Methodological Procedure for the Development of a Qualitative and Quantitative Evaluation Concept for Project Benefit Assessment

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Abstract : The fourth industrial revolution not only brings great opportunities for the economy, but also poses major challenges for all stakeholders. Manufacturing companies in particular are affected by challenges such as a lack of innovative strength or the risk of being overtaken by innovative start-ups. However, the dynamic environment and the resulting complexity require faster and better decisions to remain competitive in the long term. Current business practices of established companies do not meet this challenge and risk losing control of their core business. Taking a purely technological approach to this subject harbors costly risks. Only the integration of the various individual technologies into a holistic digital strategy creates efficiency and new growth areas. To exploit the full potential of Industry 4.0 (I4.0) in the manufacturing industry, companies must therefore take a strategic view of the technological options and adapt their organizational structure and culture. The main objective of this paper is therefore to describe the procedure for developing a suitable evaluation concept for assessing the economic benefits of digitization projects. The evaluation concept to be developed is designed to be able to perform a multidimensional examination and evaluation of digitization projects in order to enable a quick and well-founded decision on the implementation as well as the prioritization of a specific project or several projects from a qualitative and quantitative point of view. The paper therefore describes a seven-step approach to developing a multidimensional matrix diagram that serves as the basic structure for such an evaluation concept. To develop a suitable evaluation concept, the research focus will be carefully examined and in-depth research on two overarching themes will be conducted, resulting in the definition of appropriate evaluation criteria: From a methodological point of view, existing assessment models are considered in general and the strengths and weaknesses of these models are discussed. From a practical perspective, the special requirements of digitization and Industry 4.0 will be addressed. To this end, expert interviews will be conducted and a total of 100 practical examples will be selected from an extensive database and analyzed in a criteria-oriented manner in order to derive assessment dimensions and assessment criteria from both a quantitative and qualitative perspective.

Keywords: Industry 4.0, Digitization, Qualitative and Quantitative Assessment, Economic Benefits, Manufacturing Companies, Multidimensional Assessment, Matrix Diagram

1. Introduction

The rapidly increasing digitization of the economy and society is changing production and working methods. Progressive developments in key technologies are promoting change. Value creation processes are being digitized and implemented in dynamic and flexible value creation networks. Not only new value networks, but also new services and innovative business models are completely redefining existing industries. As a result, established market structures and world market shares are redistributed (BMWI 2019; acatech 2019; Kagermann et al. 2013).

The economic benefits of these efforts are currently difficult to predict. In Germany, for example, BCG expects significant increases in productivity (15-25%), turnover (30 billion EUR p.a.) and investment (250 billion EUR p.a.) over the next ten years (Rüßmann et al. 2015). Realistically, however, figures of this magnitude in the industrial sector seem a long way off. The main reason for this is that the concrete benefits of I4.0 are not apparent to many companies. This is confirmed in a study by the German Federal Ministry for Economic Affairs and Energy (BMWi), which highlights the lack of transparency regarding the benefits as one of the main obstacles to the introduction of digitization in companies. Combined with the supposed technological and financial uncertainties and excessively long implementation periods, this means that German companies are proving to be extremely reluctant to invest for the time being (BMWI 2015).

The fourth industrial revolution, while bringing great opportunities for the economy, is also associated with major challenges. Companies that want to grow profitably in the coming years, or at least continue their existing business, are thus forced to make radical changes (BMWI 2015; Fend and Hofmann 2018). The dynamic environment of markets and the resulting complexity mean that companies need to make faster and better

decisions to remain competitive in the long term. But decision-making processes can take weeks or even months, and decisions are often based more on intuition rather than hard data (Schuh et al. 2017).

However, the purely technological approach to the subject entails costly risks. Only the integration of the various individual technologies into a holistic digital strategy creates efficiency and new growth areas. To exploit the full potential of I4.0 in the manufacturing industry, companies must therefore take a strategic perspective on the technological options and adapt the company's organizational structure and culture. And they need to do this across the various corporate functions (Schuh et al. 2017; Deloitte 2016).

This paper aims to counteract this threat by providing a concept for the qualitative and quantitative assessment of the economic benefits of digitization and I4.0 projects in the manufacturing industry. This is intended to enable companies to make a quick, meaningful and reasonable decision on the implementation of a project based on the corporate strategy as early as the idea generation phase, thus preventing costly misinvestments.

2. Foundations of evaluation concepts

In the context of project evaluation, there is a fundamental problem of adequate method selection. For a successful project evaluation, not only quantitative but also qualitative aspects, such as strategic importance and economic benefits as well as the simultaneous consideration of multiple evaluation criteria are of great importance. Depending on the evaluation situation, different methods are applied. In this context, evaluation methods can contribute to ensure that decisions about starting, stopping or interrupting projects are not based on purely subjective, uncontrolled judgments of individual persons. To ensure this systematic and transparent evaluation of projects, a distinction can be made between one-dimensional, multidimensional and comparative evaluation methods (Kunz 2007). Within the literature, however, it is also possible to find further categorizations of project evaluation methods (Fornauf 2015; Knospe 1998; Baldegger 2007).

The figure below provides an overview of the potentially applicable evaluation methods assigned to the respective categories.

One-dimensional Evaluation Methods	Comparative Evaluation Methods	Multi-dimensional Evaluation Methods
Internal Rate of Return	Analytical hierarchy process	Scoring models (Utility-value analysis)
Net present value	Q-Sort	Portfolio models
Decision trees	Pair comparisons	Checklists
Risk analysis		
Payback period		
Project ROI		
Productivity index		
Sensitivity analysis		

Figure 1: Types of evaluation methods

When examining the different types of evaluation methods, it was found that multidimensional methods are best suited for the purposes of this master thesis. In contrast to one-dimensional methods, which focus almost exclusively on monetary aspects, multidimensional evaluation methods allow the simultaneous consideration of qualitative and quantitative evaluation criteria. Indeed, the goal of the concept to be developed is to make decisions not only on the basis of monetary aspects, but also to consider the strategic goals of a company.

However, the existing evaluation methods were not fully convincing. Here, among other things, an insufficient consideration of qualitative characteristics, a focus on monetary aspects as well as the lack of a holistic evaluation from different perspectives are to be criticized. The term "holistic" in this case refers to the evaluation of a project from multiple perspectives simultaneously, such as technological and economic aspects, feasibility, effort, legal and personnel issues, etc. After all, there is the risk that the manifold potentials of a project are not

sufficiently considered. In addition, many evaluation concepts require special expertise from the evaluators, such as controlling, and are also time- and cost-intensive. However, the intended concept has to be easily applicable by any "average engineer" with little effort.

3. Methodological procedure for developing a multidimensional evaluation concept

This chapter deals with the methodological procedure for developing a multidimensional evaluation concept based on the matrix diagram and is divided into two sections: Since the evaluation concept to be developed will have the structure of a matrix diagram, the basics of this instrument will be explained first. Subsequently, the methodological procedure for the development of such an evaluation concept will be presented and the individual steps will be explained in detail.

3.1 Matrix Diagram

Relationships between things are often complex (many-to-many) and require thinking in more than one dimension. Especially in digitization projects, there are various factors, such as technical, economic or management factors, whose interaction contributes decisively to the success of a project. Without considering these different dimensions, it is not possible to make a reliable statement about the benefits or prospects of success. In such projects, the matrix diagram is a suitable instrument for analyzing relatively complex issues in a simple and straightforward manner (ASQ; Tague 2005).

The matrix diagram is one of the seven new management and planning tools developed in 1976 by the Union of Japanese Scientists and Engineers (JUSE). It is used to identify, analyze and illustrate the existence and strength of relationships between two or more data sets and provides a compact way of representing many-to-many relationships with different strengths (ASQ; Tague 2005). It is particularly useful for investigating the relationships between (Burge 2006):

- a set of vague and non-measurable items with a set of precise and measurable items (such as connecting customer requirements with technical requirements)
- two sets of items that are physically different (such as design solutions for a set of technical requirements)

The purpose of this diagram is to relate two or more sets of variables or lists of items to each other (Silverman and Silverman 1994) and helps to understand complex causal relationships more easily by exposing interactions and dependencies between things (ASQ).

There are five basic types of matrix diagrams that allow different numbers of lists to be examined and one additional type (roof-matrix, also QFD - Quality Function Deployment) (Burge 2006). Each matrix is named after its configuration, which indicates the number of variable sets or article lists it contains. In the body of the matrix, various information can be displayed, such as the strength of the relationships, the degree of involvement and directional dependencies, etc. This is done according to the type of symbols used to create the matrix. The designation of the relationships is entered into the cells of the respective intersection (Silverman and Silverman 1994).

The five basic types of matrix diagrams are:

Table 1: Types of matrix diagrams

Shape	Groups	Explanation
L-matrix	2 groups	A ↔ B (or A ↔ A)
T-matrix	3 groups	B ↔ A ↔ C but not B ↔ C
Y-matrix	3 groups	A ↔ B ↔ C ↔ A
C-matrix	3 groups	All three simultaneously (3D)
X-matrix	4 groups	A ↔ B ↔ C ↔ D ↔ A but not A ↔ C or B ↔ D
Roof-matrix / QFD	1 group	A ↔ A when also A ↔ B in L or T

3.2 Procedure for developing an evaluation concept according to a matrix diagram

The basic structure of the intended evaluation concept for the qualitative and quantitative assessment of digitization and I4.0 projects is based on a matrix diagram. For the development of this concept, an approach consisting of seven basic steps has been followed, which is shown schematically in Figure 1. The steps were

developed following the process of creating a matrix diagram according to (Burge 2006). The individual steps are described in detail below.
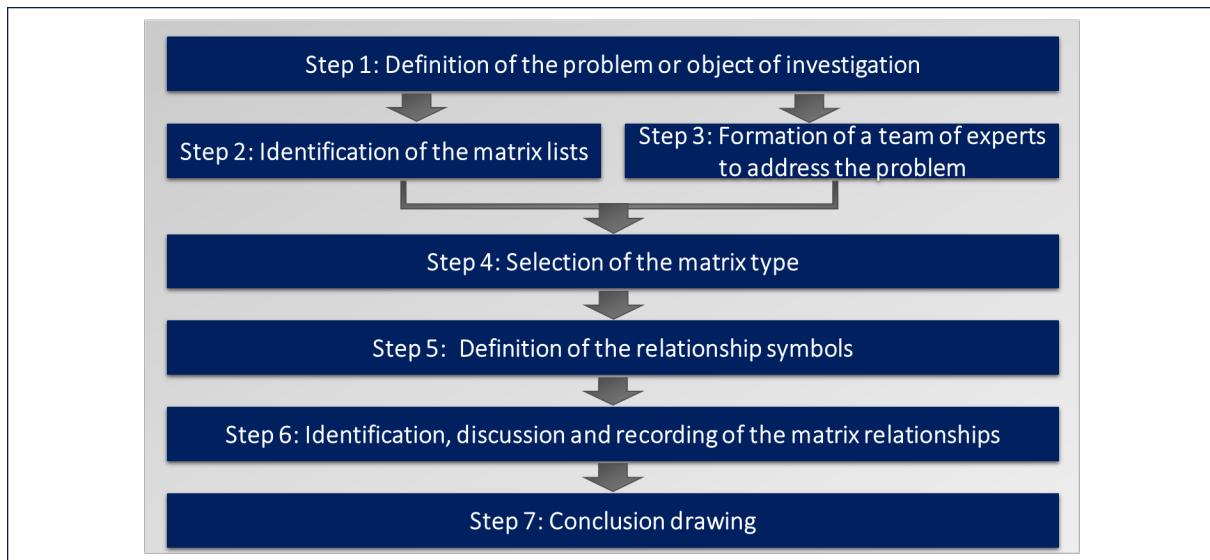

Figure 2: Methodical procedure for the development of an evaluation concept for benefit assessment according to a matrix diagram [own illustration]

Step 1: Definition of the problem and object of investigation
The application of a matrix diagram requires clarity about the problem to be investigated, the focus of the investigation and the general conditions. Furthermore, a uniform understanding of terms, especially with regard to technological aspects, is of great importance.

Step 2: Identification of the evaluation criteria and matrix lists
In an earlier work, the examination of existing evaluation concepts mainly revealed that either qualitative evaluation criteria are insufficiently considered in contrast to quantitative monetary evaluation criteria, or that the evaluation is only carried out from one perspective, e.g. the economic promise of success (Hizal 2020). An important prerequisite for the evaluation concept to be developed is therefore to address exactly these points of criticism and enable a multi-perspective evaluation on the basis of qualitative and quantitative criteria.

To develop a suitable evaluation concept, it is therefore first necessary to carefully examine the research focus and to identify the characteristic elements in relation to the required perspectives of the subject area. These may have technical, legal or economic characteristics, for example, and have to be determined individually depending on the focus of the investigation. Thus, the matrix lists result directly from the purpose of the object of investigation and contain the evaluation criteria derived from their characteristic elements.

The characteristic elements from a technological perspective are (Hizal 2020):

- Key drivers of Industry 4.0
- Enabling technologies of Industry 4.0
- Central features of Industry 4.0
- Digitization-affected innovation areas (Application areas)

Since these are only characteristics that reflect the technological perspective of the assessment, it is also important to identify characteristics that illuminate the economic perspective of the object of investigation that will also be integrated into the concept as evaluation criteria. This is necessary to ensure multidimensionality.

To identify the characteristic elements from an economic perspective, the benefits and challenges of digitization and I 4.0 have been identified using an extensive literature research and then prioritized. Prioritization was done in a group discussion with three experts who are at least Green Belt certified engineers and/or team leaders. These were then analyzed together with the characteristic elements from a technological perspective for their suitability as evaluation criteria. This validation was carried out by evaluating a total of 100 already successfully established practical examples on the basis of the defined potential evaluation criteria. The aim was to check whether it is possible to evaluate the practical examples on the basis of the identified evaluation criteria.

The results of this analysis have shown that the identified characteristic elements from an economic perspective indeed represent benefits of digitization and I4.0 projects. Based on these elements, the qualitative and quantitative benefits of digitization and I4.0 projects can be described and evaluated. Since a high number of the use cases examined originate from the manufacturing industry, they are particularly suitable as criteria for the evaluation of projects in this area. However, it is important to note that these benefits are only general examples for initiating digitization and I4.0 projects and should be revised depending on the project being evaluated.

Thus, the final list of evaluation criteria from an economic perspective is as follows:
- Automatization / Optimization of production processes
- Cost reduction
- Efficiency / Productivity
- Flexibility / Agility
- Individualization
- Quality Improvement
- Standardization
- Transparency / Strategic decision support

Step 3: Formation of a team of experts to address the problem
The expert team for carrying out the evaluation needs to be formed in parallel with the preparation of the matrix lists. This step is thus linked to step 2 and must be done before its completion. Regardless of the composition of the team, it needs to have the expertise and experience to be able to relate the lists to each other, i.e. to carry out the evaluation.

It is also important that the members of the expert team have different levels of expertise depending on the project and reflect the different hierarchical levels of a company. For example, in addition to engineers who can assess the technological aspects, managers with the appropriate decision-making authority should also be represented. The aim is to avoid concentrating only on certain aspects of the investigation, such as the technological innovation capability of a project (engineer side) or cost reduction (management side), and thus shifting the focus. Decisions need to be made under a holistic consideration of multiple aspects, such as economic advantages or the necessity of implementing a project. It is also intended to avoid time-consuming discussions and to make decisions quickly.

Step 4: Selection of the matrix type
The matrix type depends on the number of lists created in step 2 and the dimensions to be examined. The different types of matrix diagrams have already been shown in section 3.1.

Step 5: Definition of the relationship symbols
The relationship symbols fulfil two tasks:
- Indication of the existence of a relationship
- Information about the strength of the relationships

If the existence of a relationship is to be pointed out, it is possible to use any symbol for it. In most cases, however, both the existence and the strength of a relationship need to be examined. This can be done using a symbolic or numerical method. Examples for these methods are shown in the following table:

Table 2: Methods to display the existence and strength of relationships

Strength of the relationship	Symbolic Method	Numerical Method
Strong relationship	**Δ**	9
Medium relationship	□	3
Weak relationship	o	1
No relationship	-	0

When using the numerical method, other values can be chosen to show the strength of a relationship and the existence of negative relationships (e.g. -1, -3, -9). However, with this method there is the risk of using relative values or values with different ranges, which can be the trigger of constant recalibration.

Step 6: Identification, discussion and recording of the matrix relationships
The core of a matrix diagram is the identification, discussion and recording of matrix relationships in a team of experts from the subject area under investigation. A systematic approach is essential when examining possible relationships and their strength. The way of proceeding, whether row by row or column by column, depends largely on the situation and the placement of the core list. If the core list is located on the vertical axis, a line-by-line approach is often the most appropriate.

Each relationship should be considered in turn, and the presence as well as the strength debated until the team reaches a consensus. Since symbols are a measure of relative strength, it can be useful to quickly scan a row (or column) to determine the strongest relationship to which a particular symbol can be assigned. In this way, a kind of calibration is performed to match the other symbols and the consensus.

In addition to recording the presence and strength of relationships in the matrix diagram, the documentation of the resulting decisions is also of great importance. This fulfills a verification function to enable transparency and traceability of the decision made and is especially valuable in long or open debates about a relationship.

Step 7: Drawing conclusions
After completion of the matrix diagram, conclusions about the purpose of the investigation need to be drawn and communicated to the authorities concerned.

4. Conceptual design of the evaluation concept

This chapter describes the conceptual design of the planned evaluation concept. Three categories have been identified that are of great importance for evaluating the benefits of digitization and I4.0 projects. These are:
- **Enablers/Technologies/Methods:** Technologies related to digitization/Industry 4.0 or enablers of such technologies, as well as methods for implementation
- **Application Areas:** Areas strongly influenced by digitization/Industry 4.0
- **Advantages:** Potential benefits that can be generated by implementing digitization/Industry 4.0 projects

4.1 Matrix lists
The basic structure of the evaluation concept consists of a matrix diagram, presented in section 3.1. Since three categories have been identified which serve as evaluation dimensions, the matrix diagram can have the Y, T or C shape. Therefore, it is now necessary to determine which relationships are to be examined to evaluate the economic benefits of digitization and I4.0 projects in order to decide on the shape of the matrix diagram. The following options are available:
- Advantages $\leftrightarrow$ Technologies
- Advantages $\leftrightarrow$ Application Area
- Technologies $\leftrightarrow$ Application Area

The main focus of the analysis is to evaluate the economic benefits of digitization and I4.0 projects. This can be done from two angles: 1. Directly from the dimension "Advantages" or 2. Indirectly from the "Application Area". The latter covers areas of a company or organization that are experiencing structural changes in the form of innovations as a result of digitization or I4.0 and thereby generating benefits. Since two dimensions of potential benefits would be related, it is not purposeful to examine the correlation between the categories "Advantages vs. Application Area" in this respect. Therefore, only the category "Technologies" is individually related to each of the categories "Advantages" and "Application Area". From this it can be deduced which concrete technologies contribute to the generation of a certain benefit as well as in which application areas a benefit can be generated by these technologies. This corresponds to the matrix diagram of type T.

In the following, the three categories mentioned are further detailed.

4.1.1 List 1: Enablers, Technologies and Methods
One technology alone does not generate benefits. The technological possibilities of I4.0 can be transformed into benefits most efficiently by the collaborative application of various technologies (including conventional technologies) with their enablers. This can also be supported by different methods. For this reason, the list 1 of the T-matrix was subdivided into the clusters Enablers, Technologies and Methods.

Enablers refer to the technological and human resources that enable digitization. Examples for such technological enablers are:

- Big Data Analytics
- CPS
- Real time capability
- Employee qualification

The **Methods** are rather process models or approaches for the efficient design of the entire value chain of industrial goods as well as for the efficient solution of problems and development of new ideas. Example methods are:

- Design Thinking
- Agile Working (e.g. Scrum, Kanban Flowlines)
- Lean Management

The category **Technologies** is divided into the three levers of digital transformation (Hizal 2020), namely Automatization, Digitization and Networking. This division and the assigned examples are shown in Figure 4.
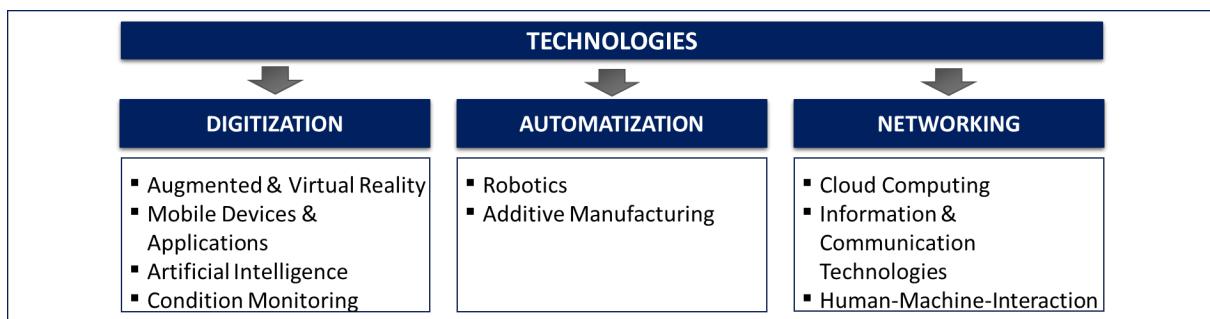

Figure 3: Evaluation Matrix: Technologies cluster [own illustration]

4.1.2 List 2: Application Areas
List 2 for the dimension "Application Area" is subdivided into three levels: Business, Product and Process (Hizal 2020). Exemplary contents for the three levels are shown in the following figure.

Figure 4: Evaluation Matrix: Application Area cluster [own illustration]

Projects in the field of digitization and I4.0 generate innovations with disruptive character, especially in the three areas of business, product and process. It therefore makes sense to continue this classification in the evaluation concept.

Furthermore, such a classification can be used to determine to what extent and with which effects the individual areas of a company are influenced and which (positive or negative) side effects occur on the other levels. Depending on the purpose of the evaluation, it is possible to make a finer or coarser division of the category "Application Area" to respond specifically to the needs of the investigation. For example, the "Business" level could be divided into the different parts of a company – sales, purchasing, engineering, etc. – or the "Product"

level could be divided into the different product life cycles from development to sales, as well as into the specific components.

4.1.3 Advantages

The following advantages of digitization projects, which are listed in Figure 6, were identified in an earlier work and validated by an analysis of practical application examples. The achievable advantages can be divided into product-related and process-related advantages. However, it is also possible to assign some of these advantages to both categories.
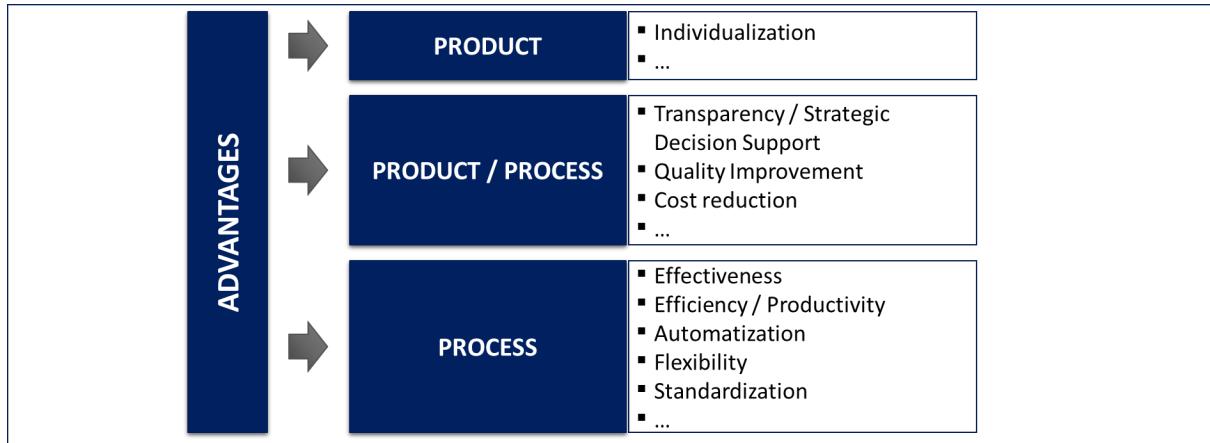

Figure 5: Evaluation Matrix: Advantages cluster [own illustration]

The advantages listed here represent merely a list of possible benefits of digitization projects, which need to be dynamically adapted (supplemented or shortened) to the purposes of the object of investigation. In a preparatory session, the evaluation team should define the benefits to be achieved by the planned project and conduct the evaluation based on these benefits.

4.2 Weighting and direction of the evaluation

For an efficient and meaningful evaluation, not only the matrix lists to be examined are of great importance, but also the determination of the relationships between these lists. Therefore, in section 3.2 various approaches to prove and display the existence and strength of the relationship between two variables were presented. When using the numerical variant, it is additionally possible to perform a weighting and then to sum up the values of the relationships.

For the evaluation concept developed in this work, two numerical weighting scales were used:
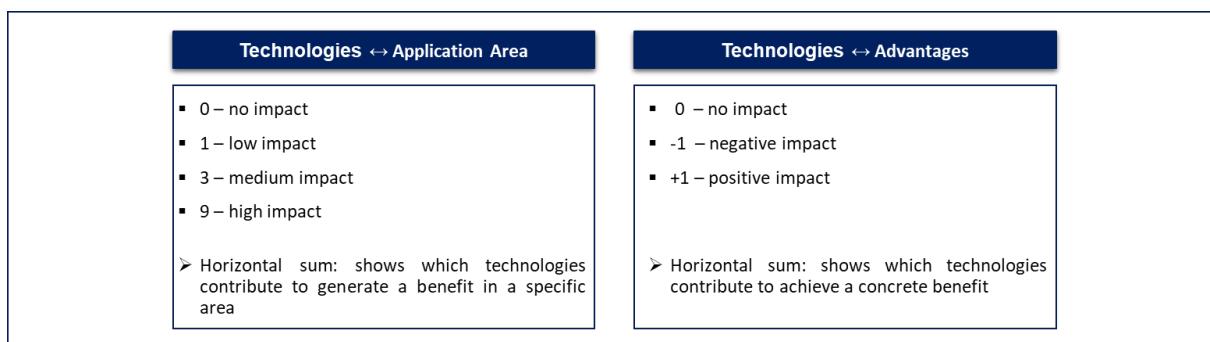
Figure 6: Weighting scales to show the relationship between the lists [own illustration]

To determine the relationships between the lists "Technologies vs. Application Area", a scale from 0 - 9 with "no impact" to "high impact" was defined. The aim of this evaluation is to identify the potential impact and thus the potential benefit of a project on an application area. Indeed, digitization and I4.0 solutions are associated with structural and disruptive changes for the application areas. However, these structural changes can have not only positive but also negative effects, as well as side effects on other areas. Therefore, it is recommended to consider reviewing negative effects.

To evaluate the relationships between the lists "Technologies vs. Advantages", a weighting scale with the options "-1", "0" and "1" was created. This is used to examine whether a particular technology is suitable for achieving a certain desired benefit and whether it has a negative impact on other benefits.

When investigating possible relationships and their strength, a systematic approach is essential. In this case it is appropriate to examine the relationships between the lists line-by-line. There are two reasons for this: 1. The core list (here: Enablers/Technologies/Methods) is located on the vertical axis and 2. At the end of the evaluation, the sum of the weightings has to be formed so that the achievable benefits and the application areas for benefit generation can be determined based on an overall score. Thus, it is possible to identify at a glance whether the proposed project is suitable for achieving the targeted benefits in the planned application area. Furthermore, it is also possible to make a statement about which technologies can be used to generate these benefits.

This leads to two directions, which have to be considered in the evaluation: The analysis direction and the weighting direction. When analyzing the relationships between the lists, the core list (List1: Enablers, Technologies, Methods) is related to the two other lists "List 3: Advantages" and "List 2: Application Areas". To derive an overall result about the areas impacted or the achievable benefits, the horizontal sum needs to be calculated. The evaluation directions are illustrated in Figure 8.
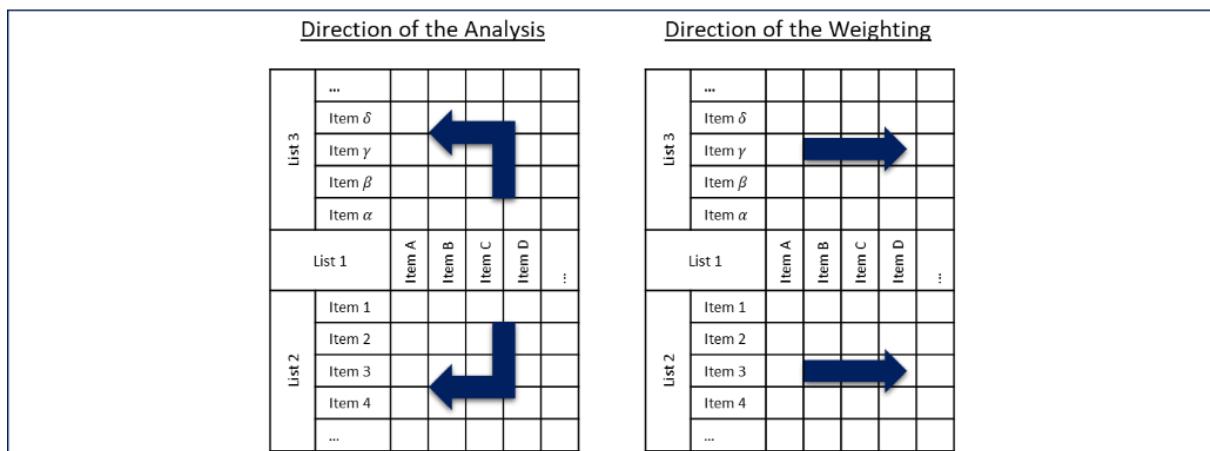
Figure 7: Evaluation directions [own illustration]

4.3 Formation of the evaluation template
If these presented components are combined, a matrix for the qualitative and quantitative assessment of the economic benefits of digitization and I4.0 projects can be compiled that is specifically tailored to the needs of the manufacturing industry. The template of the evaluation matrix is shown in Figure 9:

Figure 8: Template of the evaluation matrix

5. Summary & Outlook

This paper describes the methodological approach for developing a qualitative and quantitative evaluation concept for assessing the benefits of digitization and Industry 4.0 projects that is specifically tailored to the requirements of manufacturing companies. The evaluation concept is based on a matrix diagram and enables a multidimensional evaluation that does not require any special knowledge but can be carried out in a team of experts consisting of different disciplines to evaluate the profitability of a project or to prioritize different alternatives. The evaluation concept has already been applied and validated in various application examples. Since it is a very dynamic and flexible tool and the matrix lists have to be updated depending on the case, the tool can also be used in other fields and is therefore not limited to the manufacturing industry.

For the future, a further development of the evaluation concept is planned to the effect that the matrix lists are also correlated on the vertical axis to allow even deeper insights.

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