Key Success Factors for the Implementation of Digital Technologies in the Context of Industry 4.0

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***Abstract*— The implementation of digital technologies in general and in the context of Industry 4.0 in particular is a socio-organisational challenge. After an introduction into Industry 4.0 and a summary of its key enabling technologies, this paper presents a qualitative analysis of key factors that can influence the success of implementing digital technologies into organizations from the literature as well as from a single industrial case study at a semiconductor manufacturer. Identified key success factors are assigned to two different non-technical dimensions, management, and processes (organizational dimension), as well as corporate culture and employees (social dimension). They include for example, the creation of a common understanding of the as-is situation, the challenge to be solved and the envisaged to-be situation after technology implementation among all relevant stakeholders. Equally important, however, is active support of top management to promote implementation projects and a dedicated project manager with sufficient technical expertise in all related technical domains.**

Keywords—Success factors, industry 4.0, digitalisation

I. Introduction and Motivation

Referring to a Fourth Industrial Revolution in which the worlds of production and network connectivity are integrated through information and communications technology (ICT), Industry 4.0 is an umbrella term for a wide variety of technologies, methods and applications for improving production processes and their supporting processes [2], [4], [17]. Originally initiated in Germany, Industry 4.0 can generally be interpreted as the digitization or digital transformation of the industry, which is taking place as a result of the increasing adoption of digital technologies in the manufacturing sector.

Digitization as the progressive convergence of the real and virtual world is becoming the main driver for innovation and change in all sectors of our economy [7]. Major social, economic and political triggers for Industry 4.0 are in particular shorter development and innovation periods, individualisation on demand and increasing individualisation of products and – in extreme cases – of 'batch size one', higher flexibility in development and production, decentralisation involving a reduction of organisational hierarchies, and resource efficiency due to an increase of prices, as well as a social change in the context of ecological aspects requiring an intensified focus on environmental sustainability [6].

The digital transformation of manufacturing companies is being decisively shaped by numerous players from the ICT industry. From this perspective, Industry 4.0 describes the ongoing "informatisation" of traditional factories. In connection with Industry 4.0, Internet of Things, Cyber-Physical Production Systems, Big Data and Artificial Intelligence represent possible key technological components [4]. In further, broader definition attempts, Industry 4.0 is even referred to as complete digitization over the entire product life cycle, in which, beginning with concept definition over product development, production, use and service, action and decision-relevant knowledge is collected and integrated in a way that purposeful analyses are made possible [16], [23].

From this perspective, Industry 4.0 does not exclusively refer to the production process, but also includes upstream processes such as product development, or downstream processes such as product operation and service. According to a pioneering strategy document by Kagermann et. al [55], three integration features can be linked to the Industry 4.0 concept: Horizontal integration refers to the integration of different ICT systems in the various stages of the manufacturing and planning processes in a company, vertical integration refers to the integration of different IT systems at various hierarchical levels (e.g., actuator and sensor level, manufacturing and execution level, production level and corporate planning level) and end-to-end digitization refers to the integration of different IT systems across the entire engineering process, so that the digital and real worlds are integrated across the entire supply chain of a product and even across companies [5].

Implementing digital technologies such as the Internet of Things, Digital Twins, Augmented and Virtual Reality, Mobile and Collaborative technologies or Artificial Intelligence in organizations is a complex challenge, because organisations are socio-technical systems. As knowledge about the factors that contribute to the success of technology implementation projects is fundamental, the authors pose the following research question: *What are key success factors for the implementation of digital technologies in the context of Industry 4.0?* To answer this research question, the authors first conduct a literature review to derive key success factors and then pursue a single case study to validate them.

II. Theoretical Background

A. Internet of Things and Digital Twins

As an umbrella term for the interconnectedness of physical objects by using internet technologies, Internet of Things technologies play a central role in the context of Industry 4.0, too [35]. Therefore, many speak of an Industrial Internet or

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an Industrial Internet of Things [48], [49] and refer in summary to the increased networking of production machines with machines or the networking of the production process with the product to be manufactured.

In the context of digitization, the digital twin is playing an increasingly important role. A digital twin is able to connect the physical (real) world with the digital world [31]. In general, digital twin has mutated into a main concept in connection with the Industry 4.0 wave. A digital twin provides virtual representations of systems along their life cycles [33] and can be described as the intelligent, digital image of a real product or process [34]. For example, a digital production twin can digitally map the production process and thus enable a targeted, controlling [18], planning [32] and intervention in the production process, if the digital twin is continuously synchronized with the physical production environment. A digital twin uses data provided by sensors installed in the production process on the one hand and technologies from the Internet of Things on the other. Wireless sensor networks (WSN) and Radio-frequency identification (RFID) are used to form an extensive network for supporting IoT [2] for the further deployment of services. The future state of a fully connected manufacturing system that operates primarily without human workforce by generating, transferring, receiving and processing the necessary data to perform all the tasks required to manufacture all types of goods is often referred to as a Smart Factory [14].

B. Augmented and Virtual Reality

The augmentation of the physical environment through digital information (Augmented Reality) and the interaction of a user in a completely virtual world (Virtual Reality) show a promising potential. Augmented reality has become an integral part of Industry 4.0, as it enables workers to access digital information and overlay that information with the physical world [3]. With Augmented, Virtual and Mixed Reality technologies, knowledge-based tasks of production employees can be supported by using modern assistance systems [15] and thereby can exert a positive influence on productivity. By improving the supply of information at work while leaving both hands free and not restricting employees in their manual work practices, data glasses are often today as innovative and useful devices for employees in production, service and quality management [20]. For example, data glasses can be used to provide production workers with helpful information for the completion of their tasks, as quality information, 3D exploded views or other supporting additional information can be easily displayed in a person’s field of view [20].

C. Mobile and Collaborative Technologies

Recent developments in digitization, such as social software and mobile technologies, also offer promising opportunities to help knowledge workers in production environments by supporting knowledge processes, decision making and social interaction [1], [30]. In collaborative production environments, improving knowledge building, decision making and social interaction between team members is an important issue. Mobile technologies enable a social network based collaborative problem-solving method utilizing for instance root cause analysis to formalise problem solving instructions and expert opinions described in natural language, given that employees overcome their hesitations to share knowledge, assure their commitment to report new problems and avoid distracting them with the use of mobile devices on the shop floor [8]. Thereby experienced engineering can identify causes for a particular problem while more inexperienced people could take advantage of the mobile app to identify solutions that were successful in the past.

D. Machine Learning and Artificial Intelligence

Operating complex production machines requires not only technical knowledge about the machine to be operated, but also domain experience and process knowledge Artificial intelligence requires to integrate human process knowledge into models to (semi-)automate decision making. Therefore, Artificial intelligence technologies such as Machine Learning or Deep Learning are increasingly in demand in production environments. The aim is to identify, for example, faults in production processes such as vibrations that can lead to deviations in product quality and manifest themselves in a shortened product life or in severe application problems [21]. An almost unmanageable number of existing Machine Learning methods are contrasted with an equally large number of possible areas of use and application [26], [27]. Therefore, experienced industrial data scientists are a prerequisite to address identified problems with machine learning approaches. The use of data science and modern methods of data analysis plays an important role in the analysis of production data [50]. For instance, Stanisavljevic et al. [16] have shown that different engine configurations can be identified from analysing values measured on an engine test bench using methods from data science.

E. Organisations as socio-technical systems

In the context of Industry 4.0 and the digital transformation of companies, the role of human beings is also closely examined. Due to the rapid pace of technological change, it can be clearly seen that the role of employees in the manufacturing industry is constantly changing. The increasing automation of manufacturing processes has already dramatically reduced the amount of manual work, while the growing complexity of manufacturing systems and processes requires the remaining employees to have both increasingly broader and deeper qualifications [28].

In order to emphasize that the human being should also be at the centre of tomorrow's factories, there is a constant debate about the additional empowerment of humans through digital technologies [1], [10], [24]. Information and communication technology can help employees in collaborative production environments [12], for example, because digital technologies better support problem-solving and decision-making processes, or because access to action and decision-relevant information is further improved for employees [46]. However, digital technologies cannot only support human work, but also partially or even completely automate it. To generate cost savings, individual components of knowledge work are increasingly being automated under the guise of "robotic process automation" in addition to the classic production process automation in factories [11]. Similar to the robots in classical production automation, the standardizable parts of knowledge work usually performed by humans is conducted by software agents, which often use modern data analysis and machine learning.

Digital technologies such as Augmented or Mixed Reality, Machine Learning and Artificial Intelligence, Digital Twins or Robotic Process Automation for knowledge-based work processes are playing a key role in the digital transformation of companies [2]. Because modern work always involves a structured interaction of people with information and communication technologies, the digitalisation of industry can by no means be reduced to a mere technical dimension. In companies, people work together in an organized manner to fulfil tasks within an organizational structure. Digital technologies can help people to perform their tasks better. Nevertheless, some technologies push existing forms of organization to their limits. Therefore, the organization of work and the technologies used in the work must be aligned.

Enterprises are socio-technical systems, and the introduction of digital technologies in companies is a socio-technical undertaking: Because Industry 4.0 implementation projects always have to involve people from a wide range of different fields and disciplines [17], it is important, for example, to determine the benefits of Industry 4.0 projects in advance at the three levels, people, organization, and technology [24], [25] and to communicate them to the key stakeholders accordingly. This should ensure that the technical solutions developed in implementation projects can be transferred as smoothly as possible into productive operation. The technological solutions must also be tightly integrated into organizational processes and structures. It is obvious that although digital technologies and digital design of work can significantly modernize work processes, stakeholders must be actively involved in these change processes and must be convinced to adopt the new solution approaches accordingly [46].

F. Implications from Information Systems Research

Although terms such as digital technologies, digital transformation, or digital innovation have arrived in the German-speaking mainstream in recent years, many findings from established research on information systems can be applied to the introduction of digital technologies in the context of Industry 4.0, too. For example, it must always be borne in mind that in addition to the design of technical systems to support information and knowledge sharing, the design of organizational measures is at least as important [19]. There is no doubt that digitization and digital transformation affect not only the technological work environment, but also a wide range of social aspects such as processes, organizational structures, employee skills and corporate culture [42].

Well-known, frequently cited explanatory models from information system research, such as the technology acceptance model [36] or the information system success model [37], [38] already provide a large number of indications of success factors for the introduction of new technologies and solutions. From the technology acceptance model, essential factors such as perceived usability and perceived usefulness of the technology to be implemented can be derived [36], while the information system success model focuses on the necessity of the positive effects of introduced information systems on the levels of employees ("individual impact") and organization ("organizational impact"). Information quality, system quality and service quality also play a major role in the success of the introduction of information systems, since these aspects influence the intention whether people will use an information system or not [37], [38]. Thus, both models explain from different perspectives the relationship between the information system, the development of a behavioural intention to use the information system and the stimulated first or continuing use of the information system.

From both models it can be deduced that non-technical factors in particular play a driving role in the success of a new technical solution with end users. Furthermore, the expected success of introducing information systems also depends much on how these information systems are perceived by users in advance. It is primarily the user perception that determines the initial intention to use a novel system [36]. Therefore, measures to stimulate a positive user perception in advance are required to enhance the success of implementation projects [39].

III. A Review Of Key Success Factors

The successful design of digital workflows or digitally supported workflows usually requires an *integrated, interdisciplinary, participative and agile approach* that enables the identification, analysis and best possible support of human work practices and their context in a predominantly digital environment [10]. Therefore, the implementation of technological solutions always requires a *compatible and optimal design of the associated physical workflows*. Only then can employees successfully integrate digital solutions into their work practices. Offered digital technologies must therefore go hand in hand with digital work processes. The socio-technical design of a new, digital solution must be evaluated with the help of a suitable methodology [53].

The introduction of digital technologies in the context of Industry 4.0 is complex, since development and introduction projects usually must involve people from a wide range of disciplines and fields [17]. To create a consistent picture for all involved actors already before the factual implementation phase and eliminate communication problems between stakeholders coming from different disciplines and using a different vocabulary, a *systematic approach for the documentation and structuring of Industry 4.0 use cases to be communicated to the involved stakeholders should be applied* [17]. This use case description *includes* the *actual situation* with the currently used technology, the organizational *challenge* the envisaged digital solution should solve, the *expected target situation* after implementing the solution and the *expected benefits* for different stakeholders gained from the introduction. Having this information at hand before starting the implementation project will increase the probability that the involved stakeholders will support the implementation project sufficiently.

Richter et al. [10] rely on a careful survey of the current situation and a coordinated definition of the target situation in the sense of a 'digital work design' - in cooperation with the relevant stakeholders - and recommend the *use of personas, activity scenarios and early, non-functional prototypes for solution validation*. This user-centred approach *focuses on the current working practices* of employees, but *with the strong intention to optimally adapt them later*. To support work practices in the best possible way, or to transfer them into digitally supported work practices, the physical work practices must first be captured and understood in depth. Through such a process, employees can best learn how to use new technology and have their work practices best supported by digital technologies [40].

As with many digital technologies, and especially those designed to support communication and interaction between employees, it is important that *stakeholders are involved early in the development and deployment process and can quickly perceive the benefits* (from first-time use). The *active persuasion of users* by the project management plays a significant role in this process [29]. Here, the project management can even take on the role of a solution ambassador and encourage employees to try out and then continue using the new solution through targeted actions such as individual training, usage incentives or rapid transfer of user requirements into the solution [30].

Success factors that specifically apply to the introduction of knowledge-based documentation systems include the initial provision of a sufficiently high number of useful knowledge contributions immediately after the solution rollout as well as the *motivation of suitable persons in the company who act as multipliers* and in turn motivate other employees to use and contribute to the new solution [22], [56]. Digital technologies must be compatible with organizational processes. A further success factor is the successive *preparation of the organization for the change that the introduction of digital technologies will bring*, including the involvement and training of users and the adaptation and redesign of organizational processes to ensure that technology and processes are aligned [41].

The role of the management in the introduction of digital technologies is central [9]: However, a distinction must be made between different levels such as *management attention* to an implementation project, *management support*, and the *direct use of the new solution by the management* [22]. The strongest impact on implementation success is achieved when the management is perceived by employees not only as solution promoter, but even as an active user [39].

The existence of a concrete and understandable *digitalization strategy* helps to better classify digitalization projects within the company and to set the appropriate framework to implement them [47], [54]. Designing such a strategy is a management task. In any strategy development, it is important to work out which goals should be associated with the introduction of digital technologies in the company and then set the appropriate mechanism to monitor goal achievement. Two approaches to the introduction of digital technologies can be distinguished, but they can also be combined [43]. In an *exploration-centred strategy*, the exact way in which the solution should be used by the users is initially left to the users within the framework of a participatory approach and application scenarios are gradually identified by users themselves, whereas in the *promotion-centred strategy*, the new solution and its modes of use are communicated to users in a coordinated manner from the very beginning, with the close support of management, and then specifically trained.

The corporate culture plays a significant role in the success of the introduction of technological solutions [22], [13], [44]. An *open, innovative, and participatory culture* in which information is shared is much better suited than a closed, innovation-hostile culture in which information and knowledge are, in extreme cases, understood as a personal good and therefore not shared at all [44]. Since implementation processes are usually controlled by the management, but affect employees strongly, the way employees and managers interact and communicate with each other plays an essential role. As a rule, *shaping the corporate culture is a management task*. Managers must exemplify a culture based on trust and mutual appreciation [45]. If the corporate culture is not open, employees may see a new solution as a threat to their job.

IV. Industrial Case Study: Wafer Production

A. As-is situation and challenge

The case company is a semiconductor manufacturer that produces high-quality chips with complex production technology based on 200/ 300 mm silicon wafers for innovative applications in automotive electronics, security, smart cards, energy management and multimarket applications.

The development of new products requires a high degree of domain expertise and knowledge about the interrelationships and effects of individual manufacturing sub-processes on the manufactured product. The impact of new or modified process sequences must therefore be repeatedly tested and evaluated by conducting experiments on the production line. Experiment management is an important business process in the case company because experience management creates the fundament for faster and more efficient product development, but also for the associated production process development. The new experiment management system should work across several production sites - in the sense of a Smart Factory Cluster. Manual interventions by process operators during the conduction should no longer be necessary and should be replaced by an automated control system. The virtualization of experiment management (i.e., *the implementation of a new digital technology*) will empower employees to plan and control experiments at other locations, or to plan and control these experiments completely independently of their physical workstations, e.g., also during a business trip or from the home office.

The goal was to create a tool that is easy and intuitive to use, with which experiments can be planned and performed. Mechanisms were integrated into the tool, which can detect possible errors in the planning of experiments at an early stage or ultimately prevent them. Thus, more complex production processes across several production sites should be possible, but also controllable. The users of the new system included people who have some form of control over the production process.

B. Key success factors of the implementation project

The automation of production and production processes is a *strategically anchored project* in the case company to increase quality and efficiency and to develop and produce in a more resource-saving way. The implementation project described here is also part of this *strategic framework*. In the case company, all *key stakeholders*, both individuals and interest groups, were *involved* in the development process. This was to consider the complexity of the topic, which makes it no longer possible for individual persons to have an overview of the entire topic.

The new technical solution will affect many processes and employees in the company. It was therefore important that these *highly motivated employees* were *involved* in the *definition of requirements and approaches* to solutions at an early stage. In this sense, it was important to disregard hierarchical company structures and to *organize the project development team in a very flexible way*. Thereby, it was possible to put together a highly motivated team with the *appropriate experts from various fields*, such as IT and MES systems and production at the connected sites.

A matrix organization, consisting of a line and a project organization, enabled the participating experts to fulfill both their daily business in the company and to participate in the implementation project. For this to work smoothly, it was important to provide *experts involved with sufficient resources* and, above all, time for the implementation project, so that they could provide the best possible support for the implementation project. Nevertheless, or especially in such a project organization it was necessary to push the project results and not to lose sight of the project goals. This project coordination and management task was performed by a *dedicated project manager* who, although not an expert in all technical areas, had *sufficient technical understanding* to be able to mediate in conflict situations. Even if this may not appear efficient at first glance, a development team must also be able to pursue approaches to solutions in a complex environment that ultimately prove unsuccessful.

V. Summary and Conclusion

Although the Covid-19 pandemic has helped to spread the use of digital technologies, especially computer-based collaboration tools, enormously due to the "lockdowns" imposed by governments around the world [51], a "normal situation" in companies requires a well thought-out and structured introduction process in order to be successful. While Covid#19 left companies and employees no other option to use remote collaboration technologies that were already "available" as infrastructure, implementation projects in the field of Industry 4.0 must be treated in a differentiated way [52].

After a short introduction into Industry 4.0, the role of digital technologies in the context of Industry 4.0 and the presentation of concrete, relevant digital technologies, this paper has presented key success factors that – if considerate – can significantly improve the implementation of digital technologies. Knowledge of success factors and the adaptation of one's own actions regarding the identified success factors can increase the success of implementation projects. However, there is - as usual in success factor research - no guarantee that success will be increased. While this paper was a qualitative study of key success factors based on a literature review and a single-case study, future works should carefully examine several cases to validate key success factors and also try to quantify them.

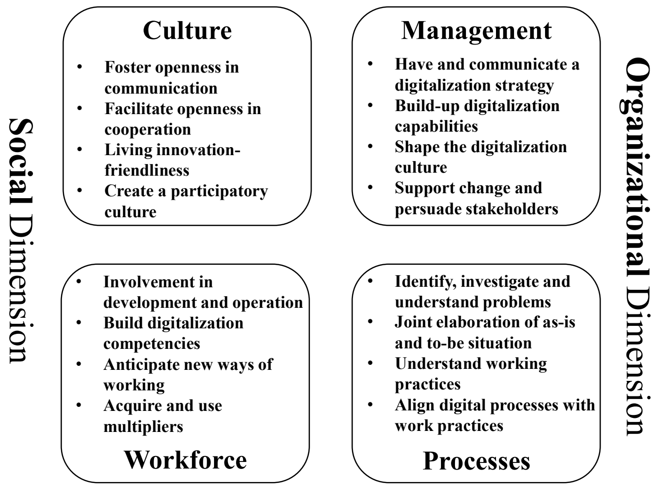

Fig. 1. Key success factors for digital technology implementation projects

Identified key success factors (cf. Fig 1) can be assigned to two different non-technical domains, management, and processes (organizational domain), as well as corporate culture and employees (social domain), while technologies themselves cannot considered a success factor. Identified key success factors include the adaptation of the relevant (manual and digital) processes, the initiation of training and persuasion processes among all users, the involvement of all relevant stakeholders in the implementation process, and the active support of the management on shaping an innovation-friendly corporate culture. Furthermore, a holistic understanding of the current situation, the organizational challenge, and the expected target situation after the implementation of digital technologies is to be formed by involving all internal and external stakeholders in this discussion process. Future studies should explore multiple use cases to derive further success factors and try to quantify them. However, the digital technologies themselves are not success factors, as success factors are factors that should facilitate the adoption of technologies. The authors' notion of key success factors as socio-organisational constructs reflects the interesting combination of people, organisation, and technology.

Acknowledgment

The iDev40 project has received funding from the ECSEL Joint Undertaking (JU) under grant agreement No 783163. The JU receives support from the European Union's Horizon 2020 research and innovation programme. It is co-funded by the consortium members, grants from Austria, Germany, Belgium, Italy, Spain and Romania.

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