Production Engineering Archives 2024, 30(1), 36-47

Production Engineering Archives

ISSN 2353-5156 (print)
ISSN 2353-7779 (online)

Exist since 4th quarter 2013
Available online at https://pea-journal.eu

Development of a systematic approach to the implementation of modern information technologies in manufacturing enterprises

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Article history
Received 15.06.2023
Accepted 10.12.2023
Available online 29.02.2024

Keywords
modern IT technologies deployment,
production management,
top-down approach,
bottom-up approach,
digital transformation.

Abstract
The paper aims to show the possibilities of using modern information technologies in production management. Successive stages of production process preparation and implementation are characterized. Information technologies that are currently being implemented in manufacturing enterprises are discussed. The focus was on the part of the process related to the product's manufacture. The paper presents the concepts of two methodological approaches to the adoption of modern information technologies: the top-down approach and the bottom-up approach. The successive stages of each of these approaches are discussed. The advantage of the top-down approach is the ability to comprehensively implement various technologies, and the disadvantage is the significant level of resource commitment. The advantage of the bottom-up approach is the high efficiency of the proposed solution, and the disadvantage is the limitation of application to projects of limited size. The proposed approaches have been verified using the example of two companies: the automotive and the control automation industries. There are correlations between the choice of the methodology used and the type and extent of implementation of the technology in question. The study's key conclusion is that both approaches are applicable in practice. The most important thing in the decision-making phase is to identify the barriers and constraints related to the organization's maturity to use a given technology. Enterprises can use the study results to help them prepare for their digital transformation.

DOI: 10.30657/pea.2024.30.3

1. Introduction

Today's manufacturing companies are subject to the pressure of a very volatile socio-economic, technological, and regulatory-legal environment. Environmental requirements are tightening, employee expectations are rising, and customer values are changing. In recent years, there have also been crises affecting significant disruptions to supply chains.

In the technological field, there is a continuous search for opportunities to improve the implementation of manufacturing processes. These activities are primarily concerned with improving the efficiency of the core technologies used in the procedures, better organization of the course of operations, and improving the work organization.

Sources of improvement may include scientific research, R&D work carried out in enterprises, or by specialized start-ups. One direction of enhancement is to strive to increase the use of digital technologies. These technologies can support, among other things, the collection of data on processes, their virtualization, simulation of their course (also in combination with real-time operation), management decision-making, and visualization.

The broad capabilities of the technologies pose a challenge regarding how to implement them in companies. In this area, it is necessary to consider the specifics of the enterprise (location, organizational culture, stakeholders, etc.) and the specifics of the industry. Implementations should have specific goals and measures of effectiveness and efficiency. Their deployment should be orderly and repeatable. The modus operandi should apply to both the execution of a single technology and the simultaneous implementation of multiple technologies.

For more than a decade, an essential context of ongoing work has been the attempt to define a new paradigm for the operation of manufacturing enterprises within the framework of the Industry 4.0 concept. That is supposed to lead to the creation of qualitatively new enterprises with so-called cyber-physical systems. The implicit assumption is that the physical system will have a complete digital representation, requiring its observability and practically useful controllability. A modification of this approach is the Industry 5.0 concept, which re-emphasizes the vital role of humans as participants and recipients of process results.

According to the American Productivity & Quality Center's classification, the elements of manufacturing process management include more than a dozen operational processes, from order acquisition, production preparation, material procurement, product manufacturing, maintenance, and production decommissioning. Each individual activity is composed of a series of simplified activities. Virtually each of the activities can be supported by digital technologies. Currently, the level of implementation of these technologies varies from country to country and industry to industry. For example, in Poland, information on this subject is provided in a report (Siemens, 2021, 2018).

In this context, the topic addressed in the paper is relevant from both a research and practical point of view. The literature mainly discusses the implementation of information systems to support the operation of enterprises. There is a practical lack of proposals for methodologies for the implementation of modern information technologies that can be used in enterprises in production areas. This applies both to the implementation of single technologies and the implementation of various compatible technologies, which would additionally give a synergy effect.

In turn, the implementations of the aforementioned information systems are evaluated in terms of design aspects, primarily their effectiveness. This is mostly true for individual implementations of specific systems. The use of such approaches in the context of cross-cutting applications, applicable to other organizations, is not evaluated. Missing is both a single-technology perspective and a more universal methodological perspective that can be applied to the implementation of different technologies.

In practical terms, there is a lack of systematized proposals that enterprises can directly implement in production areas. Analyses of the key economic effects of implementation for enterprises, the increase in the value of the enterprise, and the development potential of implementation are carried out selectively, from the perspective of the objectives of the implemented projects.

Such a research gap prompted the authors of the paper to attempt to propose a methodical approach to the implementation of modern technologies in manufacturing enterprises, preceded by the acquisition of research material from the world's leading enterprises in their industries and an analysis of the current state of their activities in the field in question. The framework of the study focused first on the qualitative aspects of the problem so that more extensive quantitative research can be carried out in the future.

In the paper, the next chapter presents an overview to outline the current state of knowledge regarding the usage of modern information technologies in manufacturing companies. Then a case study was described as a method of conducting research. In the next chapter, the results of the research in two manufacturing enterprises are given. This is followed by a proposal for a step-by-step approach to deploying modern technologies. Finally, the theoretical and practical implications of the research are indicated.

2. Experimental

2.1. Literature review

The study focused on peer-reviewed articles from the Scopus database mainly, which includes publications from key international publishing platforms (Elsevier, Emerald, IEEE, MDPI, and others).

As part of the literature analysis, publications in English published in well-known scientific journals between 1980 and 2023 were examined. During the first 15 years of the period, one to four publications appeared each year. Subsequently, one can notice an increased interest in the topics covered, and by 2013, six to a dozen items appeared annually. In contrast, since 2014, dozens of papers per year have been published, with a maximum of 166 in 2022. As part of their research, the authors expanded beyond the most recent articles, for example, from the last ten years, since modern technologies such as simulation modelling, machine learning, and others have been known and used for several decades. Interest in the issue has gained momentum since 2010, when the concept of "Industry 4.0" was introduced, while in terms of publications, the development of the issue has been noticed only until 2020. The results prove that the topic addressed is new, currently under discussion, and interesting for further research.

The literature analysis was carried out in three steps. As part of the first step, publications that described the way or possibility of implementing modern information technologies in manufacturing companies were sought. This was based on the premise that organizations take on implementations, especially as part of digital transformation. Then, after identifying publications describing implementations, the focus was on analysing the technologies selected for deployment. There was no systematic approach to the application of modern information technologies in manufacturing enterprises in this group of publications. The third step considered approaches and methodologies used in the deployment of IT projects. The results led the authors to develop a dedicated approach based on methodologies adapted from other areas of management, supplemented by the author's experience through work with manufacturing enterprises. The detailed results of the conducted preliminary literature analysis are presented in Figure 1.

At the outset, it was stated that there were relatively few publications published on the implementation of modern information technology in manufacturing companies. The analysis in the area of modern technologies development began with an examination of different approaches to implementing new technologies. The area under study was divided into 7 research groups: (1) new technologies, (2) technology implementation, (3) digital transformation, (4) manufacturing, (5) Industry 4.0, (6) digital twin, and (7) digital transformation.

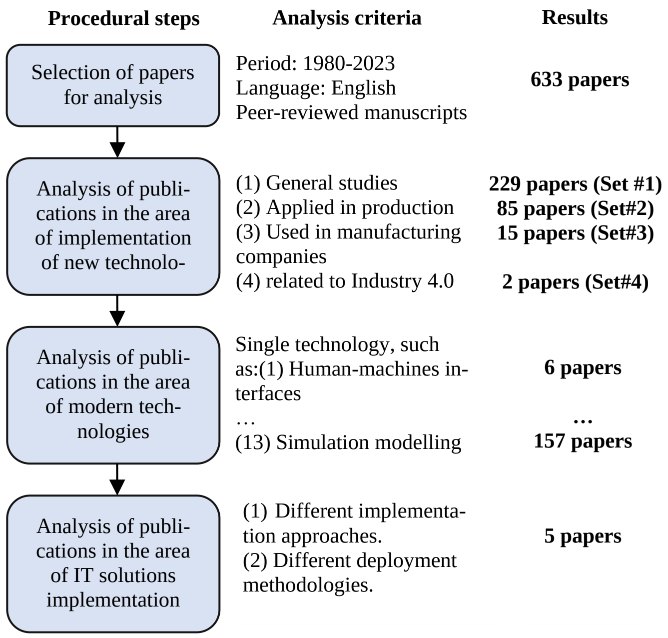

Fig. 1. Literature analysis algorithm

An appropriate set of keywords was selected for each group to enable the selection of appropriate manuscripts for the study. Within a given group, keywords can be used interchangeably and were applied as alternative words. On the other hand, individual groups (or their representatives) were applied as conjunctions. The results of the research are presented in Table 1.

Based on the established criteria (publication year, language, peer-reviewed manuscript), 633 literature items were obtained, which formed the basis for further analysis. After a preliminary review, a cross-linking map was built according to the keywords found in these publications. A cross-linking map shows the relationships occurring between different papers. In building the map, the strength of the relationship was indicated by a minimum number of occurrences of a given relationship (3 occurrences). Keywords unrelated to the studied area of modern technologies were also discarded. A total of 168 keywords were identified, based on which six thematic clusters were built. The constructed map is shown in Appendix 1. The VOSViewer program was used to prepare the map. The tool is equipped with metaheuristic algorithms for searching and reviewing literature items, speeding up the process of source analysis.

In the map presented, 6 clusters can be distinguished: (I) computer technology, (II) modern technologies, (III) learning systems, (IV) business management, (V) human impact of technology, and (VI) education.

The first cluster brings together publications characterizing computer technologies and the general possibilities of their use in enterprises (Ghobakhloo et al., 2020; Shamshlirl et al., 2018; Singh et al., 2019). Ghobakhloo and other authors presented the results of their work as a proposal for a roadmap of opportunities for the application of digital technologies in small businesses. Based on case studies, they developed a general guide for matching technologies to specific types of production or ongoing manufacturing processes. (Ghobakhloo et al., 2020). Another publication presented the possibilities of using multi-robots and human robots in the agriculture area to increase process efficiency (Shamshlirl et al, 2018). However, the solutions presented are general, focusing on describing the benefits of these technologies rather than barriers to implementation or how to develop them.

Table 1. Results of the literature analysis

Group	Set of results	I	II	III	IV	V	VI
1	Modern technology	x	x	x	x	x	x
	Modern computer technology	x	x	x	x	x	x
	Computer technology	x	x	x	x	x	x
2	Technology implementation	x	x	x	x		
	Technology adoption	x	x	x	x		
	Technology development		x				
	Technology introduction		x				
3	Digital transformation		x				
	Digital technology		x				
	Information technology		x				
	Implementation					x	x
	Adoption					x	x
	Development					x	x
	Introduction					x	x
4	Production		x	x			x
	Manufacturing		x	x			x
	Production companies				x		
	Manufacturing companies				x		
5	Industry 4.0			x	x	x	
6	Digital Twin					x	
7	Digital transformation					x	x
	Digital technology						x
	Information technology						x

The second cluster brings together publications describing key technologies used within Industry 4.0, such as AI, cloud computing, IoT, robotics, AR, and others (Chen et al., 2022; Pech et al., 2020; Tsaramirsis et al., 2022). For example, Tsaramirsis and others detail the application of selected advanced Industry 4.0 technologies to various areas like Energy 4.0, Smart Factory, and Project Portfolio Management (Tsaramirsis et al, 2022). The results obtained are promising for companies, increasing the efficiency of their operations, as well as fitting into the international trend of sustainable manufacturing. However, the papers presented lack a description of which areas a pre-enterprise should start with, which technologies are the easiest to implement or adopt. Chen and others, on the other hand, examined nearly 200 articles to identify 26 technologies used in the construction industry. They classified these technologies into five groups: (1) data acquisition, (2) analytics, (3) visualization, (4) communication, and (5) design and construction automation (Chen et al, 2022). The authors emphasize that the survey is the first systematic study of the application of new technologies, confirming that further analysis in technology application research is needed. References to the application of the digital twin concept for the optimization of a specific manufacturing process are contained in the paper (Sujová et al., 2023). There are also articles on digital transformation and technology deployment, but they have the character of very general descriptions, sometimes supported by an executed case study (Chen et al., 2019; Sandhu, 2022).

The third cluster focuses on advanced IT tools that enable technology realization in the enterprise, such as neural networks, fuzzy logic, and machine learning (Ahmed et al., 2022; Chouhan et al., 2019; Chlao, 2016). The publications present opportunities to apply advanced artificial intelligence tools. Mainly the research are focus on selected case studies or surveys that give a general overview of the applicability of selected technologies. For example, Ahmed and others present a comprehensive survey of AI and XAI-based methods adopted in Industry 4.0 (Ahmed et al., 2022). The paper (Wachnik, 2022) describes the use of artificial intelligence in managing Industry 4.0 projects in Polish industry.

The fourth cluster deals with the use of modern technologies to manage the enterprise. It contains publications describing how to apply selected computer technologies to sustainable development, decision-making process, or project management (Green, 2011; Stanley et al., 2018). Green points to the development of digital competencies over the past 20 years of research in the UK, particularly in using higher-order cognitive and interactive skills in decision-making processes (Green, 2011). In contrast, Stanley and others studied the impact of developing Industry 4.0 technologies on economic growth and productivity. In their study, they proved that digital technologies have positively contributed to economic growth, at least at the medium level. Developed countries are gaining significantly more than developing countries. Interestingly, little evidence was found that the Internet, which is the basis of Industry 4.0 technology, had a positive impact on economic growth (Stanley et al., 2018).

The fifth cluster contains publications describing the impact of modern technologies on human beings in the implementation of the business process and the impact on society as a whole in the framework of progressive digitization (Korner et al., 2019; Sinha et al., 2020; Xu, 2019). In their work, the researchers analyse the potential of robotics in the workplace. The advent of modern technologies (especially artificial intelligence) has created a sense of anxiety and uncertainty among workers about their future (Sinha et al., 2019). Korner and others point out the need to cope with new working conditions involving human-machine interaction. They studied the factors causing stress at work due to implementing modern technologies in manufacturing companies. However, it turns out that the primary stress triggers are related to technical problems of machine operation (frequent breakdowns, downtime, low productivity). They also noted that stress levels increased with workers' inability to cope with machine operations or fix breakdowns (Korner et al., 2019). These studies indicate how important it is, in addition to the effective implementation of technology, to familiarize and teach employees how to use the implemented solutions and tools. The paper (Statreček et al., 2023) analyzed the impact of implementing Industry 4.0 technologies on the required competencies of employees in the automotive industry.

The sixth cluster focuses on the characteristics of the educational process using these technologies and the teaching of technology itself, especially at universities (Ahmad et al., 2020; Dickinson et al., 2011; Naveed et al., 2020). The researchers analyse the possibilities of using various tools based on new technologies, for example, simulation games, in educational processes. However, they draw attention to the challenges facing education in this area of determining the long-term impact of technology on humans and minimizing the costs associated with the implementation of modern technologies (Dickinson et al., 2011).

The analysis made it possible to identify the range of issues considered in the literature in the context of the use of modern computer technologies. On the other hand, it was impossible to identify publications that describe ways to implement modern technologies in manufacturing enterprises.

It was noted, that significant reductions in search results were obtained whenever the results were limited to production or manufacturing, and especially to production companies or manufacturing companies.

The failure to present a comprehensive approach puts manufacturing companies in a difficult position and requires them to deal with the deployment of specific technologies on their own. The process is complex due to the interference with operational activities, the degree of complexity of the technology, the expected scope of its implementation, and the need to coordinate the many resources involved in the deployment. The implementation of some technologies seems easier and cheaper (3D Printing, Data Mining), while others require advanced resources and financial means (Big Data, IIoT, Robotics). Given the situation, companies are likely to take actions in a rather haphazard and intuitive manner rather than in a systematized way.

In the next step, an attempt was made to identify ways of implementation in connection with a specific technology. In this case, the obtained numbers of publications are not satisfactory. The most frequently described technologies are simulation modelling, Big Data, IIoT, or Machine Learning. Human-Machine Interface or Cyber-Physical Systems are the least frequently described. The results are shown in Figure 2. A standardized approach to the implementation of a given technology has still not been identified.

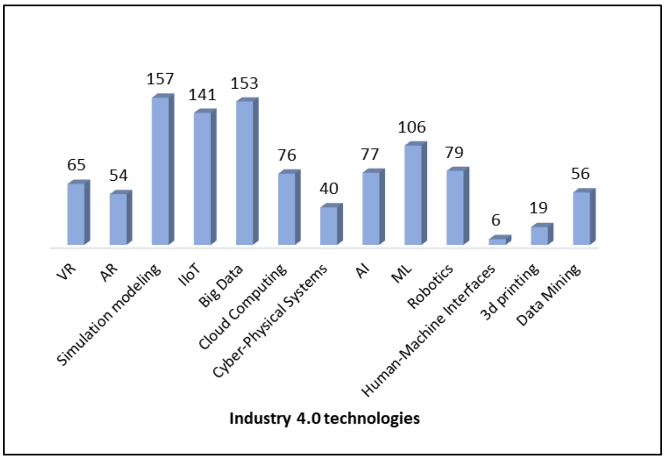

Fig. 2. Distribution of publications on the use of individual technologies in enterprises

The main approaches and methodologies used in the implementation of IT projects were analysed in the next step. This is a related area to the one analysed in the paper and, to some extent, can serve as a reference for framing the way technology is implemented in manufacturing enterprises. Traditional and pilot implementation approaches were considered, as well as cascade, agile, and development and operations (DO) methodologies (Inayat et al., 2015; Khan et al., 2016; Senapathi et al., 2018; Szyjewski, 2004).

The traditional approach consists of implementing new solutions in a pre-planned manner, in specific business areas, with the definition of requirements by technology recipients, training the recipients on the implementation, and involving them in testing the solutions. The approach can be implemented both with in-house forces (primarily for core processes) and with external support (for core and supporting processes). The approach assumes that the scope of implementation can be scaled. The subject of implementation can be the development of existing technology or the implementation of a completely new technology.

The pilot implementation approach consists of carrying out the deployment of new solutions in a limited scope and/or in a constrained area of the enterprise. The entire assumed functionality of the solution is launched. If the pilot is successful, the project is extended to the whole enterprise.

Cascade (waterfall) methodologies rely on a cascade model of work, which involves executing work steps one by one in a well-defined order. It also involves careful planning of implementation, pre-preparation of project documentation, and a fixed budget and quality indicators. Their advantages are knowledge of goals and requirements, staging and milestones, and assumed non-variability. Emphasis is placed on the precise establishment of detailed objectives for the tasks to be carried out and the predictability of the next project steps. Control in the project is implemented on a continuous basis. Project documentation must be available according to the needs of the participants, constantly updated, and recorded in a legible manner. The cycle of project tasks is usually short and closed by formulated goals. The results of project implementation should be predictable in terms of budget, work plan, and schedule. The scope of work is strictly defined, eliminating wasteful use of resources and project time.

Disadvantages are low flexibility and impaired decision-making. Inflexibility refers to the division of work into successive, disconnected stages, which are implemented iteratively. Starting the next stage is possible only after the previous one is completed – all delays accumulate. The cost of each iteration is usually high. Within each iteration, many activities are also repeated.

Agile methodologies involve dividing a project into smaller parts called iterations or sprints. The approach concentrates on meeting requirements and improving work. At the end of one cycle, it is given back to the client for feedback, and only after approval does it move on to the next cycle. A variation of this approach is called scrum. Within scrum stages, there is a strong emphasis on teamwork, such as daily meetings of a few minutes to discuss progress. Agile methodologies have already found applications in manufacturing enterprises (Dziuba et al., 2023). Their advantages are high flexibility, easy communication, self-organization, and collaboration. In this approach, project implementation focuses on the customer and their business needs. They set the framework for subsequent implementation activities. Flexibility is primarily concerned with the ability to respond quickly to sudden changes in the project environment and customer requirements. It also has the advantage of not having to define a strict roadmap at the beginning of a project, which can be fraught with uncertainty about future partial project results. Agile methodologies also allow for the expansion of the project team's independence of action and its responsibility for the quality and timeliness of the work. Disadvantages include an application area limited to projects where there is no clear vision and the work involves sudden changes, and a high reporting burden. This type of approach may also be aimed more at small project teams. Controlling the level of progress of the work is difficult due to the lack of a precisely defined benchmark. As a rule, a detailed analysis of the client's business requirements is also often overlooked. The high pace of work can contribute to increased stress levels and a deterioration of the project team's work atmosphere.

DO methodologies rely on close cooperation between the dev and operations (systems maintenance) departments and communication between them. It assumes that these teams should work together from the very beginning of the project. In fact, DO is a set of rules at the interface of software development, as well as the processes around it. Their advantages are automation of code development, easier configuration of servers, tools, and the entire work environment, and continuous analysis of work performance. By using this approach, update and change cycles in the project are more frequent, and elements of the activities can be automated. It is easier to control the progress of work, it is easier to diagnose the causes of problems, and the number of errors and the need for corrections is reduced. Supervision also covers the preparation and operation phases of the implementation. The flexibility of activities is increased, while the ability to estimate the efficiency of the work and its speed is also enhanced. The project team integrates development and operational (client-side) teams.

The disadvantages are limited application to large projects and a required change in organizational culture on the contractor's and contracting parties' sides. The use of this type of methodology and related technologies requires specialized project team members both on the side of implementing the solution and on the client side. Building or seeking such competence is usually difficult, lengthy, and expensive. Rigid organizational structures, especially among middle management, are also a barrier. It is difficult to find incentives for cooperation between specialists from different areas and people willing to become change leaders.

A comparison of the three types of methodologies discussed leads to the conclusion that the choice of an effective approach should take into account the expectations and needs of the enterprise. In general, cascade methodologies should be used when diligence, predictability, and unambiguity of implementation goals are necessary. Agile methodologies should be used when it is necessary to have flexibility in the implementation of goals, a high degree of work efficiency, and increased responsibility of the project team for the quality and timeliness of the work. DO methodologies should be used when reduction of errors and failures during implementation, better control over the preparation and operation of implemented solutions, and greater customer influence on the implementation process are needed.

At the strategic level, the rationale for assessing the impact of the proposed new methodologies on the effectiveness of IT implementation in manufacturing should be primarily the enterprise's innovation and digitization strategy, organizational culture, and employee attitudes. An enterprise's orientation to innovation and digitization is a prerequisite for successful technology implementation. A sufficient condition is the orientation of employees to the values resulting from the implementation of a given process and the attitudes of employees with regard to the implementation of innovative changes. At the operational level, this refers to the adaptation of the type of implementation methodology used to the type of technology being implemented and the type and form of the production process in which the technology is implemented.

Integration of new solutions with technologies already in use in the enterprise is also a separate issue. Integration should include efficient management of data and information flow, in terms of organizational, material, and network issues. The new technologies should communicate with the information systems in use, depending on the state of digitalisation of the company - pre-existing ERP, PLM, MES, etc. In this context, new technologies are likely to combine the business and production spheres of an enterprise's operations. Integration of new solutions will lead to a change in the business model of the enterprise, including autonomization of some of the core business processes. This will require a paradigm shift in the management of production processes, including the training of employees with new competencies, oriented towards cooperation with autonomous robots, the use of digital models, mobile applications, M2M (Machine to Machine) networks, and Predictive Maintenance.

2.2. Research method

The results of the literature research indicated the lack of a systematized approach to the implementation of modern information technology in manufacturing enterprises. Therefore, the decision was made to conduct our own research in selected manufacturing enterprises. It was assumed that the nature of the conducted study in enterprises should fulfil the following prerequisites:

- focus on a contemporary phenomenon,
- to study several units simultaneously,
- analysing the phenomenon in its natural context,
- the inability to control the research environment,
- in-depth study of the complexity of the phenomenon in question,
- and whose purpose is exploratory.

The nature of the study indicated the typical characteristics of the case study method (Benbasat et al., 1987), which determined its selection. Case studies have had a significant impact on the development of management theory (Eisenhardt, 1989). They lead to the observation and study of a scientifically relevant phenomenon and then make it possible to carry out a reliable description of its course, i.e., a study of reality (Czakon et al., 2021; Jarvensivu et al., 2010). The case study methodology is strictly established and homogeneous (Goffin et al., 2019). Although the case study method is very well described in the literature, the way of designing a case study is still varied and tuned to the individual course of research (Beverland et al., 2010). The standard research procedure using the case study method is as follows (Czakon, 2006):

1. Formulation of the research question.
2. Selection of the case/cases.
3. Development of data collection tools.
4. Field research.
5. Data analysis.
6. Forming generalizations.
7. Confronting the literature.
8. Closure of the study.

The study presented here uses an exploratory case study, i.e., on little-known and poorly defined phenomena that are in the preliminary stage of recognition (Ellram, 1996).

3. Results and discussion

The study was conducted by a multi-disciplinary team of research staff specializing in production management, information technology and business management. Continuous observation of processes was carried out, documentation provided by enterprises was analysed, employees and managers were interviewed.

Two case studies were implemented in the study. The first was carried out at a company in the industrial automation industry. The second at a company in the automotive industry[1]. The study analysed enterprises with mass production and high-volume production. The production flow is a line production, that is, a systematized, predetermined sequence of operations performed at specific workstations. Both selected companies are large multinational enterprises and use global capital (both financial and intellectual). Both companies employ tens of thousands of workers worldwide (several thousand in Poland). Their revenues are in the tens of billions of euros. The organizational culture of both companies includes an orientation toward innovation and the pursuit of growth opportunities. Dozens of different production processes are implemented in the companies. The conditions presented create an opportunity to implement Industry 4.0 technology in a given production area. Therefore, the authors decided to study the indicated companies.

The initial stage of implementation was studied, after the company had defined the purpose and scope of implementation. Each case study was described according to the selected methodology. The studies were explanatory in nature.

3.1. Results

The same research procedure was used in both cases, according to the description of the methodology given in Chapter 2. The next steps of the procedure were as follows.

1. Formulation of the research question. (a) What was the purpose and scope of the implementation determined? (b) What resources were decided to use? (c) How was it decided to carry out the implementation?

2. Selection of the case/cases. In both cases, data on the enterprise, data on the production process(es), and data on the resources expected to be used were available. The cases studied were extreme and diverse in nature. Case 1. concerned the implementation of only one technology (simulation modelling) in a selected production area. Case 2. concerned the implementation of multiple technologies (simulation modelling, AI, IIoT) in a single production process. In both situations, the assumptions of the deployment differed from typical process improvements in companies, oriented mainly toward improving economic efficiency. The emphasis of the survey was on the level of detail of the initial state and the expected end state of the implementation.

3. Development of data collection tools. Various data sources applied in the management of production processes were used. Data were collected in an iterative manner, using the method of successive approximations, according to the obtained state of knowledge of the implementation.

4. Field research. The research was conducted primarily during visits to enterprises, interviews with employees responsible for technology implementation, analysis of post-obtained documents, and analysis of publicly available data on enterprises.

5. Data analysis. Data analysis consisted of extracting and assigning a description of the implementation to successive, consecutive stages. On this basis, the patterns of the implementation course in each case were defined. Then the obtained patterns were analysed in terms of their internal structure. The patterns obtained in both cases were compared. In addition, the ways of handling the implementation process and the scope and manner of resources used were analysed.

6. Forming generalizations. Based on the analysis, the information obtained was synthesized into methodological guidelines for implementing new technologies.

7. Confronting the literature. The obtained results were related to the conclusions of the literature review of methodological approaches to the implementation of modern information technologies.

8. Closure of the study. The study ended with the formulation of the conclusions of the research.

Table 2 synthesizes information about the conducted study for Case 1, and Table 3 for Case 2. respectively.

Table 2. Case 1: survey results

1. Background information about the research subject – Case 1	
Industry	Industrial automation
List of current technologies in use	Robotization Automated production lines
Scope of technology deployment	Partial implementation in selected production areas
Type and form of production organization	Medium volume manufacturing, production line
2. Data collection method	
List of methods used to collect data	Continuous observation Interviews with employees (workers / managers) Documentation analysis
3. Characteristics examined	
Name of the technology to be implemented	Simulation modelling
Purpose of technology implementation	Improving the efficiency of production process execution
Indicators / measures of implementation	Quantitative indicators of process execution (production capacity, OEE) Process visualization
Implementation area	1 production process implemented within 1 work floor, consisting of 8 sub-processes.
Implementation scope	Full implementation of technology
Implementation time	6 months
Number of technologies implemented simultaneously	1 technology
Human resources involved	Own resources (4 people) External resources
Funding	Operational expenditures (Total amount 0.02 million [EUR])
Risk analysis	No risk analysis done
Relation to other company processes	Benchmark (standard) for subsequent implementations of a given technology in other areas

[1] The companies' consent to release and publish the data was not obtained.

Table 3. Case 2: survey results

1. Background information about the research subject – Case 2	
Industry	Automotive
List of current technologies in use	Semi-automatic production line
Scope of technology deployment	Partial implementation in selected production areas
Type and form of production organization	Medium volume manufacturing, production line
2. Data collection method	
List of methods used to collect data	Continuous observation Interviews with employees (workers / managers) Documentation analysis
3. Characteristics examined	
Name of the technology to be implemented	Simulation modeling, IIoT, AI,
Purpose of technology implementation	Building a cyber-physical system
Indicators / measures of implementation	Detail of process logic mapping Reliability and business continuity indicators
Implementation area	1 production process implemented within 1 work floor
Implementation scope	Full implementation of technology
Implementation time	12 month
Number of technologies implemented simultaneously	3 technologies
Human resources involved	Own resources (dozen people) External resources
Funding	Operational expenditures Capital expenditure Total amount 3 million [EUR]
Risk analysis	Risk analysis required as a condition for obtaining funds
Relation to other company processes	Reference solution for decision-making on digitization of other areas of the enterprise

Steps 1. - 4. of the study were carried out. They were performed according to the assumptions of the case-study method. The results were obtained, within the scope of the set research questions. The description of steps 5. - 8. of the method is presented in Section 3.2.

3.2. Discussion

The survey indicated a diverse approach of manufacturing companies to the deployment of modern technologies. The main difference is due to the purpose and scope of deployment, mainly the number of technologies implemented simultaneously. The most relevant factors were evaluated to determine a structured implementation activity (pattern), as a part of the comparative assessment. The results are presented in Table 4.

The identified implementation patterns contain the same elements for both cases. However, the implementation of individual elements differs significantly between the approaches. In order to better understand the differences, it was decided to describe how the patterns were implemented in each case.

Table 4. Results of case comparison

Characteristics	Case 1	Case 2
Level of management decision-making Availability of technology in the enterprise before implementation	Relevant to the purpose and scope of implementation – middle-level management, assigning tasks directly to selected employees	Relevant to the purpose and scope of implementation – the top-level management, assigning tasks to employees according to the organizational structure
Purpose and scope of implementation	Narrow – activities oriented on the single technology implementation	Broad - complex implementation of several technologies
Degree of own resources use: **- informational** **- human** **- financial**	 Low Medium Low	 High Medium High
Availability of technology in the enterprise before implementation	Available – positive influence on business decision	Not available – no influence on business decision
Support for implementation by external entities	Available (technical university) – positive influence on the business design decision	Available (technical university, engineering company) – positive influence on the business design decision
Implementation method	With some risks – execution of deployment as an informal activity, but according to project management rules	Relevant to the purpose and scope of the implementation – execution of deployment strictly in the project formula
The implementation maturity level of the enterprise	Low – no prior assessment	Low – no prior assessment
Identified pattern	**Bottom-up**	**Top-down**

The results indicate that Case 1 can be qualified as a bottom-up initiative by employees to carry out the implementation. It assumes the implementation of one technology through incremental execution and resource commitment at a low level. The scope of implementation is narrow, focusing on a technology representative for the enterprise's further development plans. Its goal is to the local efficiency improvement of the realized processes. Thus, this pattern of proceedings shows some similarities in decision-making to a bottom-up approach.

This approach is used when there is a need to build a base for implementing larger-scale activities, as well as when there is a need to experiment with different technologies or tools to find the best solution. The bottom-up approach requires a great deal of communication between the people implementing the activity, as it is their knowledge and experience that the implemented activities are based on. However, larger projects cannot be managed well in this way. The implementation template for the bottom-up approach is shown in Figure 3.

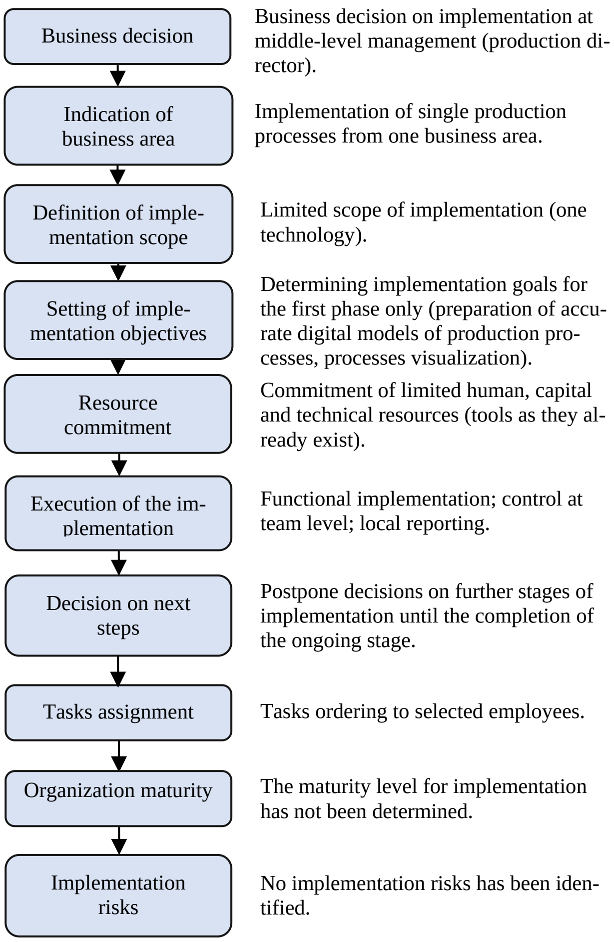

Fig. 3. Bottom-up approach pattern

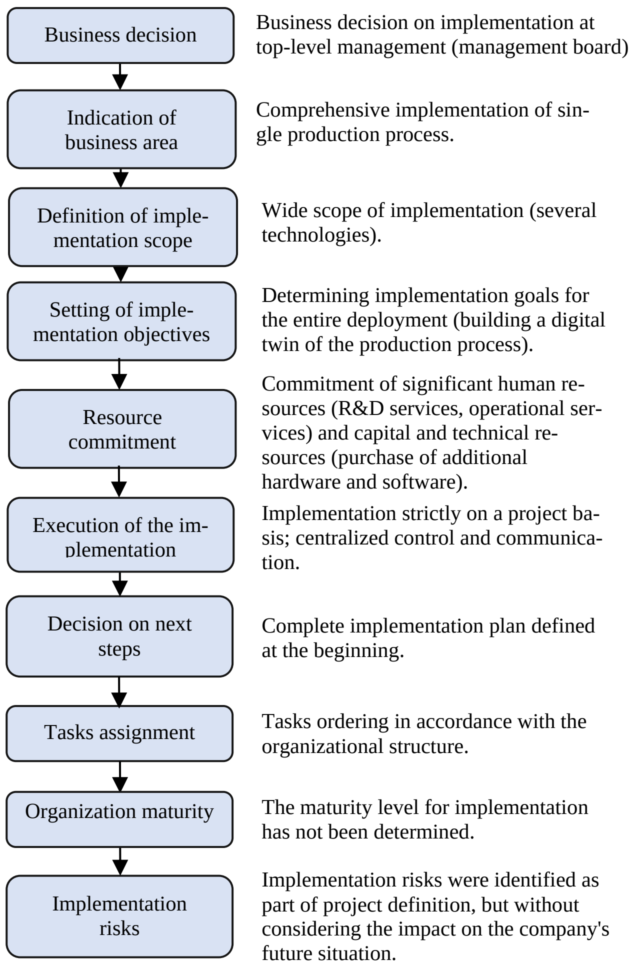

Fig. 4. Top-down approach pattern

Case 2, on the other hand, can be classified as a top-down initiative. It assumes the implementation of multiple technologies through a comprehensive implementation and with a significant level of resource commitment. The scope of the implementation is broad and aims to apply a new paradigm for the realization of production processes - building elements of a digital twin of the actual production process. Thus, this pattern shows some similarities in decision-making using a top-down approach.

The top-down approach helps to break down complex problems and activities into smaller elements that are easier to manage and implement. It also helps to prioritize individual tasks, identifying those that are key or necessary for implementation. The approach also has the advantage of structuring activities that can serve as a template for other areas of the company. The implementation template for the top-down approach is shown in Figure 4.

As described in Section 2.1, the noted differences in the deployment of the two approaches and their applicability have not been described in the literature on the implementation of modern information technology in production enterprises. Nor are they similar to the IT project management methodologies described. The literature has not identified methodologies that address most of the elements identified in the study.

The novelty of the research results is the identification of the sub-alignment of the approaches used with top-down and bottom-up methodologies well known in the management literature (Jones et al., 2011). Because of the great dissimilarity of these approaches, it is interesting to observe that each approach was applied. The bottom-up approach is considered less risky for the implementation of modern information technology, easier to evaluate effectiveness and efficiency, and likely to produce positive economic results more quickly.

However, as the study showed, also the top-down approach is used. This is probably due to the different ways R&D is managed in the company, where it is one of the strategic objectives. As established, the company devotes significant resources to the implementation of innovation and development projects. However, it has to anticipate that some projects will not bring an immediate and expected return on the invested resources.

4. Summary and conclusion

The adopted research method proved sufficiently effective and feasible for a research team. When formulating research conclusions, it is necessary to note that the adopted research method was qualitative in nature. A feature of qualitative methods is the attempt to describe the interdependencies between the phenomena occurring. The research questions focus on interpreting the causes of the subject's behavior. This is also the nature of the results obtained. This limits, in a sense, the scope of use of the conclusions.

However, from the study perspective, the literature on the subject does not contain systematized proposals for the sought-after implementation methodologies for modern information technologies. Thus, the survey can provide a starting point for more extensive work in this area.

Conclusions also could provide a basis for formulating hypotheses and defining the scope of quantitative research. Such research could form answers to questions about the scale of application of the described approaches and their precise description, or help identify other approaches.

In evaluating the proposed solutions, it should be noted that a major advantage of the bottom-up approach is the commitment and even initiative to carry out the implementation on the part of employees and middle management. Focusing on the gradual implementation of a single technology, on the one hand, simplifies the operation, increasing the chances of its effectiveness, but on the other hand, it is limiting from the point of view of the needs of the entire enterprise. Also, a financial improvement in the efficiency of a single production process is a benefit to the enterprise, but in relation to the overall performance of the enterprise, it will probably no longer be so significant, which may influence the decision to implement the part of senior management. Such an approach can be recommended as a pilot activity or an activity for local improvement of the efficiency of the company's operation. Due to easier evaluation of the implementation course, the risk is lower, and possible losses are lower.

The top-down approach, on the other hand, is much more complex, bringing about changes in the functioning of many areas of the organization, but requires a much greater commitment of resources and management of the course of implementation at a higher level. This approach provides an opportunity to disaggregate and prioritize goals and plan operational activities into smaller components that are easier to manage, although they require more coordination. The approach requires that R&D activities are already embedded in the company's strategy and organizational culture at the start of implementation. The risk of not getting a quick return on the invested funds is much higher, but also the success of the activities will give greater financial co-benefits. Such an approach can be recommended for more mature companies that are prepared to implement large innovation projects, especially in the area of automation and even autonomization of production processes.

In assessing the study itself, it needs to be noted that only two cases were analyzed. Regardless of the desired quantitative research, the work should be extended to include additional case studies, for situations in other enterprises. In particular, it would be interesting to conduct research on how individual technologies are implemented and whether there are similarities or differences in this regard. An important direction of further research is the analysis of models of the maturity of enterprises for digital transformation. Such research would make it possible to determine the current and future state in a general way.

Practical conclusions lead to the observation that decisions made in the field of implementation depend on the enterprise strategy and the orientation of employees to innovative activities. A criterion for actions is also their economic efficiency and available resources. At present, each of the approaches described can be applied, depending on the business context.

On the basis of the study, it is possible to formulate an outline of general methodological guidelines for the deployment of new information technologies in production enterprises. When starting the work, it is necessary to determine the enterprise's goals for implementing new technologies and the scope of implementation. It would also be desirable to identify the maturity level of the enterprise for implementation. Another element is to indicate what resources the enterprise is ready to devote to deployment. It is advisable to consider the use of external resources (especially know-how) if the enterprise's discernment of the chosen technology is not satisfactory. It is also necessary to determine the risks of implementation. The above elements can form the basis for deciding how to execute the deployment.

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Appendix

Appendix A

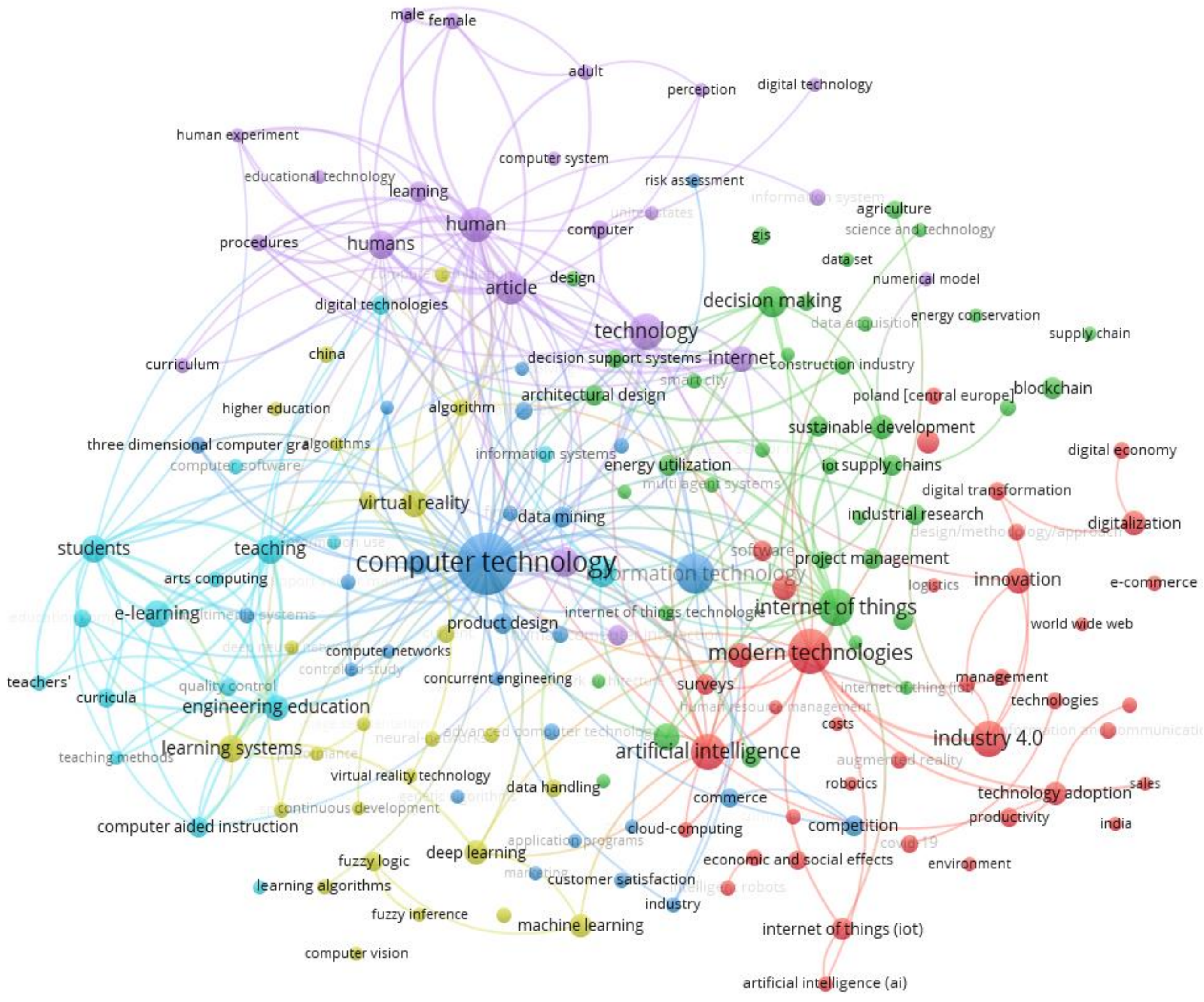

Fig. 5. Cross-linking map of the issues analyzed in the implementation of modern information technologies