difference between them. This concerns not only individual processes, but the technologies as well.

4. Exigency of improving business processes

Based on a literature review and previous research, we decided to develop a new, simple Industry 4.0 necessity index for quantifying process improvement exigency related to Industry 4.0 (I4). This index is not intended to identify the current state of I4 or a company's readiness for this concept, but to assess the need to implement it. By implementing the Industry 4.0 concept we mean mostly deploying intelligent technologies, informatisation, and the automation of business processes. Our philosophy is to develop a simple design for a minimum number of factors that may give rise to an internal or external need to implement I4. The secondary output of the I4 necessity index is a quantification of the level of potential process improvement of selected production and logistical processes. We selected eight basic factors that take into account the internal and external pressure on I4 implementation.

4.1. Industry 4.0 indexes and maturity models

Since Industry 4.0 emerged, many maturity models have been developed. One of the main objectives of this book is to develop an I4 necessity index for quantifying the exigency of process improvement related to I4. We focus on pressure that affects the selected production and logistic processes, either internally or externally. That pressure on process improvement is expressed through selected exigency factors. The literature review helped us to understand how other authors perceive I4 readiness and I4 maturity and what factors are most important for our research and for developing an I4 necessity (I4N) index.

Our literature review started with a general analysis of I4. More than 10,000 papers related to I4 were found in Web of Science and Scopus databases. We selected papers that describe the factors of I4 readiness and I4 maturity. Nazarov and

Klarin (2020) presented a taxonomy of Industry 4.0 by mapping scholarship and industry insights. According to them (2020), the state-of-the-art review of the entire scholarship on Industry 4.0 demonstrates three broad clusters: the implications of automation for industry, the integration of technologies, and technological advancements driving the Fourth Industrial Revolution. Interesting research was also conducted by Kosacka-Olejnik and Pitakaso (2019), who analysed the main contributions published on the topic of Industry 4.0. A study by Ghobakhloo (2020) could serve Industry 4.0 stakeholders – leaders in the public and private sectors, industrialists, and academics – to better understand the opportunities that the digital revolution may offer for sustainability and to work together more closely to ensure that Industry 4.0 delivers the intended sustainability functions around the world as effectively, equally, and fairly as possible. A general view on I4 was also offered by Schott et al. (2020), Culot et al. (2020), Mana et al. (2018), and Pessot et al. (2020). We focussed on the newest papers.

Jesus and Lima (2020) determined the key factors for the development of generic and specific maturity models for I4. They identified factors for the development of specific maturity models which are orientated towards unique conditions, located in specific contexts, and can cover both the need for self-diagnosis of the level of preparation and the actions that could progressively reconfigure and guide the company through continuous improvement towards Industry 4.0. Their systematic literature review of 67 papers resulted in the identification of five factors for development of a specific maturity model: context characterisation, conceptual characterisation, interaction with practitioners and experts, development of surveys, and qualitative research. The key ingredients for evaluating an organisation's Industry 4.0 readiness and the interrelationships that exist between these readiness factors were also described by Sony and Naik (2020). Their research can help organisations identify the factors which they need to critically assess before implementing Industry 4.0. All those factors are primary related to I4 maturity and I4 readiness. According to Hughes et al. (2020), the roadmap towards Industry 4.0 is complex and multifaceted, as manufacturers seek to transition towards new and emerging technologies whilst retaining operational effectiveness, and these factors are further evaluated via the presentation of their new Industry 4.0 framework. A unique view on the I4 maturity model for machine tool companies was presented by Rafael et al. (2020), who claimed that a maturity model (MM) can be very useful, since it helps in the evaluation of a company's initial state and the planning of a development road map.

The dominant drivers of I4 integration are societal pressure and public awareness, government policies supporting I4, top management involvement and its support, and government incentives and regulations (Harikannan et al., 2020). Ramingwong et al. (2019) stressed the human factors leading to I4. Strategy, leadership, and culture were found to be the key elements of transformation in the journey towards I4; additionally, the design and development of digital twins, virtual testing, and simulations were also important factors for manufacturing firms to consider (Narula et al., 2020; Zabolotniaia, Cheng, Vasin et al., 2018). Pech and Vrchota (2020) used the Index of Industry 4.0 and confirmed the assumption that large enterprises have greater opportunities to use new technologies and to transform into smart factories. Hizam-Hanafiah et al. (2020) explored many I4 readiness models. According to Hizam-Hanafiah et al. (2020), it is critical for organisations to self-assess their Industry 4.0 readiness in order to survive. Their review identified 30 I4 readiness models with 158 unique model dimensions, and they proposed six dimensions (technology, people, strategy, leadership, process, and innovation) that can be considered the most important ones for organisations. Another seventeen enablers that can affect the adoption of Industry 4.0 in the manufacturing industry in India were explored through an extensive review of the available literature and the perspectives of industry and academic experts by Jain and Ajmera (2020). A systematic literature review presented by Hoyer et al. (2020) discussed a comprehensive list of potential factors that influence the implementation of Industry 4.0 and strengthened the idea that further research is necessary in order to address contradictory findings and develop efficient Industry 4.0 implementation frameworks. Simetinger and Zhang (2020) stated that the potential of the Industry 4.0 concept lies in increased productivity, improved cost efficiency, or higher product attractiveness. The adoption of this concept comes with many challenges and risks. A possible solution to address these challenges and risks is to adopt or implement this concept using maturity models. Simetinger and Zhang conducted a comparative analysis of significant maturity models.

The Fourth Industrial Revolution has provided an unprecedented platform for innovation in various spheres (Kruger and Steyn, 2020). We agree with this innovation potential, and as such would like to quantify the process improvement exigency related to I4. It is important to consider all drivers and barriers, as did Stentoft et al. (2020) in their investigation of the drivers and barriers for Industry 4.0 readiness and practice among Danish small and medium-sized manufacturers. Rauch et al. (2020) and Peukert et al. (2020) similarly investigated small and medium-sized enterprises using a maturity level-based assessment tool to enhance the implementation of I4 and a process model for the successful implementation and demonstration of SME-based I4. Herceg et al. (2020) also provided a deeper analysis of the digital maturity model and the I4 driving forces and implementation barriers. Cimini et al. (2020) investigated the organisational implications of adopting I4 technologies,paying specific attention to operations. The basis for determining our exigency factor also comes from Wagire et al. (2020), who developed a maturity model for assessing the implementation of Industry 4.0. We emphasise that not maturity, but a real necessity of I4 implementation was the main goal of this book. We found the research of Nafchi and Mohelska (2020) to be inspirational. They found that the size and type of an organisation influence the innovative culture and consequently the readiness of an organisation for implementing Industry 4.0. Another factor for process improvement could be cost-driven motives, which were described in detail by Stentoft et al. (2020). We will not consider these financial aspects, but rather a framework for a quality discipline that supports the fourth industrial revolution (Zonnenshain & Kenett, 2020).

Maturity models and I4 implementation frameworks have also been described by Kiraz et al. (2020), Facchini et al. (2020), Santos and Martinho (2019), Tortorella, Giglio, and Dun (2019), Pacchini et al. (2019), Frederico et al. (2019), Gajsek et al. (2019), Basl and Doucek (2019), Colli et al. (2019), Mittal et al. (2018), Bibby and Dehe (2018), Sjodin et al. (2018), Asdecker and Felch (2018), and Ganzarain and Errasti (2016). All these studies resulted in a similar group of factors or maturity levels. The level of informatisation, the level of automatisation, and the level of the process integration to an MES/ERP, customers, and suppliers are the most important exigency factors which are involved in an I4N index. For example, Kuo et al. (2020) also proposed a smart system to prevent customer dissatisfaction. Each factor is assessed separately in our proposal. Calculating the I4N index uncovers the process improvement exigency related to I4.

The next factors are focussed on the production system. Raj et al. (2020) described the specific barriers to the adoption of Industry 4.0 technologies in the manufacturing sector. Ivascu (2020) discussed the implications of sustainable manufacturing in the context of Industry 4.0. The importance of I4 mainly in production systems was also described in Doltsinis et al. (2020). As we mentioned above, process improvement related to I4 and its quantification is the main goal. This was supported by Queiroz et al. (2020), who identified 26 drivers that have an impact on improved business processes. Tupa and Steiner (2019) and Jena et al. (2020) also emphasised that production companies are adopting new methods for improving their management of production processes and for sustainable manufacturing. Hahn (2019) and Tortorella et al. (2019) explored the relationship between I4 and supply chain improvement. The implications of the literature review have been transferred to our I4N index for calculating the exigency of process improvement related to I4.

4.2. New Industry 4.0 necessity index

From the analysis of existing research, we selected eight basic factors that take into account the internal and external pressure on I4 implementation. There are many existing perspectives on I4 implementation and business readiness. In determining the factors, we focussed on the basic criteria, which were the simplicity and generality of the resulting I4N index. The internal and external I4 exigency factors were as follows: $I4N_1$ – production system; $I4N_2$ – product variability; $I4N_3$ – existence of the process; $I4N_4$ – level of informatisation of the process; $I4N_5$ – level of automation of the process; $I4N_6$ – integration of the process to the MES/ERP; $I4N_7$ – customer request for using intelligent technologies in the process; and $I4N_8$ – supplier request for using intelligent technologies in the process.

As the first internal factor, the production system ($I4N_1$) was divided into four basic types of production, namely job shop production, batch production, mass production, and continuous production. These four types comprise the elementary classification of production systems. The literature review showed that the larger the production volume, the greater the potential pressure to deploy intelligent technologies. However, this factor also fundamentally affects the second factor, which is product variability ($I4N_2$). This factor, although defined separately, is related to the type of production system. The greater the variability of products, the greater the potential pressure to deploy intelligent technologies in business processes.

The third factor is the existence of given production or logistics process ($I4N_3$). Here, the nature of this factor is very simple. If the process exists in the company, logically, potential pressure is created. If the process does not exist, the pressure is zero. As mentioned earlier in the book, we followed the known production and logistics process defined in our previous research. The processes involved in the I4N index are as follows: P1 – forecasting; P2 – product development; P3 – prototype production and evaluation; P4 – commercial prototype production planning; P5 – commercial prototype production and evaluation; P6 – demand management; P7 – tool management; P8 – material management; P9 – scheduling; P10 – manufacturing planning and control; P11 – manufacturing; P12 – converting manufacturing processes; P13 – non-conformity management; P14 – continuous improvement; P15 – reporting; P16 – maintenance; P17 – quality control; P18 – visual management; P19 – waste management; P20 – change management; P21 – purchasing; P22 – warehousing; P23 – dispatching; P24 – transportation; P25 – manipulation; and P26 – delivering.

The level of informatisation of the process ($I4N_4$), as the fourth factor, represents the proportion of process activities which are informatised. Informatisation of an activity means that its input, transformation, and output are recorded in some information system (manually or automatically). The higher the level of informatisation, the less pressure there is to deploy intelligent technologies. This is similar with the fifth factor: level of process automation ($I4N_5$). The term automation of activities refers to an activity performed automatically without human labour. The higher the level of automated process activities, the less pressure there is to deploy intelligent technologies and vice versa.

The sixth factor, the integration of a process into the MES/ERP ($I4N_6$), is related to the fourth factor. We determined the sixth factor separately due to its uniqueness. Informatisation means that data are recorded in some isolated software and databases. If the information system is integrated and modular covering all organization needs, there is a high probability that intelligent technologies will be easier to use. We have defined a general category of such MES or ERP systems.

The last two factors are external pressure to implement I4. One of them is customers' request that intelligent technologies be used in the process ($I4N_7$). Yes, the customer may require the organisation to deploy a specific type of intelligent technology in a specific process. This is how the customer and the organisation are connected. We consider this pressure to be one of the driving forces of I4 implementation. It is similar to the input. We determined suppliers' request to use intelligent technologies in the process ($I4N_8$) as the last factor. In the case of a supplier, mainly logistics processes are interconnected, but interconnection also occurs in production processes.

Calculating the I4N index is relatively simple. It is true that if the practical value of any of the factors for a given process is lower, the pressure to deploy intelligent technologies is greater. The sum of the partial factors yields the final value. This value represents the pressure to deploy intelligent technologies in a given process and can be interpreted as the improvement potential related to the process. As a result, we can also calculate the overall I4N index, which as an arithmetic average determines the potential through the whole set of involved/existing processes.

Mathematical formulas below from (10) to (19) apply to the calculation of individual partial values of exigency factors *I4N1*, *I4N2*, *I4N3*, *I4N4*, *I4N5*, *I4N6*, *I4N7*, and *I4N8*.

$I4N_1$: Production system

$$I4N_{ij} = 25 \vee 50 \vee 75 \vee 100\ [\%] \tag{10}$$

where $i = (1; 2; \ldots; n)$, $n = 8$ as a number of all exigency factors, $j = (1; 2; \ldots; m)$, and $m = 26$ as a number of all processes; the value 25 represents job shop production, 50 represents continuous production, 75 represents batch production, and 100 represents mass production. The higher the value, the higher the pressure to introduce I4.

$I4N_2$: Product variability

$$I4N_{2j} = 25 \vee 50 \vee 100\ [\%] \tag{11}$$

where the value of 25 represents low product variability (1; 10), 50 represents medium product variability (11; 50), and 100 represents high product variability (more than 50 standardised products). The higher the value, the higher the pressure to introduce I4. This factor and its value are always the same for all processes. The factor $I4N_{2j}$ and $I4N1$ thus characterise the basic attributes of the production system.

$I4N_3$: Existence of the process

$$I4N_{3j} = P_{3j} \times 100 \ [\%] \quad (12)$$

where $P_{3j} = 1 \vee 0$; if P_{3j} = 1, the given process is running in the organisation; if P_{3j} = 0, the given process is not running in the organisation. This factor can take only two extremes as its value, namely 0 or 100. If the value is 0, there is no pressure; if the value is 100, we calculate the maximum pressure, which is of course reduced by the weight of this factor in the I4N index.

$I4N_4$: Level of informatisation of the process

$$I4N_{4j} = 100 - P_{4j} \ [\%] \quad (13)$$

$$P_{4j} = \frac{X}{Z} \quad (14)$$

where Z represents the number of all activities/steps of the given production or logistics process and X represents the number of activities whose inputs/outputs are recorded in some information system. The higher the value of P_{4j}, the lower the pressure to introduce I4. Therefore, in formula (13), we had to reverse this value from 100 in order for the value of $I4N_{4j}$ to correspond to the real amount of pressure to introduce I4.

$I4N_5$: Level of automation of the process

$$I4N_{5j} = 100 - P_{5j} \ [\%] \quad (15)$$

$$P_{5j} = \frac{Y}{Z} \quad (16)$$

where Z represents the number of all activities/steps of the given production or logistics process and Y represents the number of activities which are automated and done without human work. The higher the value of P_{5j}, the lower the pressure to introduce I4. Therefore, in formula (15), we subtracted this value from 100 so that the value of $I4N_{5j}$ corresponds to the real amount of pressure to introduce I4.

$I4N_6$: Integration of the process to the MES/ERP

$$I4N_{6j} = 100 - (P_{6j} \times 100) \ [\%]; \quad (17)$$

where $P_{6j} = 1 \vee 0$; if P_{6j} = 1, then the given process is integrated into the MES/ERP; if P_{6j} = 0, then the given process is not integrated into the MES/ERP. This factor, like the one above, assumes two extremes: 0 and 100. If the process is integrated, then the pressure is at 0%, whilst if it is not integrated, then the pressure is at

100%. In the final calculation, the value is reduced by the weight. We do not consider partial levels of integration inot the MES/ERP, either the process is integrated or it is not.

$I4N_7$: Customer request to use intelligent technologies in the process

$$I4N_{7j} = P_{7j} \text{ x } 100 \text{ [\%]} \quad (18)$$

where $P_{7j} = 1 \vee 0$; if $P_{7j} = 1$, then some customer requests that intelligent technologies be used in the given process; if $P_{7j} = 0$, then no customers request that intelligent technologies be used in the given process. We believe that if any customer requires the use of intelligent technologies, it is a relevant pressure of 100%.

$I4N_8$: Supplier request to use intelligent technologies in the process

$$I4N_{8j} = P_{8j} \text{ x } 100 \text{ [\%]} \quad (19)$$

where $P_{8j} = 1$ Ú 0; if $P_{8j} = 1$, then some supplier requests that intelligent technologies be used in the given process; if $P_{8j} = 0$, then no suppliers request that intelligent technologies be used in the given process. We believe that if any supplier requires the use of intelligent technologies, it is a relevant pressure of 100%.

The final calculation of the I4N index is represented by formula (20). In this equation, we took into account the weights of individual factors. These weights were obtained through the brief empirical research among the sample of industrial companies. *IN4j* is the value of the pressure for improvement related to Industry 4.0 of the given process *j*.

$$I4N_j = (0.15 \text{ x } I4N_{1j}) + (0.05 \text{ x } I4N_{2j}) + (0.1 \text{ x } I4N_{3j}) + (0.1 \text{ x } I4Nj_4) + (0.2 \text{ x } I4N_{5j}) + (0.15 \text{ x } I4N_{6j}) + (0.2 \text{ x } I4N_{7j}) + (0.05 \text{ x } I4N_{8j}) \quad 20)$$

Figure 4.1 Theoretical matrix for calculating the I4N index

	$I4N_{1j}$ x w_1		+ $I4N_{2j}$ x w_2		+ $I4N_{3j}$ x w_3		+ $I4N_{4j}$ x w_4		+ $I4N_{5j}$ x w_5		+ $I4N_{6j}$ x w_6		+ $I4N_{7j}$ x w_7		+ $I4N_{8j}$ x w_8		= $I4N_j$
P_1	$I4N_{1,1}$	.15	$I4N_{2,1}$	.05	$I4N_{3,1}$	.1	$I4N_{4,1}$	.1	$I4N_{5,1}$	.2	$I4N_{6,1}$	.15	$I4N_{7,1}$	.2	$I4N_{8,1}$	.05	$I4N_1$
P_2	$I4N_{1,2}$	.15	$I4N_{2,2}$	.05	$I4N_{3,2}$	.1	$I4N_{4,2}$	.1	$I4N_{5,2}$	.2	$I4N_{6,2}$	.15	$I4N_{7,2}$	.2	$I4N_{8,2}$	.05	$I4N_2$
P_3	$I4N_{1,3}$	.15	$I4N_{2,3}$	.05	$I4N_{3,3}$	.1	$I4N_{4,3}$	.1	$I4N_{5,3}$	.2	$I4N_{6,3}$	.15	$I4N_{7,3}$	.2	$I4N_{8,3}$	.05	$I4N_3$
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
P_j	$I4N_{1,j}$	.15	$I4N_{2,j}$	.05	$I4N_{3,j}$	.1	$I4N_{4,j}$	.1	$I4N_{5,j}$	.2	$I4N_{6,j}$	.15	$I4N_{7,j}$	.2	$I4N_{8,j}$	.05	$I4N_j$
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
P_m	$I4N_{1,m}$	.15	$I4N_{2,m}$	.05	$I4N_{3,m}$	.1	$I4N_{4,m}$	.1	$I4N_{5,m}$	.2	$I4N_{6,m}$	.15	$I4N_{7,m}$	.2	$I4N_{8,m}$	.05	$I4N_m$

$$\text{Overall I4N} = \frac{\sum_{j=1}^{m} I4N_j}{m}$$

Again, the range of processes *j* is individual, because the I4N index can be applied to any process regardless of the total set of them. We used the known set of 26 production and logistics processes for verification. We know that factor I4N3 would not have to be used, but since we would like to calculate the overall I4N index as the arithmetic average of all *I4Nj*, it is necessary to know whether the process is or is not used by the organisation.

Based on the mathematical formula, we can create a theoretical matrix for the calculation, application, and interpretation of results. This matrix is shown in Figure 4.1.

Each calculated I4N index for a given process quantifies the pressure to implement the I4 concept. If an enterprise requires the determination of only one value, it can also calculate the overall I4N index as the arithmetic average of all partial I4N indexes, as shown in Figure 4.1. The number of *m* processes depends on the company and if any particular process does not take place there (the value of I4N3 is equal to zero), this process is added to the total number of *m* processes when calculating the overall I4N index.

However, this overall I4N index is not as relevant as partial I4Nj indexes, which take into account all factors and reality related to the process. By quantifying the partial I4Nj indexes, we determine the exigency of the process improvement related to I4.

4.3. Empirical research focused on gap analysis based on the Industry 4.0 necessity index

Our new I4N index can serve for a gap analysis of business process improvement. We conducted the gap analysis of the industrial enterprise, a multinational corporation. It is a medium-sized enterprise and it manufactures components for washing machines. The company has mass production and low product variability, as it focusses on precisely defined components specified by the customer.

After selecting an industrial enterprise, we identified all production and logistics processes running in the company. Our theoretical set of processes contains 26 production and logistics processes. We identified 20 processes running in the company under real conditions. From the theoretical set from our previous research, these included the following processes: P6 – demand management, P7 – tool management, P8 – material management, P9 – scheduling, P10 – manufacturing planning and control, P11 – manufacturing, P13 – non-conformity management, P14 – continuous improvement, P15 – reporting, P16 – maintenance, P17 – quality control, P18 – visual management, P19 – waste management, P20 – change management, P21 – purchasing, P22 – warehousing, P23 – dispatching, P24 – transportation, P25 – manipulation, and P26 – delivering. The first group of processes – forecasting, product development, prototype production and evaluation, commercial prototype production planning, and commercial prototype production and evaluation – are not performed. This is because those processes are assured at the headquarters of the multinational company; the national branches are not responsible for these processes. We identified the set *m* = 20 processes.

For a simpler application of the I4N index, we decided to use a spreadsheet application, in which we transformed the mathematical equations into formulas between individual cells. The spreadsheet is shown in Figure 4.2.

After developing the tool in the spreadsheet programme, we validated it by determining the maximum and minimum values that individual exigency factors I4N1 through I4N8 can acquire.

The minimum value for any of the factors is 0 and the maximum value of the given *I4Nj* index for the given process is 100. By validating and defining the minimum and maximum values, we checked the internal structure of cells and their relations. Based on our validation we defined following intervals:

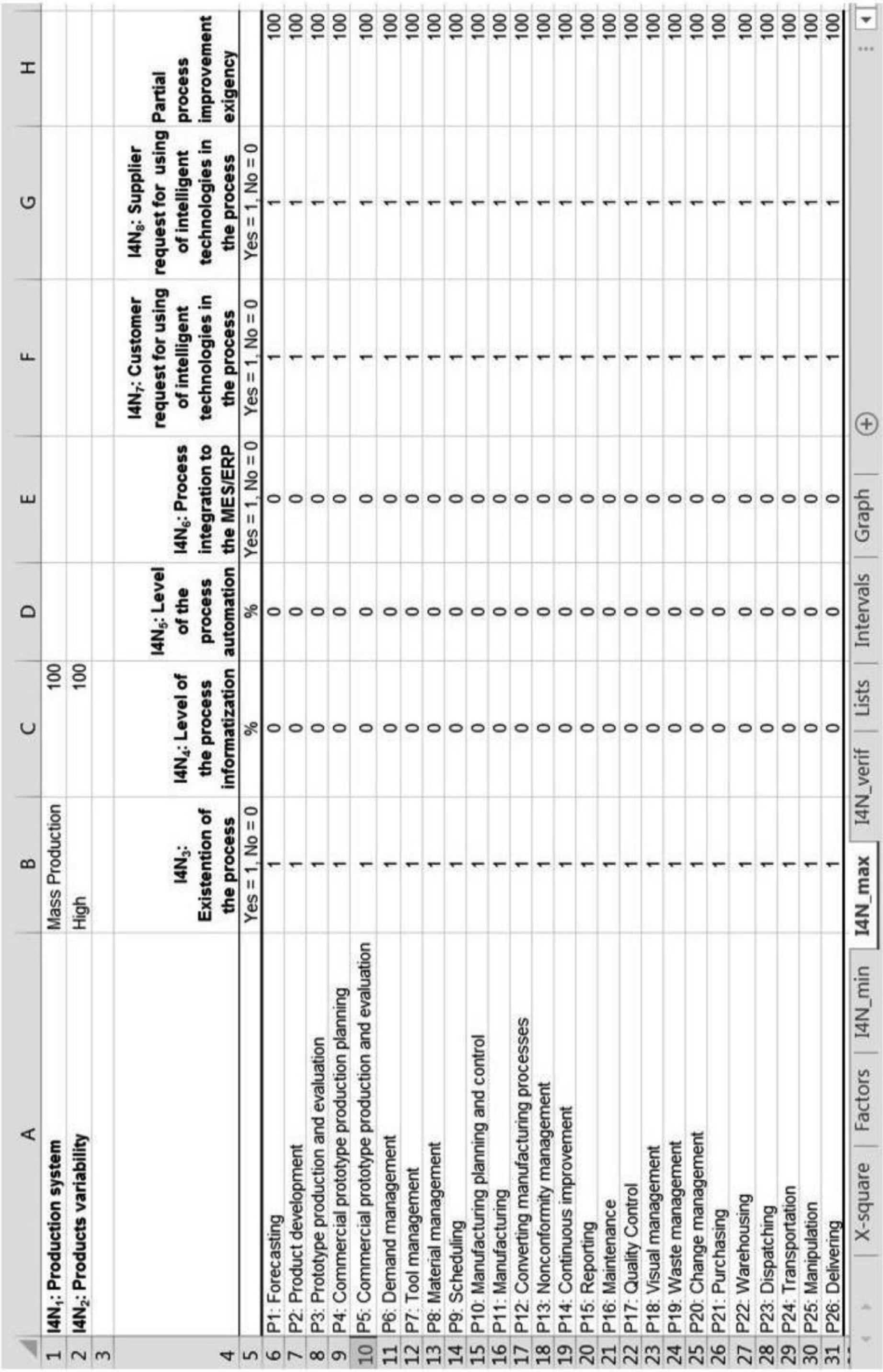
- $I4N_j$ = (0;50] – low necessity for process improvement related to I4
- $I4N_j$ = (50;75] – medium necessity for process improvement related to I4
- $I4N_j$ = (75;100) – high necessity for process improvement related to I4.

We know that intervals form 0 to 100 are usually divided evenly to three same parts. However, we decided to determine the intervals so that the low necessity for process improvement related to I4 is defined on the first half of the permissible values, from 0 to 50. In this way we avoid creating enormous pressure on companies to automatically improve their processes. We defined the pressure as high at values from 75 to 100.

If we know the set of ongoing processes, we can use a tool in the spreadsheet to start with a real analysis of individual processes. The first two factors are common to all *m* = 20 processes. The factor *I4N1j* = 100 because it is mass production. The factor *I4N2j* = 25 because the variability of the products is low. The same applies to the existence of the process – all the processes involved in the company are present, so the factor *I4N3j* = 1.

We had to perform a detailed analysis for all other factors. In the analysis of the level of informatisation of the given process *I4N4j*, we identified the number of activities that the given process needs to have in order to achieve the required outputs. For each activity, we identified that it was recorded electronically. The proportion of informatised activities among all activities of a given process is shown in Table 4.1. We proceeded likewise in the quantification of the factor *I4N5j*, where we identified the degree of automation.

Figure 4.2. **Spreadsheet for the I4N index application**



	A	B	C	D	E	F	G	H
1	**$I4N_1$: Production system**	Mass Production	100					
2	**$I4N_2$: Products variability**	High	100					
3								
4		**$I4N_3$: Existention of the process**	**$I4N_4$: Level of the process informatization**	**$I4N_5$: Level of the process automation**	**$I4N_6$: Process integration to the MES/ERP**	**$I4N_7$: Customer request for using of intelligent technologies in the process**	**$I4N_8$: Supplier request for using of intelligent technologies in the process**	**Partial process improvement exigency**
5		Yes = 1, No = 0	%	%	Yes = 1, No = 0	Yes = 1, No = 0	Yes = 1, No = 0	
6	P1: Forecasting	1	0	0	0	1	1	100
7	P2: Product development	1	0	0	0	1	1	100
8	P3: Prototype production and evaluation	1	0	0	0	1	1	100
9	P4: Commercial prototype production planning	1	0	0	0	1	1	100
10	P5: Commercial prototype production and evaluation	1	0	0	0	1	1	100
11	P6: Demand management	1	0	0	0	1	1	100
12	P7: Tool management	1	0	0	0	1	1	100
13	P8: Material management	1	0	0	0	1	1	100
14	P9: Scheduling	1	0	0	0	1	1	100
15	P10: Manufacturing planning and control	1	0	0	0	1	1	100
16	P11: Manufacturing	1	0	0	0	1	1	100
17	P12: Converting manufacturing processes	1	0	0	0	1	1	100
18	P13: Nonconformity management	1	0	0	0	1	1	100
19	P14: Continuous improvement	1	0	0	0	1	1	100
20	P15: Reporting	1	0	0	0	1	1	100
21	P16: Maintenance	1	0	0	0	1	1	100
22	P17: Quality Control	1	0	0	0	1	1	100
23	P18: Visual management	1	0	0	0	1	1	100
24	P19: Waste management	1	0	0	0	1	1	100
25	P20: Change management	1	0	0	0	1	1	100
26	P21: Purchasing	1	0	0	0	1	1	100
27	P22: Warehousing	1	0	0	0	1	1	100
28	P23: Dispatching	1	0	0	0	1	1	100
29	P24: Transportation	1	0	0	0	1	1	100
30	P25: Manipulation	1	0	0	0	1	1	100
31	P26: Delivering	1	0	0	0	1	1	100

We already had a list of activities, so we calculated the proportion of those that take place without human intervention. The sixth factor was relatively easy to calculate, as *I4N6j* always takes a value of 1 or 0. We found that the company has a modular ERP system and some of its production and logistics processes are integrated into it. We did not examine the integration at the level of individual activities, but we examined whether the inputs and outputs of the process as a whole are recorded in the ERP system.

For the last two factors, *I4N7j* and *I4N8j*, we focussed on customer and supplier requirements. We investigated whether any customer or supplier required the application of intelligent technologies in any process. If so, we assigned a value of 1 to the given factor; if not, we assigned the factor a value of 0. We did not analyse the number of customers and suppliers in detail. We were also able to identify the proportion of customers and suppliers who require smart technologies. In our opinion, however, if any customer makes such a request, we can see it as pressure to improve the process. The values of the individual I4N index factors are shown in Table 4.1.

Table 4.1. **Values for exigency factors $I4N_{4j}$ through $I4N_{8j}$**

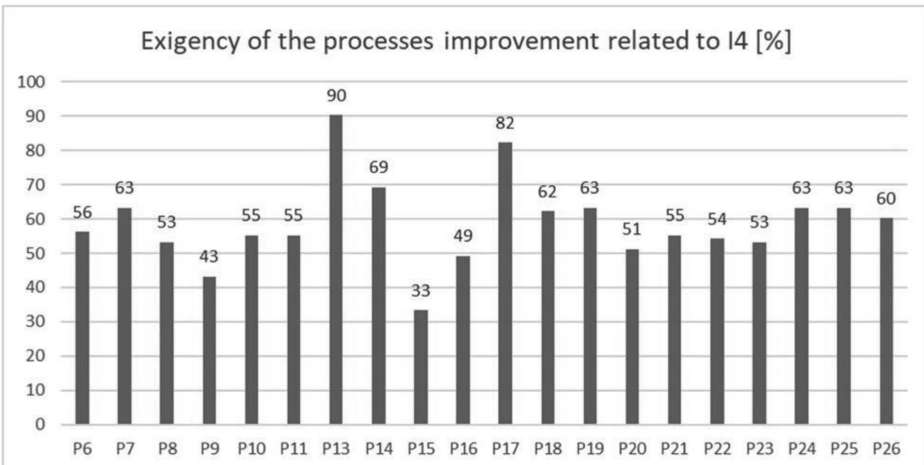
	I4N4j	I4N5j	I4N6j	I4N7j	I4N8j
P6: Demand management	90	10	1	1	0
P7: Tool management	30	10	0	0	0
P8: Material management	80	10	1	0	1
P9: Scheduling	80	10	1	0	0
P10: Manufacturing planning and control	70	10	1	0	1
P11: Manufacturing	40	40	1	0	1
P13: Non-conformity management	20	10	0	1	1
P14: Continuous improvement	10	0	0	0	0
P15: Reporting	90	50	1	0	0
P16: Maintenance	50	10	1	0	0
P17: Quality Control	50	20	0	1	1
P18: Visual management	40	5	0	0	0
P19: Waste management	30	10	0	0	0
P20: Change management	40	10	1	0	0
P21: Purchasing	70	10	1	0	1
P22: Warehousing	80	5	1	0	1
P23: Dispatching	80	10	1	0	1
P24: Transportation	40	0	0	0	0
P25: Manipulation	20	20	0	0	0
P26: Delivering	80	0	1	1	0
Ratio [%]			60	20	40
Average [%]	55	13			

If we know the values of I4N factors for individual processes, we can also calculate – as optional information – the vertical values of factors as a ratio or average expressed as percentages. In the last two rows of Table 4.1 we can see the given exigency factor and its value for the whole set of $m = 20$ processes.

The total level of informatisation in the organisation is 55%; the level of automation is 13%; the degree to which processes are integrated into the ERP system is 60%; the pressure from customers is for 20% of processes; and the pressure from suppliers is for up to 40% of production and logistics processes.

Of course, pressure from customers and suppliers exists because the range of intelligent technologies used is low among the given processes. If we look at the processes horizontally, we can calculate the partial *I4Nj* indexes for specific *j* processes. The values are shown in Figure 4.3.

Figure 4.3. **Values of the partial $I4N_j$ indexes**



We interpret the value of any partial *I4Nj* index as pressure or exigency to improve a given process in relation to Industry 4.0. Improving the process in relation to I4 means deploying an intelligent technology. Bear in mind that the final values of the partial *I4Nj* indexes are reduced values according to the significance of individual factors. Figure 4.3 shows that P13 (non-conformity management) processes have a high necessity to implement intelligent technologies and improve the process P17 (quality control). A medium necessity for process improvement was found for processes P6 (demand management), P7 (tool management), P8 (material management), P10 (manufacturing planning and control), P11 (manufacturing), P14 (continuous improvement), P18 (visual management), P19 (waste management), P20 (change management), P21 (purchasing), P22 (warehousing), P23 (dispatching), P24 (transportation), P25 (manipulation), and P26 (delivering). Only three processes had a low necessity: P9 (scheduling), P15 (reporting), and P16 (maintenance).

Our I4N index for quantification of process improvement exigency related to I4 is primarily applicable in industrial enterprises. As we stated earlier, this is not the limit for its application in other business environments. As we can see from the verification in a real company, it can answer the need to improve processes according to individual exigency factors related to I4.

As shown by the verification in Table 4.1 and Figure 4.3, we see that only two processes were identified as having a high need for improvement, with improvement meaning the deployment of intelligent technologies. Most processes were within the interval of a moderate need for improvement. If we analysed these partial *I4Nj* indexes, we would find that most of them are in the lower part of the interval. Three processes were identified with a low need for improvement related to I4. Of course, the need for improvement expressed in numbers does not refer to specific improvement measures. The I4N index highlights those processes that could be improved as a matter of priority. However, if we focus on specific I4N exigency factors in a specific process, then we will see which values are low and which are high. This way, we can get a detailed look at a specific process.

If we identified a high need for improvement in two processes (P13 – non-conformity management and P17 – quality control), we can analyse it in detail according to the importance of factors. Take the process P13 as an example: the most important factors are the level of informatisation and the level of automation. As we can see in Table 4.1, the values of these factors are 20% and 10%, respectively. Therefore, improvement in terms of increasing the share of informatisation and automation of P13 process activities seems to be critical. The way to do this depends on the management of the company. Other important factors are the requirements from customers or suppliers for the implementation of intelligent technologies. As we can see, the process P13 is under pressure from both the supplier and the customer. Therefore, the value of the partial I4N13 for P13 is very high. The priority of the company is therefore on processes that have values in the range of 75 to 100.

Of course, the company can also decide for one overall number, which will be the arithmetic average of the partial *I4Nj* indexes. In the case of our selected industrial enterprise, we calculated the overall I4N index as the arithmetic average of 20 values from Figure 4.3. The result for I4N of 56% can be assessed as medium or even low need to improve processes.

However, this arithmetic mean is only informative and it is important to know the partial values of the indexes so that we can decide to improve a particular process. The expansion of our I4N index presupposes making several adjustments if it is implemented in a company other than one with production and logistics processes. For example, if we wanted to define the I4N index in a company that provides services, we would have to define the following:

- the set of *m* processes that we want to subject to the quantification of process improvement exigency related to I4
- the factor I4N1, which would characterise the type of enterprise, for example, in terms of its size expressed by the number of employees
- the factor I4N2, which would characterise the variability of services provided or the variability of customer needs.

Conclusion

The main objectives of this scientific monograph were to describe the theoretical aspects of business process management and process performance management and to analyse the utilisation of business process models and intelligent technologies in business practice. The secondary output of this book is a new index for calculating exigency for Industry 4.0 principles in manufacturing companies.

The book introduces a novel approach to organisational development based on the systematic management of organisational maturity using PBOA for assessing organisational maturity. It brings a new structure (attributes) of requirements for a process-based organisation combined with the methodology of its use as an integral part of organisational development. PBOA works as an assessment tool for auditing the level of maturity of the organisation as well as a knowledge base for its consequential development. As the main output of the organisation audit process according to PBOA, the audit report contains detailed information about particular aspects of the identified level of process orientation, and about their importance for the further development of the organisation. The audit thus results not only in determining the level of process orientation, but also in a detailed identification of specific strengths and weaknesses connected with the identified state. This information should be exploited to focus the further development efforts in terms of the general principles of the organisational maturity model. In this way, the organisation gains a powerful tool for designing sophisticated strategies for further organisational development actions under the rules of the maturity model. At the same time, each audit also yields an important experience which should be used for the improvement and further development of the standard itself. This ensures that even the standard has the same dynamics as all other aspects of the process-based organisation. This book reviews the initial methodological resources concerning the organisational maturity models in the field of process-orientated management and discusses the crucial role of standards in the organisational development. Then the essence and the content of the standard are explained together with the rules for its use.

This book also answers two questions: What are the attributes of the performance indicators and what is the minimum set of attributes of the performance indicator that would indicate a consistent performance management system? We determined 21 attributes that are necessary for a consistent PMS. The main implications for companies as an output of our book is the knowledge of 21 attributes, by which it is able to describe all PIs involved in a PMS, the specification of a minimum set of attributes that are important to determine for all PIs in order to make PMS consistent. Companies can select their own set of defined attributes of the PI; however, the sense of consistency is that they use this set for all indicators.

We also focussed on increasing business process performance. We chose a specific view of business processes, namely that of the pressure to implement intelligent technologies. It is intelligent technologies that represent Industry 4.0 as its tangible and real attributes. In this monograph, we did not examine individual intelligent technologies. We know that there are a number of indexes and frames that can, as a result, create a road map leading to the introduction of Industry 4.0. However, we analysed these aspects in terms of the pressure that can actually act on the processes. We cannot determine in advance what measures the company must take, but we can identify where there is the greatest urgency to improve the process. Those ideas we transformed to the new I4N index.

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