Information Inputs and Outputs of Quality Planning Processes and the Possibilities of Their Improvement through Digital Transformation

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ABSTRACT

Purpose: The article aims to identify the key information inputs of quality planning processes, analyse their availability in the company practice, and propose framework measures for their effective digital transformation.

Methodology/Approach: The quality planning process was divided into 10 sub-processes, and a total of 90 information inputs and outputs were identified. Based on the importance evaluation 20 most important information inputs of quality planning were determined. The average digitalisation degree and maturity of the used storage systems were analysed in company practice for these information inputs. The average degree of availability of these inputs was then evaluated, leading to framework proposals for improvement.

Findings: The analysis revealed that many key information inputs of quality planning processes are not sufficiently available in practice. Consequently, framework measures to improve the availability of information for quality planning processes were proposed.

Research Limitation/Implication: This article provides valuable insights for companies aiming to enhance competitiveness through more effective quality planning in accordance with Industry 4.0 principles.

Originality/Value of paper: The paper identifies the information inputs and outputs of quality planning processes and offers framework suggestions for effectively incorporating digital transformation into these processes.

Category: Technical paper

Keywords: quality planning; digital transformation; Quality 4.0; information inputs and outputs; competitiveness and innovation

Research Areas: Quality 4.0; Quality Management

1 INTRODUCTION

The fourth industrial revolution brings changes in processes, technologies, and approaches to quality management. According to Ramakrishna, Y. et al. (2023), digital transformation trends define Quality 4.0, which adapts quality management activities to Industry 4.0 principles. Currently, there is an ongoing digital transformation from traditional quality management to Quality 4.0, as described by Jiju et al. (2022) and Dias et al. (2022). There are a number of current articles dealing with Quality 4.0 in quality control, i.e. in production processes; for example, the research by Singh et al. (2022) proved improvement in the quality of the product after introducing Quality 4.0 to production. Adel (2022), in relation to the further development of Industry 4.0 attributes, such as artificial intelligence, IoT, robots, 3D printing, and cloud computing, introduces the vision of Industry 5.0, where humans and machines collaborate to enhance the efficiency of industrial production.

Quality 4.0 shifts away from manual, paper-based systems, reduces human errors, removes obstacles to collaboration across the supply chain, and solves traceability issues. Companies can better understand and meet customer requirements by collecting and analysing data digitally. Digitalising key processes and information inputs/outputs of quality planning is crucial for achieving higher efficiency, innovation, and competitiveness in the modern digital environment. Businesses that successfully integrate digital technologies into their quality planning processes can expect significant improvement in all aspects of their operations. However, Quality 4.0 in quality planning has received little attention so far, making it necessary to focus more on this area. This statement is confirmed by the article by Chiarini (2020), which states that despite trying to systematise current knowledge and approaches to quality planning in the context of Industry 4.0, Industry 4.0 is still largely perceived as a process of converging industrial production with information and communication technologies. Klippert et al. (2020) add that Industry 4.0 affects all areas but is even more associated with the area of production and logistics.

Durana, et al. (2019) state that for the effective implementation of Industry 4.0, it is absolutely critical for businesses to analyse the current situation and focus their attention on improving and ensuring quality, usage of information and their overall efficiency. Gunasekaran et al. (2019) emphasise the importance of research in the turbulent environment of the rapid development of Industry 4.0. Quality management cannot be limited only to quality control, but the literature lacks relevant case studies and quality planning methodologies in Industry 4.0 conditions. Quality planning includes sub-processes that are key to ensuring competitiveness and customer satisfaction. Digitalisation and the use of Industry 4.0 principles bring new opportunities in these processes for efficient data collection and data analysis. The benefits of digitalisation are unlimited in all sub-processes of quality planning, from the identification of product requirements to the preparation of production.

2 THE IMPORTANCE OF QUALITY PLANNING IN THE CONDITIONS OF INDUSTRY 4.0

Quality management represents a set of business activities aimed at achieving the required level of quality of products and services. Quality management activities can be divided into four basic quality management processes: quality planning, quality control, quality assurance and quality improvement. These processes are interconnected, and their contribution is to maximise customer satisfaction and loyalty while minimising consumed resources.

Quality planning is a key process within an organisation's quality management system. De Feo (2016) defined quality planning as "the process of formulating quality objectives and developing the means to meet those objectives". Nenadál et al. (2018) state that it is a process that focuses on setting goals that must meet the conditions of measurability, attainability, comprehensibility, and economy and must improve the overall result of the processes and necessary resources in order to ensure that the requirements for the quality of the product and service are met. It aims to prevent errors already in the pre-production stages. Achieving this goal affects customer satisfaction and loyalty, process efficiency and efficient use of resources to achieve profit. Well-planned processes and properly defined quality requirements help minimise errors, reduce costs, and increase customer trust in the brand.

Quality planning includes activities that fundamentally influence the concept of the future product. In the pre-production stage, when decisions are made about meeting customer requirements for the product and its competitiveness, deploying the Industry 4.0 principles is crucial. Many publications agree that there is a need to address product quality at the quality planning stage when the cost of eliminating nonconformities is lower (Nenadál et al., 2008). It is reported that quality planning determines up to 80% of the final product quality (Plura, 2001) (Tulkoff, 2014). This is one of the reasons why attention should also be paid to the analysis of risks that may occur during quality planning (Polláková and Plura, 2016).

A useful framework for understanding the development of the concept of quality in the current conditions of Industry 4.0 was brought by Jiju et al. (2022), who described four levels of quality management from Quality 1.0 to 4.0. Each phase represents a fundamental shift in how organisations approach quality, from basic quality inspection to integrating digital technologies. Furthermore, the evolution of the approach to quality from product/process control to dynamic operational excellence is presented. Operational excellence (Quality 3.0) emphasises quality that is perceived as a key element for competitiveness and business success. Dynamic operational excellence (Quality 4.0) is data-driven and fully integrated into all organisation processes. In earlier research, Slancová (2021) stated that the elements of Industry 4.0 in the manufacturing industry are predominantly applied in medium and large companies, specifically in production. Typical features of Quality 4.0 are digitalisation, feedback from machines, linking inputs and outputs between the quality department and production, etc. Reedy (2020) calls Quality

4.0, together with Industry 4.0, as "the dawn of digital transformation", using artificial intelligence (AI), machine learning, augmented reality, the Internet of Things, robotics and other technologies in order to improve communication between people, data and devices (Reedy, 2020).

An article by Joković et al. (2023) focuses on the use of advanced digital technologies in manufacturing and states the need for intelligent supply chain involvement. In the study, the authors primarily focused on production processes. The interesting results are recommendations for introducing uniform knowledge databases and defining clear customer requirements. Defining customer requirements is part of quality planning processes.

Digital transformation in quality planning processes opens up possibilities for significant improvements. Modern digital technologies increase the efficiency of processes and provide new possibilities for predictive analysis and optimisation, which minimises errors, reduces the time needed to react to changes, and facilitates fact-based decision-making. Digitalisation increases the transparency of processes and facilitates cooperation between departments or external links in the logistics chain.

Vasiliev et al. (2019) explored the extensive possibilities of how digital technologies can enrich and strengthen traditional approaches to quality management. The authors suggested streamlining production processes using digital technologies and PLM systems (Product Lifecycle Management), ERP (Enterprise Resource Planning), PDM (Product Data Management) and MES (Manufacturing Execution System). All of these systems work with some quality planning processes, providing information about the product even from the pre-production stages, but they are not comprehensive software support for quality planning. In particular, PLM appears to be a suitable system for the digitalisation of pre-production and production processes. Production processes are prioritised, although the benefits of pre-production processes have been proven many times before.

PLM is the most comprehensive product life cycle management description and closely cooperates with information system ERP. Stark (2013) stated that PLM carries the data of what the product should be, and ERP realises the transformation of the vision into the given product. These systems can be integrated into quality management processes to streamline production, reduce errors and increase overall customer satisfaction. All these digital technologies and systems work based on the data inputs and outputs. It is, therefore, necessary to correctly identify information inputs and manage them in such a way as to achieve the desired outputs. In particular, there is a need to address the digitalisation of data, inadequate data quality, the absence of a data manager, missing standards, the creation of reports with incorrect data and unclear links between structured and unstructured data (Ulrych, 2017).

The tool for the digital transformation of quality management can be 11 key components and their tools and approaches for a comprehensive framework for the implementation of Quality 4.0 defined by the Juran Institute and Attain Partners (2019). This framework enables the transition from traditional quality management systems to advanced systems. 11 key components (data, analytics, connectivity, collaboration, application development, scalability, management system, compliance, culture, leadership and competence) include tools and techniques from traditional approaches to quality to Quality 4.0. Juran Institute and Attain Partners (2019) further reported on their blog that 37 % of organisations perceive it as problematic that data has different data sources and is stored in different systems.

The introduction of Quality 4.0 is supposed to improve cooperation between departments, communication and decision-making efficiency. This framework can be supplemented by RAMI 4.0 (Reference Architectural Model Industry) (MPO, 2017), which provides a structured framework for organisations when planning, designing and implementing tools, technologies and systems in the conditions of Industry 4.0 and divides them into three dimensions, namely: value stream of life cycle, hierarchy levels and interoperability layers (Lars et al., 2023).

Research by Dutta et al. (2021) points to the need to implement digital transformation in the area of quality management. The authors focused on quality management processes in the PDCA cycle (Plan-Do-Check-Act) that are suitable for digitalisation; these are: design for quality, compliance, incoming and outgoing goods control, statistical process control and complaint management. The authors recommend digitalisation of these five processes primarily to shorten the time to market. These processes include quality planning processes.

3 METHODOLOGY

The study began by identifying the sub-processes of quality planning and their information inputs and outputs. Based on theoretical starting points, analysis of the latest findings and consultations in company practice, a total of 10 sub-processes of quality planning and 90 different information inputs and outputs were identified, and a model of information flows was created. Based on the frequency of use of individual information inputs and evaluation of their importance in individual sub-processes, their resulting importance was evaluated, and twenty key inputs of quality planning were determined.

At three selected industrial companies that design and develop their products, an analysis of the use of identified inputs and outputs was performed in the form of interviews, and the degree of digitalisation and degree of maturity of data storage systems was evaluated for key information inputs. Based on these data, these key information inputs' average degree of availability was then evaluated. This survey in company practice led to the conclusion that the surveyed companies work with the vast majority of identified inputs and outputs, but the availability of some key information inputs is not at a sufficient level. The causes of this insufficient degree of availability of these inputs are not only the low degree of their digitalisation but also the low degree of maturity of the storage used.

On the basis of these findings, framework proposals were developed to improve the information assurance of quality planning processes through digital transformation. These proposals should be implemented as a priority for the identified key information inputs, but gradually, they should be applied to all information inputs and outputs of quality planning.

4 RESULTS

4.1 Identification of sub-processes of quality planning and their information inputs and outputs

Quality planning includes a number of sub-processes. Sub-processes of quality planning extend to other stages of the product life cycle, help minimise risks during production and ensure customer satisfaction. Based on the theoretical foundations of the work and research by Plura and Klaput (2023), quality planning processes were divided into ten basic sub-processes: Identification of product requirements, Transformation of product requirements into product quality characteristics, Product design and development, Optimisation of product design in terms of risks of potential failures, Product design review, Process design and development, Optimisation of the process design from the point of view of the risks of potential failures, Process design review, Pilot production and verification of process capability, Preparation of production.

The quality planning sub-processes are further specified below. A model of information inputs and outputs flows was created for all sub-processes of quality planning. The identified information inputs and outputs are based on theoretical principles and were consulted in the environment of an automotive industry supplier. The flows of information inputs and outputs for individual sub-processes of quality planning are shown in Fig. 1.

4.1.1 Identification of product requirements

The sub-process "Identification of product requirements" is the first quality planning sub-process; it identifies the requirements of customers, other stakeholders and legislation. A significant difference from other subsequent sub-processes of quality planning is the higher amount of data received from external sources and the generation of primary data for the quality planning process and subsequent processes. When implementing the process, it is necessary to create the characteristics of the intended product, work with a list of potential customers and other stakeholders, with the skills of product users, with information about current material and technological options, information about the competitors, benchmarking results and with experience with similar products. The result of this process should be concretely formulated customer requirements for the product, conditions of its use, legislative requirements, requirements of the producer and other stakeholders and an evaluation of the weight of the requirements for the product is appropriate (see Fig. 1 and Table 1).

4.1.2 Transformation of product requirements into product quality characteristics

The transformation of product requirements into product quality characteristics follows the previous sub-process, "Identification of product requirements". In the model, the inputs and outputs of the previous sub-process are fully inputs into this quality planning sub-process. Customer requirements are often formulated in customer language, and the producer's task is to transform these requirements into technical specifications. A suitable method in this process is the QFD method, the House of Quality. The sub-process "Transformation of product requirements into product quality characteristics" should provide the following main information outputs (see Fig. 1 and Table 1):

- Evaluation of competitiveness in meeting requirements,
- Activities to improve the ability to meet requirements,
- Importance of product requirements,
- Product quality characteristics determining the fulfilment of requirements,
- Relationships between quality characteristics and requirements,
- Evaluation of competitiveness in terms of quality characteristics,
- Importance of quality characteristics,
- Interrelationships between quality characteristics,
- Target values of product quality characteristics,
- Tolerance of target values of product quality characteristics.

4.1.3 Product design and development

"Product design and development" aims to create a product design where the quality characteristics will reach the required target values. All information inputs and outputs of previous sub-processes enter this process (see Fig. 1 and Table 1). The sub-process "Product design and development" should provide the following main information outputs:

- Product design,
- Prototype (physical or virtual),
- Design for manufacturing, etc. (DFX),
- Product design verification results,
- List of necessary materials and their availability,

- Preliminary list of suppliers,
- Preliminary design of the production process,
- Results of the feasibility study.

4.1.4 Optimisation of product design in terms of risks of potential failures

Optimisation of product design in terms of risks of potential failures is an important way of optimising the designed product. In order to ensure an acceptable level of risk, the FMEA method of product design is most often used. The sub-process "Optimisation of product design in terms of risks of potential failures" should provide the following main information outputs (see Fig. 1 and Table 1):

- Potential product failures,
- Risks of potential product failures,
- Weaknesses in product design,
- Weaknesses in product design verification,
- Proposals and implementation of risk mitigation actions,
- Risks of potential product failures after implementation of actions,
- Modified product design, ensuring acceptable risks.

4.1.5 Product design review

The product design review takes into account all the inputs identified so far. Product design review is a very important point in terms of information flow. In total, 42 information inputs and 3 information outputs are identified in the model: Product design review results, Product design change recommendations and Final product design (see Fig. 1 and Table 1).

4.1.6 Process design and development

The quality planning process, "Process design and development", is important for companies that develop the product and those that do not. This sub-process should lead to the design of a technological procedure to produce the designed product in the required quality. In addition to several external information inputs, such as customer requirements for the process and its control, legislative requirements for the process, logistic requirements, or information about potential suppliers, it is important to use many information outputs or inputs from the previous processes (see Fig. 1 and Table 1). The sub-process "Process design and development" should provide the following main information outputs:

- Process design,
- Design of a process control method,
- Draft of a control plan,

- Work instructions,
- Requirements for input materials,
- List of suppliers.

4.1.7 Optimisation of process design from the point of view of the risks of potential failures

This sub-process aims to minimise the risks of non-conforming products during production or the failure of the designed process. By default, the FMEA method is used in this sub-process. This sub-process should provide the following main information outputs (see Fig. 1 and Table 1):

- Potential failures during production,
- Risks of potential failures during production,
- Weaknesses in process design,
- Weaknesses in the process control method,
- Proposals and implementation of risk mitigation actions,
- Risk of potential failures during production after implementations of actions,
- Modified process design ensuring acceptable risks.

4.1.8 Process design review

Process design review constitutes a comprehensive, systematic, and objective assessment of the process design carried out by a team of independent experts from various fields. A total of 37 information inputs and 4 information outputs were identified in the model: Process design review results, Process design change recommendations, Reviewed process design, and Pre-launch control plan (see Fig. 1 and Table 1).

4.1.9 Pilot production and verification of process capability

Pilot production and verification of process capability is carried out under real conditions to verify that the process can consistently provide products of the required quality at the predicted capacity performance. Several information inputs and outputs of previous quality planning sub-processes enter the process. This sub-process should provide the following main information outputs (see Fig. 1 and Table 1):

- Results of product validation,
- Results of preliminary process capability,
- Results of measurement systems analysis,
- Deficiencies of the verified process,

- Proposals and implementation of actions to eliminate process deficiencies,
- Final process design,
- Production control plan.

4.1.10 Preparation of production

Preparation of production is the last identified sub-process of quality planning. It is an important part of the information flow between quality planning and subsequent product life cycle processes. Preparation of production works with 59 information inputs and ten information outputs, which include, for example, the production plan, inspection procedures, ensuring methods of protection, handling and storage of materials and products, maintenance plan, etc. (see Fig. 1 and Table 1 for more details).

Fig. 1 graphically shows the information flows in the individual sub-processes of quality planning. The top row in Fig. 1 shows the numerical designation of information inputs and outputs listed in Table 1. The yellow colour represents primary information inputs, which are external sources of information where the manufacturer must do his best to ensure that these inputs have the required quality. From the point of view of digital transformation, there must be pressure for primary inputs to create and preserve these information inputs in a usable digital form and to the necessary extent. The orange colour represents information inputs already used in one of the previous sub-processes of quality planning or the outputs of these previous sub-processes. The emphasis here is on the easy availability of data and, if possible, their automatic transfer (without human intervention). The information outputs of the individual quality planning processes are highlighted in blue. Subsequently, they become inputs to the following processes. The optimal solution is the creation of databases from which authorised users, i.e. sub-processes of quality planning, could obtain the required information inputs for their transformation into the outputs of the given sub-process of quality planning with minimal manual intervention. This would lead to significant streamlining of quality planning processes.

Further research was based on the assumption that individual information inputs have different importance for ensuring the successful course of quality planning processes. Digitalisation and easy availability should be ensured as a priority for the most important information inputs.

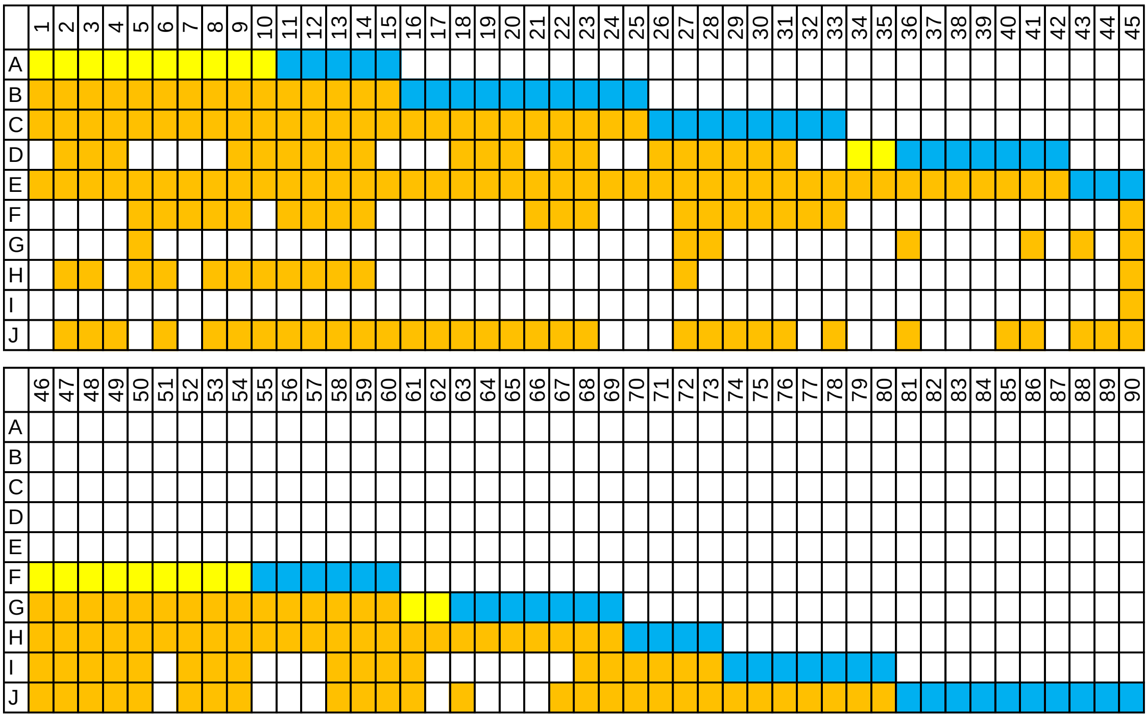

Figure 1 – Information inputs and outputs of sub-processes of quality planning (Own processing)

Legend:

Sub-processes of quality planning are shown in the first column: A – Identification of product requirements, B – Transformation of product requirements into product quality characteristics, C – Product design and development, D – Optimisation of product design in terms of risks of potential failures, E – Product design review, F – Process design and development, G – Optimisation of process design from the point of view of the risks of potential failures, H – Process design review, I – Pilot production and verification of process capability, J – Preparation of production.

Information inputs and outputs are in the top line and are marked 1-90; they are listed in Table l.

Table. 1 – List of information inputs and outputs of quality planning (Own processing)

No.	**Information inputs and outputs of quality planning**	**No.**	**Information inputs and outputs of quality planning**
1	Characteristics of the intended product	46	Customer requirements for the process
2	List of potential customers	47	Customer requirements for process control
3	List of other stakeholders	48	Legislative process requirements
4	Customer (users) skills	49	Logistics requirements
5	Current material and technological options	50	Information on the required production volume
6	List of current legislative documents	51	Information on potential suppliers
7	Overview of current development trends	52	Data on the capability of production facilities
8	List of competitors	53	Requirements for the qualifications of workers
9	Current product benchmarking results	54	Experience in manufacturing similar products
10	Experience with similar products	55	Process design
11	Customer requirements for the product	56	Process control method design
12	Product terms of use	57	Draft of control plan
13	Legislative requirements for the product	58	Working instructions

No.	Information inputs and outputs of quality planning	No.	Information inputs and outputs of quality planning
14	Requirements of the producer and other stakeholders	59	Requirements for input materials
15	Weight of product requirements	60	List of suppliers
16	Evaluation of competitiveness in meeting requirements	61	Results of risk analyses of potential failures in similar processes
17	Activities to improve the ability to meet requirements	62	Tables of criteria for risk assessment
18	Importance of product requirements	63	Potential failures during production
19	Product quality characteristics determining the fulfilment of requirements	64	Risks of potential failures during production
20	Relationships between quality characteristics and requirements	65	Process design deficiencies (possible causes of failures)
21	Evaluation of competitiveness in terms of quality characteristics	66	Deficiencies in process control
22	Importance of quality characteristics	67	Suggestions and implementation of actions to mitigate process design risks
23	Interrelationships between quality characteristics	68	Risks of potential failures during production after implementation of actions
24	Target values of product quality characteristics	69	Modified process design ensuring acceptable risks
25	Tolerance of target values of product quality characteristics	70	Process design review results
26	Product design	71	Recommendations for process design changes
27	Prototype (physical or virtual)	72	Reviewed process design
28	Design for manufacturing etc. (DFX)	73	Pre-launch control plan
29	Product design validation results	74	Product validation results
30	List of necessary materials and their availability	75	Results of preliminary process capability analysis
31	Preliminary list of suppliers	76	Results of measurement systems analysis
32	Preliminary design of production process	77	Deficiencies of the verified process
33	Feasibility study results	78	Proposals and implementation of measures to eliminate process deficiencies
34	Results of risk analysis of potential failures in similar products	79	Final process design
35	Criteria tables for assessing the risks of potential product failures in similar products	80	Production control plan
36	Potential product failures	81	Agreed delivery parameters
37	Risks of potential product failures	82	Necessary parameters of production equipment
38	Deficiencies in product design (causes of potential failures)	83	Production plan
39	Deficiencies of product design verification	84	Production control system setting
40	Proposals and implementation of actions to mitigate product design risks	85	Material flow parameters
41	Risks of potential product failures after implementation of actions	86	Inspection procedures
42	Modified product design, ensuring acceptable risks	87	Ensuring methods of protection, handling and storage of materials and products
43	Product design review results	88	Maintenance plan
44	Recommendations for product design changes	89	Information flow setting
45	Final product design	90	Production success indicators and their target values

4.2 Analysis of the importance of information inputs for quality planning

The importance of inputs of quality planning was evaluated with regard to:

a) Frequency of use of information input in sub-processes of quality planning

The frequency of use of information input in sub-processes of quality planning indicates how many sub-processes of quality planning the given information input is used. There are ten sub-processes of quality planning, so the maximum value of the frequency of use is ten.

b) The importance of information input in individual sub-processes of quality planning

The importance of information inputs of quality planning in individual sub-processes was evaluated on a scale of 1 to 5 points (with 5 points indicating high importance of the input and decreases by descent). The importance of information inputs follows from the previous evaluation of the frequency of use of information input in sub-processes of quality planning. If the given input was part of a sub-process, its importance was also evaluated.

c) The overall importance of information input for all quality planning sub-processes

For the calculation of the overall importance of the information input, the following formula was used:

$$S_j = \sum_{i=1}^{10} V_{ij} \tag{1}$$

S_j - overall importance of information input in all ten quality planning sub-processes

V_{ij} - evaluation of the importance of the "j" input in the "i" sub-process of quality planning

Based on the analysis of the importance of individual information inputs, it was possible to identify key information inputs that, according to the initial model, could significantly influence the successful course of the quality planning process.

For further evaluation, the order of individual inputs was determined according to frequency of use and overall importance. In cases where the evaluated criteria reached the same values, the average ranking was calculated.

In the next step, the average ranking was calculated for individual information inputs from the point of view of both criteria and the most important inputs from the point of view of both criteria were determined. Table 2 represents the twenty most important information inputs. The colour-highlighted information inputs are fully part of the first sub-process of quality planning, "Identification of product requirements".

Table 2 – The most important information inputs for quality planning in terms of frequency of use and overall importance and their average degree of digitalisation, repositories and availability in company practice (Own processing)

Rank	Average rank	Information inputs	Average degree of		
			Digitalisation	Repositories	Availability
1	1	Current product benchmarking results	0.64	0.52	0.33
2	2	Legislative requirements for the product	0.93	0.61	0.57
3	3	Customer requirements for the product	0.82	0.64	0.52
4	4.5	Current material and technological options	0.50	0.56	0.28
5	4.5	Requirements of the producer and other stakeholders	0.71	0.61	0.43
6	6	List of potential customers	0.59	0.38	0.22
7	7	Product terms of use	0.88	0.48	0.42
8	9	List of current legislative documents	0.98	0.63	0.62
9	9	List of competitors	0.58	0.53	0.31
10	9	Experience with similar products	0.89	0.54	0.48
11	11	Prototype (physical or virtual)	0.97	0.38	0.37
12	12	Customer (users) skills	0.88	0.53	0.47
13	16.5	Final product design	1.00	0.63	0.63
14	16.5	Customer requirements for the process	0.81	0.56	0.45
15	16.5	Customer requirements for process control	0.89	0.56	0.50
16	16.5	Legislative process requirements	1.00	0.64	0.64
17	16.5	Logistics requirements	0.81	0.52	0.42
18	16.5	Information on the required production volume	0.93	0.60	0.56
19	16.5	Data on the capability of production facilities	0.81	0.64	0.52
20	16.5	Requirements for the qualifications of workers	1.00	0.54	0.54

The most important information inputs listed in Table 2 include, for example, product requirements, process requirements, or stakeholder requirements. Processing these information inputs often requires a multidisciplinary approach: the collaboration between different departments and teams within the organisation or the whole supply chain. Working with information inputs that go across the logistics chain is also demanding from the point of view of data management, and it is necessary to address, for example, storage information, data quality, data sharing, data duplication management, etc. Their digital transformation can significantly reduce the time required to process these information inputs.

4.3 Analysis of the availability of key information inputs of quality planning in company practice

For the key information inputs of quality planning, an analysis of the degree of digitalisation and maturity of storage in company practice was conducted using interviews at three selected manufacturing companies that carry out product and process design and development. First, it was investigated to what extent the data for the key information inputs of quality planning process are kept: **in digital form:** on the disk of the employee's personal computer (primary disk of the company server), on the company server (on a shared disk), on the cloud, as part of software support or in an information system (e.g. SAP, ABAS, QI…); **in paper form** or as knowledge of the employee.

The degree of digitalisation of individual information inputs was evaluated as a proportion of types of data in digital form from the total number of all types of data. The average degree of digitalisation of all key information inputs was found to be approximately 0.83 (83%) (Company A: 0.81, company B: 0.77 and company C: 0.91). The average degrees of digitalisation of individual key information inputs of quality planning in the surveyed companies ranged from 0.5 (50%) to 1 (100%) (see Table 2).

The highest average degrees of digitalisation in corporate practice were achieved by these information inputs: Legislative requirements for the process, Final product design, Employee qualification requirements, List of current legislative documents, and Prototype (physical or virtual). This means that the surveyed companies have these information inputs highly digitalised. On the contrary, the least digitalised information inputs include Current results of product benchmarking, List of competitors, List of potential customers, Current material and technological options and Requirements of the producer and other stakeholders.

These information inputs are often stored outside the digital environment as employee knowledge. At the same time, these information inputs are rated as one of the most important (see Table 2) and are the primary information inputs and information outputs of the first sub-process of quality planning "Identification of product requirements" used as information inputs for other quality planning processes and subsequent quality management processes.

To be able to assess the availability of the individual key information inputs of quality planning, an assessment of the level of maturity of digital data repositories was conducted at the surveyed companies. Each type of storage was assigned a value according to maturity and suitability of data storage in the conditions of Industry 4.0 according to this scale: 1 point – memory of the employee's personal computer, 2 points – company server, 3 points – information system and SW supporting quality planning that are compatible with information system; 4 points – cloud storage. With the help of interviews in the three investigated companies, the share representation of individual digitalised data repositories was determined for individual inputs, and the weight average score for individual companies was calculated. Consequently, the average point score for all three companies was calculated and the average level of storage maturity was calculated as a share of the maximum value of 4.

Calculated average values of the degree of the maturity of the repositories of key information inputs for quality planning in the surveyed companies are listed in Table 2. The average assessment of the degree of maturity of the repositories of individual key information inputs ranged from 0.38 to 0.64; the overall average maturity of the repositories was 0.55. The highest average levels of storage maturity were found for the surveyed companies for the information inputs Legislative requirements for the process, Customer requirements for the product and Data on the capability of production facilities. The lowest average level of storage maturity was found in the surveyed companies for the key information inputs List of potential customers, and Prototype (physical or virtual). The data for these information inputs are stored in digital form, but their storage is unsuitable for the conditions of Industry 4.0 (data stored in the memories of employees' personal computers).

Based on the average degree of digitalisation and the average degree of maturity of the repositories, the average degree of availability of individual information inputs was calculated as the product of these two values. The resulting degree of availability is presented in Table 2, and a graphical comparison of the average degrees of availability of key information inputs is shown in Figure 2. The average degree of availability reflects the extent to which quality planning information inputs can be effectively used regarding their digitalisation level and the repositories' maturity. A higher value of the degree of availability indicates that information inputs are more easily available in company practice. The higher the value of the degree of availability, the easier it is to obtain the relevant data, which significantly contributes to the efficient course of quality planning processes.

The best ratings in terms of availability were received by information inputs related to legislation (Legislative requirements for the process, List of current legislative documents, and Legislative requirements for the product) and Final product design. These information inputs are available in digital form in higher-level storage in corporate practice. These are inputs that are commonly used and shared with other stakeholders in corporate practice; their digitalisation and storage in more advanced repositories make it easier for companies to work with them. Low availability values were found for the information inputs: List of potential customers, Current material and technological options, List of competitors, and Current product benchmarking results in the surveyed companies.

The reason for the low availability of information inputs is either a low level of digitalisation or, a low level of storage maturity or both. So, for example, in the case of information inputs, such as current material and technological options, list of competitors, and current results of product benchmarking, the cause of low availability is mainly the low degree of digitalisation. In the case of the information inputs: Prototype, and Terms of use of the product, the cause of low availability is mainly the low level of maturity of the storage, and in the case of the information input List of potential customers, both the low level of digitalisation and the low level of maturity of the storage contribute to the low level of availability. This information is an important basis for determining appropriate measures to improve the availability of quality planning information inputs.

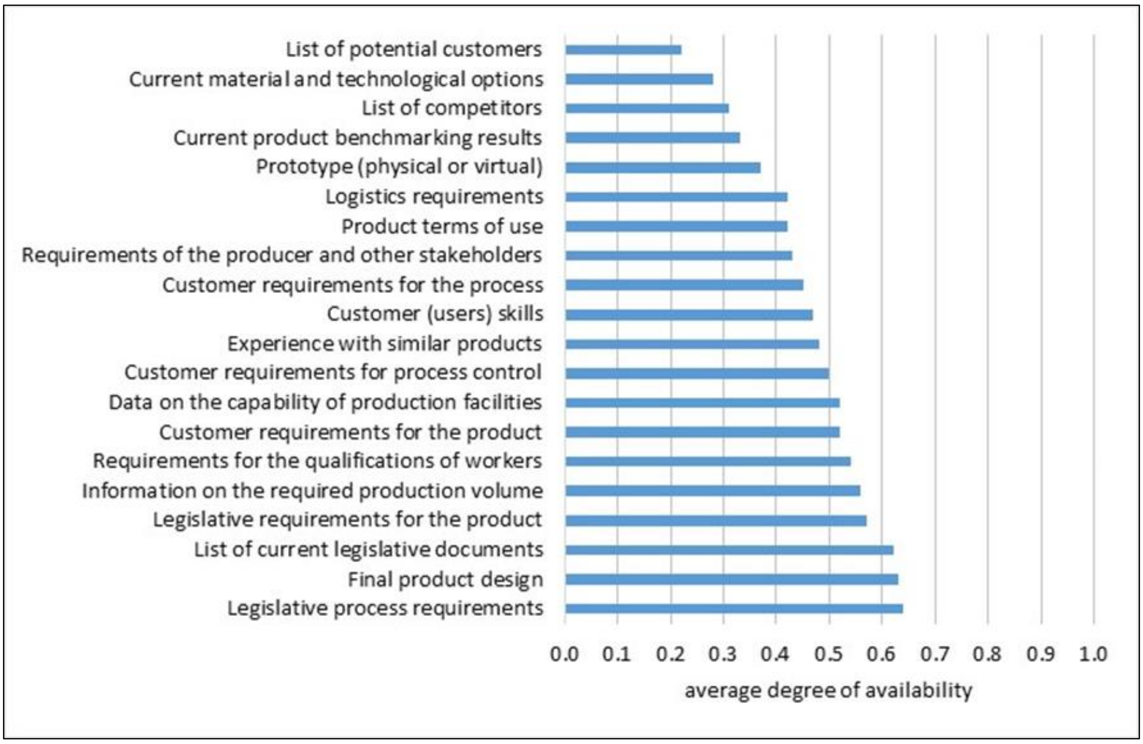

Figure 2 – Average degree of availability of key information inputs of quality planning in company practice (Own processing)

For information inputs with a low degree of availability, it is necessary to start digital transformation as a priority. For example, for the lowest-ranked information input List of potential customers, the availability rate can be improved by storing the data in systems that are not only technologically advanced but also easily accessible to all authorised employees. By improving the availability of information inputs and outputs of quality planning processes, businesses can move closer to real-time quality management, improve a multidisciplinary approach, and streamline the overall product development and manufacturing process.

The analysis revealed that many key information inputs for quality planning are not sufficiently available in practice. The average degree of digitalisation for the 20 most critical inputs was found to be low, and the maturity of storage systems was often inadequate. This lack of digitalisation and maturity of storage negatively impacts the efficiency and effectiveness of quality planning processes.

4.4 Framework proposals for improving information assurance of quality planning processes

Framework proposals for improving information assurance of quality planning processes are based on background research and conducted analysis, and their goal is to ensure the digital transformation of information inputs and outputs of quality planning. Framework proposals for improvement focus not only on improving the availability of information inputs, but also on other aspects related to digital transformation. As already mentioned, digital transformation should be implemented as a priority for the key information inputs of quality planning identified in Table 2, but gradually it should be ensured for all identified information inputs and outputs (see Table 1).

Based on the background research and the conducted research, the following framework proposals can be formulated to improve the information assurance of quality planning processes:

1) Ensuring the digital form of quality planning information inputs. Digitalisation of information is essential for faster data processing, better security, and easier sharing of information between teams and departments. Creating a centralised place where all data are stored allows easy access and manipulation of data for all authorised persons. The improvement process should be prioritised to focus on the primary inputs occurring in the sub-processes "Identification of product requirements" and "Process design and development". The key information inputs are shown in Table 2.

2) Creating a unified repository with easy access. A centralised data repository should be created to store all information inputs and outputs of quality planning processes. This repository should be designed to be compatible with different types of data and formats and allow easy access to all authorised users from different departments, even those outside the organisation. This would ensure the use of information inputs and outputs in other quality management processes, during quality control in production and quality improvement. Such a solution supports collaboration, improves information flow, and simplifies data management. The implementation of cloud technologies and services can offer a flexible and scalable solution for storing, sharing, and managing data, while at the same time increasing the availability and resilience of the system.

3) Introduction of standardised formats and appropriate data structure in quality planning's individual information inputs and outputs. This step ensures that data is structured consistently across different systems and applications. This will facilitate its integration, searching and analysis. This step must be implemented when creating primary information inputs and outputs; a multidisciplinary approach is necessary here because primary information inputs obtain data mostly from outside the organisation. It is important to design a format and structure that supports the efficient course of quality planning processes and facilitates access to information for all stakeholders. In practice, this means creating a logical and intuitive data categorisation system that includes both metadata and the context of the information so that it is easily identifiable, sorted and analysed. To fulfil this point, it is possible, for example, to use a modular approach to organising data and their interconnections. For implementing the modular approach, the following important information was presented in this article: the sub-processes of quality planning were identified, their information inputs and outputs were determined, and the analysis of data flows in the sub-processes of quality planning was performed.

4) Ensuring automated collection processes for selected information inputs and outputs. Due to the different nature of information inputs and outputs of quality planning, this step is only possible for selected information inputs and outputs (e.g. automatic data collection on legislative requirements for the product) and for inputs that were previously used during the quality planning process. Where possible, data collection and processing should be automated to reduce human impact and increase accuracy. It is important to integrate with external data sources and set up a data flow mechanism between information inputs and outputs of quality planning with the aim of minimising the influence of the human factor.

5) Ensuring controlled updating of information inputs. It is necessary to ensure that all information inputs are updated in a controlled mode (e.g., by identifying different design versions, updating benchmarking data, etc.). Maintaining data integrity and ensuring an efficient decision-making process is very important.

6) Ensuring data security and integrity. Quality planning involves working with sensitive data, handling customer intellectual property, and non-disclosure agreements, which are common practice in the design and development stage. The key challenges of digitalisation are ensuring the security and integrity of data, which must be responded to appropriately and ensure the protection of sensitive information from cyber threats. In addition to robust security protocols and encryption, it is also essential to implement a sophisticated data backup system. This system should include regular backups at multiple independent and geographically separated locations to minimise the risk of data loss due to physical or technical failures. Furthermore, it is necessary to solve problems associated with resistance to system failures and to ensure that the digitalisation of selected information inputs and outputs of quality planning does not lead to the creating of new weak points in the logistics chain.

5 DISCUSSION

The findings of this study reveal significant gaps in the digitalisation and availability of key information inputs for quality planning processes. While some information inputs are partially digitalised, their availability remains a major challenge due to the inadequacies of current storage systems. This indicates that companies need to prioritise the digital transformation of these critical inputs to fully realise the benefits of Quality 4.0.

The proposed framework improvements are designed to address these gaps by recommending specific actions for enhancing the digitalisation and availability of key information inputs. These improvements include adopting advanced digital technologies, improving data integration, and enhancing storage system capabilities. Implementing these measures can assure significant improvement in the effectiveness of quality planning processes and the competitiveness of companies.

Future research should focus on case studies of successful digital transformation implementations in quality planning to provide more concrete examples and best practices. Additionally, exploring the impact of emerging technologies such as artificial intelligence and machine learning on quality planning processes could offer valuable insights for further improvement.

Overall, the digital transformation of quality planning processes is essential for achieving higher efficiency, innovation, and competitiveness in the Industry 4.0 era. By addressing the identified gaps and implementing the proposed framework improvements, companies can enhance their quality planning processes and ensure long-term sustainability and customer satisfaction.

6 CONCLUSION

In the context of digitalisation and the implementation of Industry 4.0 principles, this article focused on identifying sub-processes of quality planning and their information inputs and outputs. Key information inputs were identified based on the analysis of the importance of individual information inputs, for which digital transformation should be prioritised.

For the key information inputs of quality planning, the average degree of digitalisation and the average degree of storage maturity were evaluated in terms of company practice, based on which the average degree of availability of these information inputs of quality planning was determined. The analysis of the state of availability of the most important information inputs in the conditions of company practice showed that the average degree of digitalisation of some important information inputs is not sufficient in many cases, and even those digitalised information inputs and outputs are often difficult to access due to the repositories used.

Based on the background research and conducted research, framework proposals for improving the information assurance of quality planning processes have been formulated. The proposed framework improvements should be prioritised for application to identified key information inputs of quality planning, but gradually, they should be applied to all identified inputs and outputs. This is an important step not only for increasing efficiency of quality planning processes, but also for other quality management processes (quality control and quality improvement) that follow quality planning and use its information outputs.

The development of digital transformation in the field of quality planning is not only a trend, but it is becoming a crucial element for ensuring customer satisfaction and companies' long-term sustainability and competitiveness.

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CONFLICTS OF INTEREST

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