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Stakeholder Identification for Manufacturing Change Management

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Editors' Preface

In times of global challenges, such as climate change, the transformation of mobility, and an ongoing demographic change, production engineering is crucial for the sustainable advancement of our industrial society. The impact of manufacturing companies on the environment and society is highly dependent on the equipment and resources employed, the production processes applied, and the established manufacturing organization. The company's full potential for corporate success can only be taken advantage of by optimizing the interaction between humans, operational structures, and technologies. The greatest attention must be paid to becoming as resource-saving, efficient, and resilient as possible to operate flexibly in the volatile production environment.

Remaining competitive while balancing the varying and often conflicting priorities of sustainability, complexity, cost, time, and quality requires constant thought, adaptation, and the development of new manufacturing structures. Thus, there is an essential need to reduce the complexity of products, manufacturing processes, and systems. Yet, at the same time, it is also vital to gain a better understanding and command of these aspects.

The research activities at the Institute for Machine Tools and Industrial Management (iwb) aim to continuously improve product development and manufacturing planning systems, manufacturing processes, and production facilities. A company's organizational, manufacturing, and work structures, as well as the underlying systems for order processing, are developed under strict consideration of employee-related requirements and sustainability issues. However, the use of computer-aided and artificial intelligence-based methods and the necessary increasing degree of automation must not lead to inflexible and rigid work organization structures. Thus, questions concerning the optimal integration of ecological and social aspects in all planning and development processes are of utmost importance.

The volumes published in this book series reflect and report the results from the research conducted at iwb. Research areas covered span from the design and development of manufacturing systems to the application of technologies in manufacturing and assembly. The management and operation of manufacturing systems, quality assurance, availability, and autonomy are overarching topics affecting all areas of our research. In this series, the latest results and insights from our application-oriented research are published, and it is intended to improve knowledge transfer between academia and a wide industrial sector.

Rüdiger Daub　　Gunther Reinhart　　Michael Zäh

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This dissertation is the result of my work as a research associate at the Institute for Machine Tools and Industrial Management (*iwb*) at the Technical University of Munich (TUM).

I would like to take this opportunity to thank all persons who have accompanied and supported me during this project. This dissertation would not have been possible alone, or at least it would have been a lot less fun.

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My time at *iwb* was one of the most challenging, exciting, but, above all, most enjoyable times in my professional career to date. This was primarily due to my exceptional colleagues at the *iwb* and especially in the department of Production Management and Logistics. During my time as a research associate and also as a group leader, I could always rely on your collegiality, your expertise, and your honest feedback. We have worked and achieved a lot together, but we also experienced many memorable moments outside of work. It was a pleasure and an honor to work with you!

On a personal note, I would like to thank my parents, Albert and Barbara, my grandparents, and my girlfriend Pia for their unconditional support over the years.

Garching, September 2024 Fabian Sippl

Contents

List of Abbreviations and Acronyms

Abbreviation	Term
AI	Artificial Intelligence
BPMN	Business Process Modeling and Notation
CIA	Change Impact Analysis
CIRP	College International pour la Recherche en Productique
CM	Change Management
CP	Change Profile
CRISP-DM	Cross-Industry Standard Process for Data Mining
CRP	Change Responsibility Profile
CSA	Change Similarity Assessment
DRM	Design Research Methdology
DSI	Descriptive Study I
DSII	Descriptive Study II
EC	Engineering Change
ECM	Engineering Change Management
ERP	Enterprise Resource Planning
FN	False Negative
FP	False Positive
HR	Human Resources
IT	Information Technology
KPI	Key Performance Indicator
L*	Life Cycle Model of Process Mining Projects
LR	Literature Research
MC	Manufacturing Change
MCM	Manufacturing Change Management
ML	Machine Learning

NLP	Natural Language Processing
OC	Organizational Change
OCM	Organizational Change Management
PDM	Product Data Management
PM	Process Mining
PS	Prescriptive Study
RASCI	Responsible Accountable Supportive Consulted Informed
RC	Research Clarification
SI	Stakeholder Identification
SM	Stakeholder Management
SOM	Self-Organizing Maps
STEP	Standard for the Exchange of Product Data
TCM	Technical Change Management
TN	True Negative
TP	True Positive
TUM	Technical University of Munich
UML	Unified Modeling Language
VBA	Virtual Basic for Applications
VUCA	Volatility Uncertainty Complexity Ambiguity
XES	eXtensible Event Stream

1 Introduction

"The world hates change, yet it is the only thing that has brought change."
Charles Kettering

1.1 Motivation

Drastic political, societal, cultural, and economic changes have occurred worldwide in recent years. First, the intensifying consequences of climate change have led many movements to campaign for higher environmental protection. This request also involves a change in the behavior of consumers and companies (GARETTI & TAISCH 2012). Secondly, the global COVID-19 pandemic caused the collapse of global supply chains that had long been considered robust. This uncertain supply situation requires companies and consumers to be able to react rapidly to new circumstances. Third, the pandemic also accelerated the shift to digital and remote working. This opened up new opportunities for companies to reorganize business processes and the collaboration of their employees (ARDOLINO ET AL. 2022). Fourth, in the last 30 years, globalization opened access to new markets and caused intensified global competition. It also allowed companies to distribute their value-adding processes worldwide. However, military conflicts and political drifts are leading today to opposite tendencies. Companies are considering relocating value-creating activities to politically and economically stable regions (FERNÁNDEZ-MIGUEL ET AL. 2022). These examples illustrate that individuals, societies, and companies face a rapidly and fundamentally changing environment and must respond efficiently and effectively.

The concept of the VUCA environment conceptualizes the volatility, uncertainty, complexity, and ambiguity of the described environment (BENNIS & NANUS 1985). It forces manufacturing companies to adapt to new requirements by changing their factories or products in parallel with intense global competition. Therefore, the ability to cope with change is considered a decisive factor for the success of these companies (ELMARAGHY 2009, p. 6).

The necessity for changes is caused by manifold factors such as the factory life cycle, legislation, technological innovations, or changing consumer demands. These factors act on and within the company and trigger the so-called change receptors, which transmit changes in the environment to the factory and the production system (CISEK ET AL. 2002). Examples of receptors are the product, quantity, or quality. This chain of effects from the environment via the receptors to the factory ultimately causes deviations between the target and the actual state of the factories (cf. Figure 1). To overcome these deviations, companies are forced to apply changes to the product (Engineering Change) (HUANG & MAK 1999), the organization (Organizational Change) (GRAETZ & SMITH 2010), and the factory (Manufacturing Change) (STANEV ET AL. 2008). An example of a MC is the replacement of existing machines with more energy-efficient alternatives triggered by new environmental regulations. The processes of organizing the different change types are accordingly called Engineering Change Management (ECM) (JARRATT ET AL. 2011), Organizational Change Management (OCM) (ERRIDA & LOTFI 2021), and Manufacturing Change Management (MCM) (KOCH 2017).

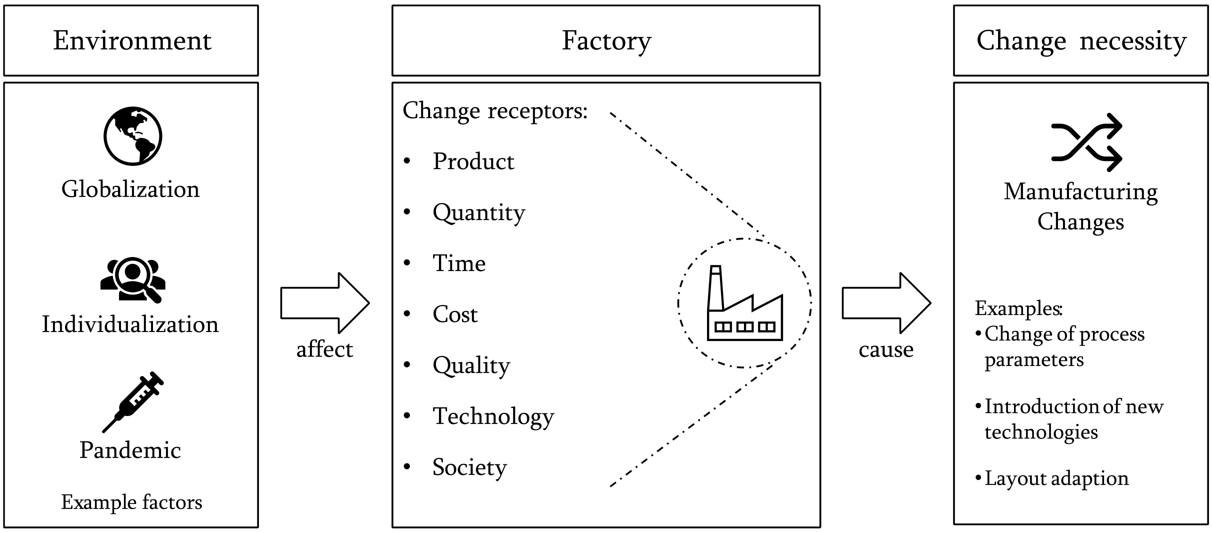

Figure 1. The emergence of the need for MCs.

The handling of product changes has been the focus of research for decades. Numerous process-oriented approaches have been developed for this purpose (e.g., WICKEL ET AL. 2015, AßMANN 2000, PFLICHT 1989). They aim to improve different aspects of ECM, e.g., the consideration of changing customer requirements in a late phase of the development process. In addition, methods were introduced to support individual steps within ECM, e.g., the evaluation of change alternatives (CLARKSON ET AL. 2004).

In contrast to ECM, the research interest concerning the handling of MCs developed later. An increasing interest in specialized approaches emerged after ProSTEP iViP was one of the first to introduce the concept of MCM in 2014 (PROSTEP IVIP E.V. 2014). This interest was confirmed by the introduction of specific methods and processes in the following years (e.g., PLEHN ET AL. 2016). The work of KOCH (2017) should be emphasized, as it extensively and in detail describes the process of MCM with relevant roles and deliverables. This process is divided into the proactive, reactive, and retrospective phases in reference to ECM. In the reactive phase, possible solutions to resolve the reasons for change are identified and evaluated, e.g., concerning the expected costs or risks, and finally planned as well as implemented. This task is crucial for efficient management of changes and is called Change Impact Analysis (CIA) (PLEHN 2017, p. 3).

The CIA is tailored to the change object, i.e., the system that is being modified. The change object of MCs is the factory, which represents a complex system with a large number and variety of elements that are involved in diverse and dynamically changing cause-and-effect relations (PLEHN 2017, p. 21). These characteristics imply that changes can affect all factory areas, with direct, indirect, and often unintended consequences. Therefore, an efficient communication during MCM necessitates the identification of all relevant employees and departments. This task is in the following referred to as Stakeholder Identification (SI). It is especially relevant for the evaluation and selection of change alternatives as well as the subsequent planning and implementation. Failure to consider relevant stakeholders may lead to high financial and time expenditures, e.g., through production stops or delays in change implementation (RÖßING 2007, p. 3). Wickel (2017, p. 88) states from an ECM perspective that by not integrating relevant stakeholders, "change impacts may not be fully considered, which may lead to significant and cost-intensive wrong decisions".

A recent survey with 99 respondents investigated the application of MCM in the industry (RAMMO & GRAF 2023, pp. 421-423). The results are illustrated in Figure 2.

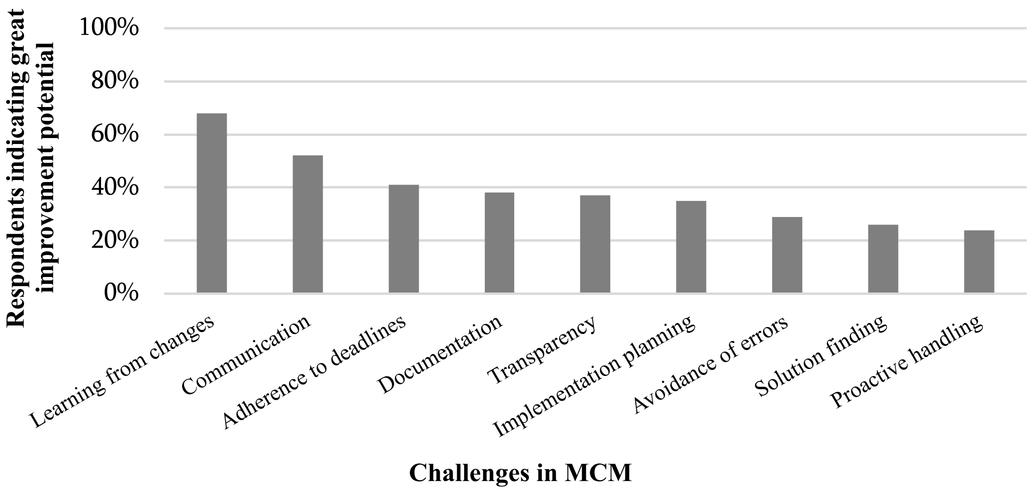

Figure 2. Improvement potentials in the domain of MCM based on the survey by RAMMO & GRAF (2023).

The survey revealed that 84% of manufacturing companies use a structured process to manage MCs, and 73% of companies conduct a CIA. However, the CIA is still primarily based on expert estimates. The general importance of MCM is also confirmed, as 94% of respondents stated that MCM will become important or very important in the next five to ten years. The survey also analyzes improvement potentials in MCM. The experts indicated great improvement potential in learning from past changes (68%) and in the communication within the process (52%).

Data-based approaches are considered a potential approach to learn from past changes (PLEHN 2017, p. 159). They have already illustrated their value in the field of ECM and MCM (RIESENER ET AL. 2021, WICKEL & LINDEMANN 2015, DO 2018). The general prerequisite for these approaches is the use of digital systems in Change Management and the storage of the resulting data. The majority of manufacturing companies (89%) use digital tools, such as SAP, Excel, or workflow management tools (RAMMO & GRAF 2023, p. 422). The reason for the high penetration of Change Management by digital tools is, on the one hand, the more efficient organization of the MCM process which affects a multitude of areas in the company. On the other hand, legal requirements demand detailed documentation of changes, e.g., in the medical technology industry. The wide spread of digital tools implies the availability of change data describing individual changes, such as the title and the description of the change, and of change process data describing who did what in the process (WICKEL 2017, p. 27). Therefore, the current status quo of the manufacturing industry fulfills the prerequisites for using data-based approaches for SI in Change Management.

In summary, the communication during MCM offers room for improvement. In particular, failing to integrate all relevant persons and departments during the CIA represents a high risk of unnecessary financial and time expenditures. Only a few approaches address the SI task. They either originate from the field of ECM or do not actively support the SI for a specific change to be evaluated but instead provide basic communication guidelines (e.g., KOCH 2017, p. 233). In addition, the potential of data-driven approaches has not yet been sufficiently exploited which opens up new research opportunities for learning from past changes and supporting SI in MCM.

1.2 Objectives

Existing literature from the fields of ECM and MCM emphasizes the need to identify and integrate all relevant stakeholders in MCM. The task's importance is generally confirmed for ECM, MCM, and particularly for the analysis of change impacts (WICKEL 2017, p. 88, RÖßING 2007, p. 3, KOCH 2017, p. 16). Despite the importance of SI, preliminary work has yet to focus on providing suitable approaches for change-specific SI in MCM which consider different change scenarios and leverage the possibilities of data-based methods.

Knowledge from three central domains is necessary to address this research gap. The first domain addresses the factory system, representing the change object under consideration. Its high complexity is a key challenge for the success of change initiatives. It is to understand the factory system's functions, such as assembly or quality management, and their dependencies. The factory system's complexity must be considered during change processes. The second area, therefore, deals with Change Management in factories. On the one hand, this domain addresses the change process, i.e., the process steps and tasks. On the other hand, the groups of employees involved in the change process must be considered. This includes the employees organizing and implementing the changes. Knowledge about their challenges and requirements is necessary to ensure the usefulness of the intended support. The third domain relates to the digitalization of the manufacturing industry. The majority of companies use digital tools to organize their change processes. An understanding of the digital landscape in manufacturing and the opportunities for exploiting the resulting data is required to enable data-based support for SI in MCM.

This thesis builds on these knowledge elements and pursues the primary objective ***of supporting change managers in effectively identifying relevant stakeholders before the assessment of change impacts. This should improve communication in the MCM, reduce the number of not-considered change impacts, and provide the basis for an effective comparison of change alternatives.***

In general, research differentiates five different strategies for dealing with changes to the product and factory (FRICKE ET AL. 2000): prevention, front-loading, efficiency, effectiveness, and learning. This thesis primarily addresses the last three, as it aims to make change planning more efficient and effective by learning from past changes. Effectiveness refers to the "evaluation of changes in terms of their necessity and usefulness with the aim of rejecting uneconomical changes at an early stage"[1] (WICKEL 2017, p. 20). Efficiency refers to the necessary effort and the time required to implement changes. The learning strategy focuses on creating knowledge about past changes to improve the handling of new changes.

Figure 3 illustrates the effects of the intended SI approaches in an initial impact model as proposed by BLESSING & CHAKRABARTI (2009). First, an improved SI supports the CIA as more relevant stakeholders contribute their expertise. This helps companies to select and plan upcoming changes more efficiently. Second, the communication in the MCM process is supported by incorporating all relevant stakeholders. It ensures an effective information flow between all relevant stakeholders. Third, the intended use of change data directly contributes to the strategy of learning from past changes. This strategy is acknowledged as a leverage to improve MCM's efficiency and effectiveness. An efficient management of changes can positively impact customers, e.g., through faster response to customer requests.

[1] Translated by the author. Original text: "Bewertung von Änderungen hinsichtlich ihrer Notwendigkeit und Nützlichkeit mit dem Ziel, unwirtschaftliche Änderungen früh abzulehnen" (WICKEL 2017, p. 20).

In conclusion, an improved ability to handle changes can increase the companies' competitiveness.

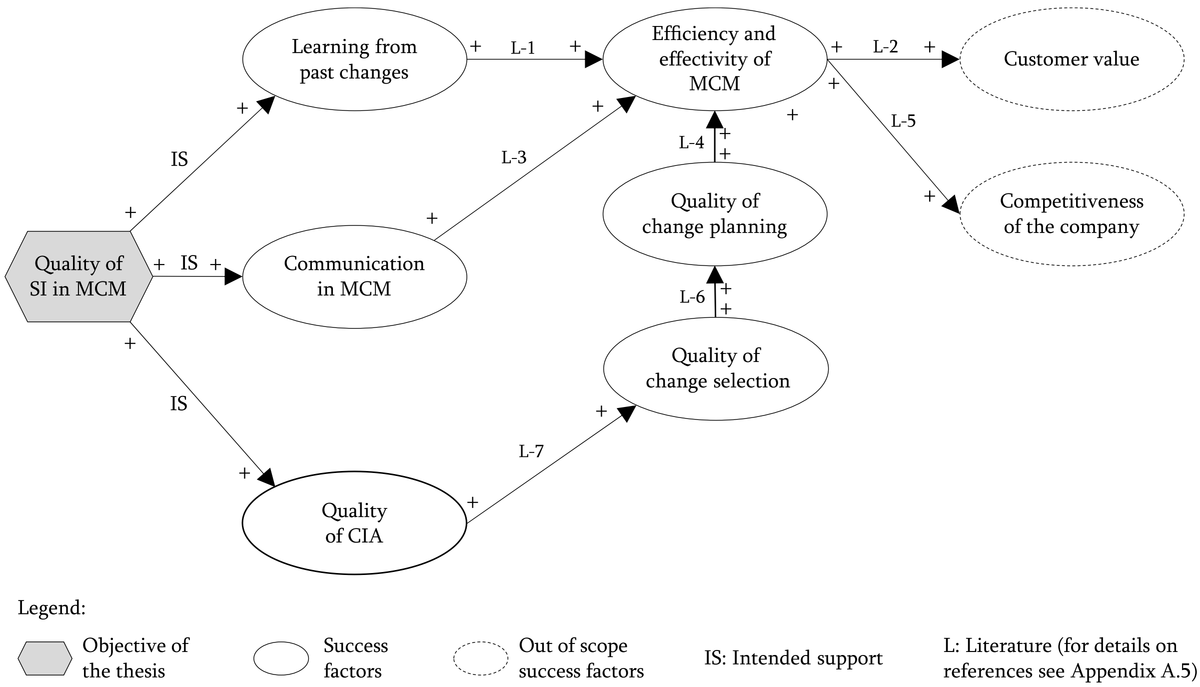

Figure 3. Initial impact model based on BLESSING & CHAKRABARTI (2009) and DEL RÍO TREVIÑO (2021).

Three sub-goals must be achieved to support the identification of relevant stakeholders in MCM and to make a contribution to the research domain of MCM and the industrial handling of MCs:

SO1: Differentiation of relevant scenarios for SI in MCM

The possibilities for Stakeholder Identification in MCM largely depend on the availability of change data within the company under consideration. Therefore, SI scenarios shall be introduced which differentiate the data availability. A scenario-dependent selection of SI approaches shall allow companies a flexible and efficient handling of MCs.

SO2: Conceptualization and introduction of approaches for SI in MCM

This thesis intends to provide support for the individual SI scenarios. The scenario's characteristics shall explicitly be considered during the conceptualization of solution approaches. The final approaches shall offer a structured procedure for the different SI scenarios.

SO3: Application and evaluation in an industrial context

The SI approaches shall be applied and evaluated in industrial use cases. These use cases shall incorporate realistic changes and data bases. Change Management experts familiar with the use cases shall carry out the evaluation to ensure valid conclusions about the approach's result quality and economic viability. A critical discussion of the obtained results shall be conducted to identify potentials for future research.

The primary target group of the SI approaches are change managers, who have the task of "delegating and approving/rejecting activities and deliverables during the MCM process" (KOCH 2017, p. 125). This task includes identifying departments, persons, and roles that should contribute to the CIA. Examples include the production planning department or a person responsible for a specific technology or production area.

1.3 Scenarios for Stakeholder Identification

Data-driven methods have the potential to support MCM, as mentioned in Section 1.1. This implies that, on the one hand, the general availability and accessibility of change and change process data must be considered an influencing factor. On the other hand, it is also necessary to take into account whether similar past changes have already been carried out. These changes represent a knowledge base from which new insights can be gained. SI, therefore, requires a flexible approach that takes into account data availability on a company-specific and change-specific perspective. This thesis differentiates three different SI scenarios to address this aspect. The scenarios and the decision process for method selection are visualized in Figure 4 based on the Business Process Modeling Notation (BPMN) (OMG 2014).

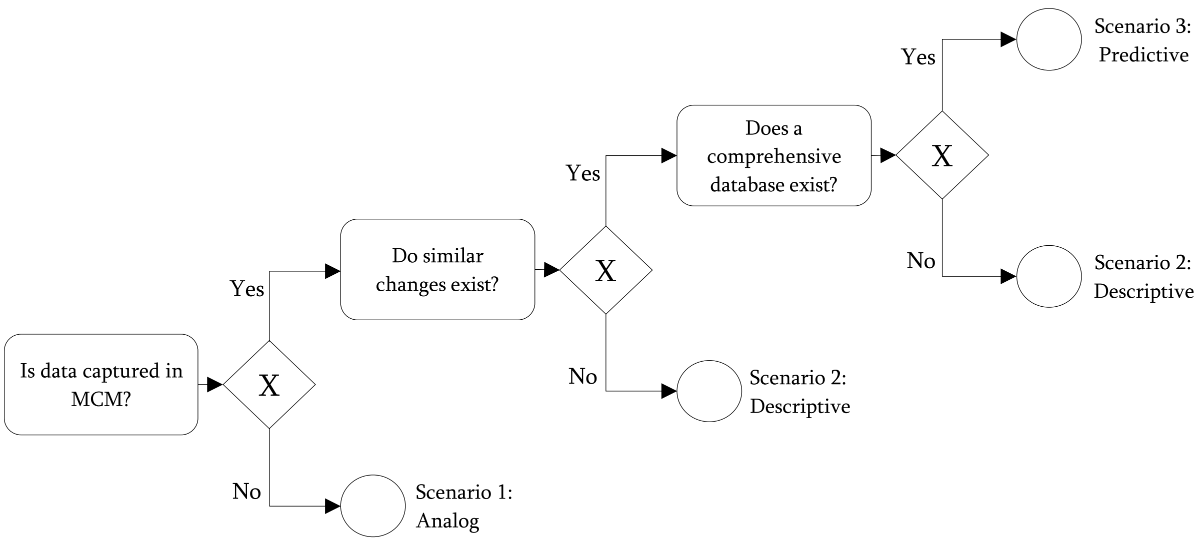

Figure 4. The decision process for the scenario-specific method selection.

This thesis addresses three scenarios: Analog, Descriptive, and Predictive. The analog scenario describes a situation in which no data is recorded in MCM by the company or no comparable changes to the one currently under consideration have been carried out. A SI is required for this scenario that does not rely on change data. Instead, it must provide support based on the change characteristics. The descriptive scenario occurs when only a small amount of change data is available, e.g., due to a generally low change volume. In this case, evaluating the data on similar past changes can provide an indication for the change manager. The predictive scenario requires a comprehensive database to enable an analysis of the implicit relationships between MCs and stakeholders. The objective of the predictive scenarios is to directly predict relevant stakeholders.

1.4 Scientific Approach

The following sections first characterize the field of research before outlining the chosen research methodology and its correlation with the structure of the thesis.

1.4.1 Scientific theoretical classification

Figure 5 presents a simplified overview of an innovation process. It can be seen that research is an essential prerequisite for the creation of innovations. The preliminary stage of an innovation is an invention, i.e., the discovery of previously unknown solutions to problems (VOIGT 2008, p. 369). An invention is often the result of research work, which is characterized by the basic principle of striving for new knowledge (SCHMOCH 2003, p. 59). Research itself is an essential part of science, which can be divided into formal sciences and empirical sciences. Formal sciences, such as philosophy or mathematics, are primarily concerned with the construction of sign systems. Within the empirical sciences, the basic science and the applied science can be distinguished (ULRICH & HILL 1976, p. 305). Basic science focuses on the explanation of empirical sections of reality without a specific practical application in mind. Applied action sciences consider the analysis of human action alternatives, aiming at the creation of new decision models and processes. Therefore, applied action sciences are directed toward a specific practical objective. The engineering sciences can be assigned to both areas and use findings from both areas, due to the variety of research questions (OECD 2015, pp. 47-54). Experimental development often follows the applied research (cf. Figure 5). This phase builds upon the findings from research and practical experience and generates the knowledge necessary for new products (OECD 2015, pp. 55-57). The innovation then refers to the sustainable use of the invention (VOIGT 2008, p. 369).

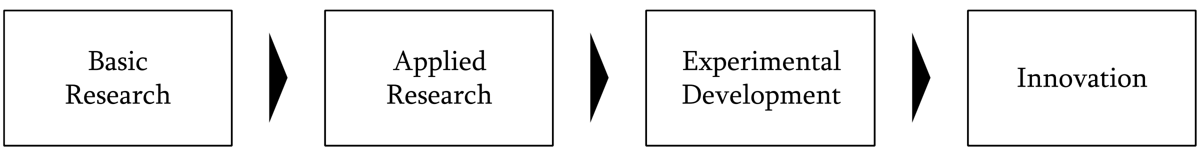

Figure 5. Simplified innovation process based on SCHMOCH (1996) and IRVINE & MARTIN (1984, p. 15)[2].

[2] The figure is based on the science-push model and describes a simplified (linear) form of the innovation process, e.g. without iterations or opposing information flows (MANLEY 2002).

This thesis deals with a specific decision problem, namely the identification of affected stakeholders for MCs. It aims for the introduction of new decision-support methods for this problem. Thus, it can primarily be assigned to the applied research sciences. However, there are also links to the adjacent phases of the innovation process. The first prototypical implementation and application, as well as a first industrial evaluation, can be considered as the transition to the phase of experimental development. In contrast, the necessary methods such as modeling techniques or data analytics methods were developed in the field of basic sciences. This preliminary work is integrated in the approaches for SI, which represent an invention in the field of MCM. The approach's maturity level should be sufficient for a later innovation and to lay the foundation for a sustainable industrial application.

The creation of knowledge is necessary to achieve this goal. This process of gaining knowledge and its background are described in the concept of heuristic research design (KUBICEK 1976). Research can be understood as an iterative learning process. In this process, the researcher formulates questions about reality based on his prior understanding. The answering of these questions and the gained knowledge cause new questions (p.13). The perspective of the researcher has a decisive influence on this process. It influences the problem's theoretical definition and the selection of solution alternatives. The heuristic framework specifies the author's perspective and experiences. In the case of this thesis, the author's prior experience results from academic education, industrial experience in consulting projects, and internships. Additionally, frequent exchanges with numerous manufacturing companies were carried out during the work as a research assistant at the Institute for Machine Tools and Industrial Management at the Technical University of Munich. This resulted in a focus on the areas of Production Organization, Digitalization, Data Analytics, and Factory Planning. The term Digitalization focuses in the context of this work explicitly on the increasing software-based support of business processes and the resulting data availability. The heuristic framework of this thesis is illustrated in Figure 6.

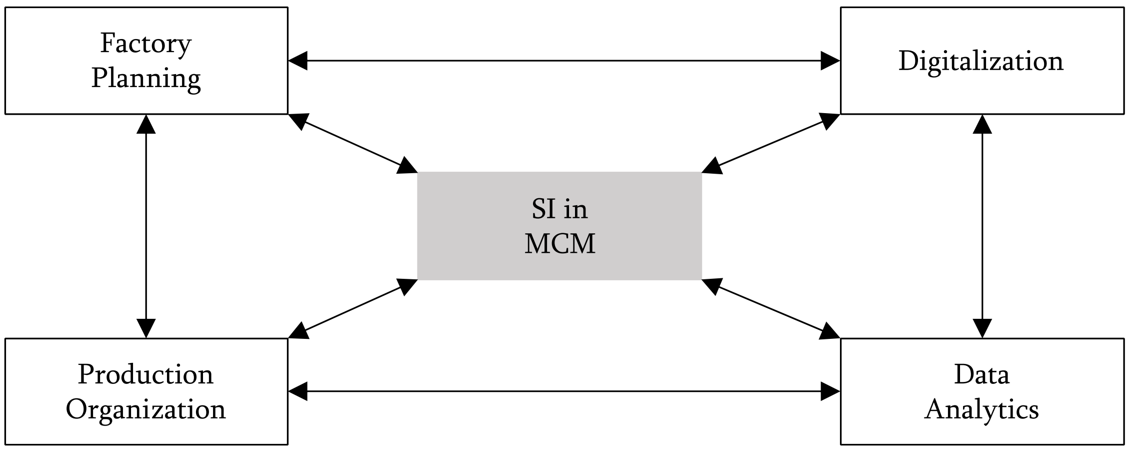

Figure 6. The heuristic framework of this thesis. Illustration based on DILLINGER (2024).

Chapter 1.2 describes the knowledge required to create support for SI in the field of MCM. The great similarity with the elements of the heuristic framework indicates that the author's knowledge and experience form a good starting point for achieving the thesis objectives.

1.4.2 Research methodology and structure of the thesis

A standardized research procedure, on the one hand, increases the comprehensibility of the research process and also the likelihood of valid results although this cannot be guaranteed (BLESSING & CHAKRABARTI 2009, p. 14). On the other hand, a research methodology helps to structure the research documentation logically and comprehensibly. The Design Research Methodology (DRM), according to BLESSING & CHAKRABARTI (2009), is applied in this research work. There are several arguments for the use of this methodology. First, the detailed description of the procedure and the indications on suitable research methods are an advantage. This information guides the researcher during the conceptualization and implementation of the research activities (KOCH 2017, p. 8). The DRM also acknowledges that research activities may have different foci or limitations, e.g., the level of detail of individual steps. Seven different research types are presented for this purpose, allowing the researcher to categorize his specific research project. In addition, the DRM explicitly considers the integration of other methods such as Systems Thinking, if needed. Finally, it should be pointed out that the DRM has already proven to be a suitable choice in a multitude of production engineering research work (e.g., KNOLL 2021, PLEHN 2017).

As described in Section 1.4.1, this research task can be classified as applied research, as it aims to provide support for a decision problem relevant for industrial practice. This complies with the focus of the DRM on Design Research, i.e., the creative and constructive problem solving, since design can be understood as “the process through one identifies a need and develops a solution - a product - to fulfill the need” (BLESSING & CHAKRABARTI 2009, p. 12). The DRM is generally divided into four phases: Research Clarification, Descriptive Study I, Prescriptive Study, and Descriptive Study II. The configuration of these phases depends on the selected research type. The present work can be assigned to research type 5. It is based on a comprehensive analysis of the current status quo in research and industry, new solutions are introduced, and the results are evaluated in initial application cases. Figure 7 illustrates the chosen configuration of the DRM and its correspondence with the structure of the thesis. The applied research methods were selected based on the quality criteria for methods, namely objectivity, reliability, and validity (HELFRICH 2016, p. 96). The values of the worldwide research community served as an additional foundation for the conducted research. They are outlined in the guidelines of good scientific practice of the German Research Association (2013).

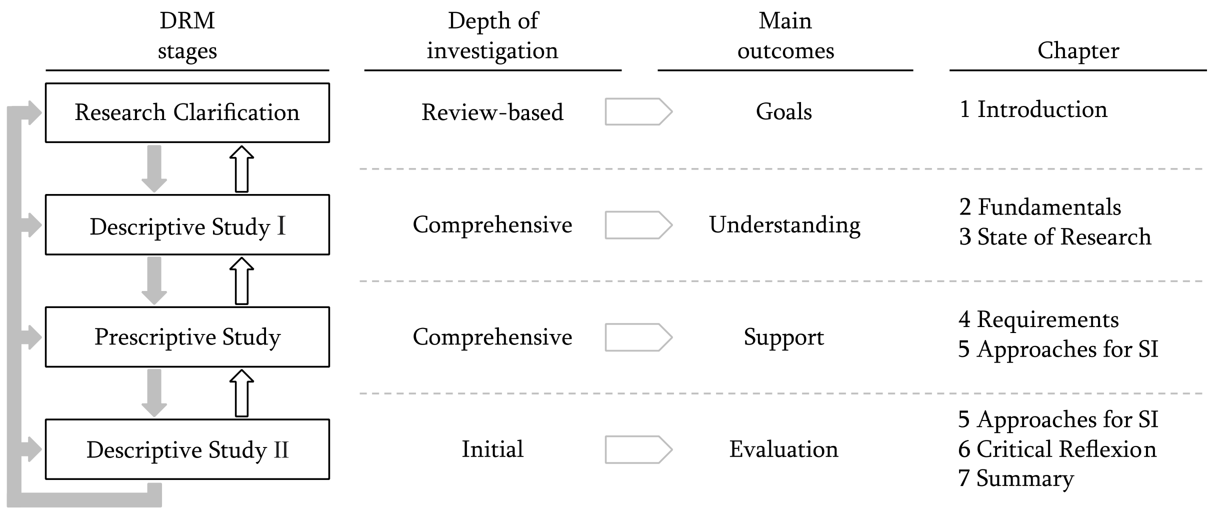

Figure 7. Specification of the DRM framework for this thesis.

The **Research Clarification (RC)** phase focuses on clearly understanding the planned research work. For this purpose, the initial situation, existing problems, and the motivation to tackle the issue of Stakeholder Indentification in MCM are explained in Chapter 1. An initial impact model (cf. Figure 3) can illustrate underlying impact dependencies, which can later be exploited during the solution-finding process. This model provides an essential orientation for the subsequent phase of Descriptive Study I. Building on this, realistic and valuable research objectives (cf. Section 1.2) and requirements are formulated. They constitute an important basis for the solution development in the Prescriptive Phase and for evaluating the results in Descriptive Study II.

Within **Descriptive Study I (DSI)**, the understanding of the research area under consideration is further extended, and relevant previous scientific work is discussed. Therefore, the current state of research is presented based on a systematic literature analysis (cf. Chapter 3). The results were additionally verified and extended through interviews and an industry survey (cf. Chapter 1). The findings collected in this phase were included in the further development of the impact model (cf. Figure 3) and the requirements (cf. Section 4.1).

Based on the knowledge gained during RC and DSI, the **Prescriptive Study (PS)** pursues the fulfillment of the defined objectives (Chapter 1.2). Therefore, this thesis introduces three methods for the identification of relevant stakeholders in MCM (Chapter 5), which address the defined SI scenarios. The methods were developed based on literature reviews, expert interviews, and the analysis of initial use cases. This procedure can be classified as empirical-inductive as well as analytical-deductive. The fulfillment of the requirements (Chapter 4.1), as well as a sufficient level of detail for a first evaluation, were ensured during method development.

The **Descriptive Phase II (DSII)** scientifically evaluates and validates the research results. Three manufacturing companies applied the developed methods for realistic MCs. The corresponding evaluation was divided into a success and application evaluation, according to DRM (BLESSING & CHAKRABARTI 2009, p. 37) . Several Change Management experts evaluated the applicability and result quality in the scenarios "Analog" and "Descriptive". A data-based evaluation of the result quality and an expert-based evaluation of applicability were carried out in the scenario "Predictive". The economic efficiency is evaluated, and further potential for improvement and research is derived.

2 Fundamentals

This chapter introduces the fundamentals essential to this thesis. The aim is to enable and facilitate the reader's understanding of the methods developed and applied. Additionally, the terminology and the basics of the three central domains of this thesis are described. First, important definitions from the field of MCM are explained. This is followed by an introduction to the field of Stakeholder Management, as the term “Stakeholder” is especially of central importance in this thesis. The final chapter briefly introduces Process Mining and Natural Language Processing, as the analysis of process data and textual data plays a significant role in the developed solutions.

2.1 Manufacturing Change Management

2.1.1 Introduction

The MCM addresses the factory as its change object. A factory system “comprises the spatial arrangement, relations, and properties of technology, personnel, and infrastructure in a differentiable sub-section of a manufacturing plant, where the system boundary should be drawn depending on technological or product-oriented deliberations” (PLEHN ET AL. 2015). Two main perspectives can be distinguished regarding the handling of changes in a factory.

First, a multitude of prior work describes the necessary characteristics of production systems, such as flexibility, changeability, reconfigurability, and agility. These characteristics are often conceptually united as the so-called “ilities” (ROSS ET AL. 2008). Additionally, approaches were developed to analyze, evaluate, and enhance these properties (WECK 2011). The properties address different aspects of the factory system. For example, agility describes how quickly changes are responded to, and solutions are found. Reconfigurability refers to the ability of a system to switch between similar products with as little effort as possible (ELMARAGHY 2009, p. 13). An increase in these properties is a driver for the efficient handling of changes (KOCH 2017, p. 28).

The second perspective comprises methods and process models that are intended to support and structure the handling of MCs. In this context, methods can be understood as a “description of a rule-based and planned procedure according to which certain activities are to be carried out in order to achieve a certain objective"[3] (LINDEMANN 2009, p. 57). Several definitions of the term process can be found in the literature. It is defined for this work synonymously with the term business process as "a set of logically related tasks performed to achieve a defined business outcome" (DAVENPORT & SHORT 1990, p. 4).

Several concepts are closely related to MCM, such as factory planning (VDI 5200), continuous factory planning (NOFEN 2006), and project management (KUSTER ET AL. 2023). A clear differentiation of these concepts is challenging, as the objectives are similar to MCM or overlap. Factory planning can be differentiated from MCM in terms of its timeframe. The former ends before series production (SCHADY 2008). In contrast, MCM focuses on adaptations of a factory in operation. Similarities can also be identified between MCM and project management, as well as continuous factory planning. Project management techniques can also be used to implement factory changes and continuous factory planning attempts to improve a factory through a loop-based application of factory planning methods. However, none of the related concepts and disciplines provide a detailed description of the necessary activities of the business process. Therefore, MCM represents a unique perspective on dealing with MCs.

2.1.2 Change types

Changes can be differentiated according to the change object under consideration. Changes to the product are referred to as ECs. An EC can be defined according to JARRATT ET AL. (2005) and based on several previous studies, e.g., TERWIESCH & LOCH (1999), as follows:

> An **Engineering Change (EC)** is an "alteration made to parts, drawings, or software that have already been released during the product design process. An EC can be of any size or type, can involve any number of people, and take any length of time".

Research focused early on the handling of ECs (e.g., PFLICHT 1989) but did not specifically consider the handling of changes to factory systems. This focus was also reflected in the terminology. Initially, there was no term specifically addressing MCs, as they were simply referred to as "EC in production" (AURICH ET AL. 2004). Own definitions for changes to factories were introduced later, such as by STANEV ET AL. (2008) and PROSTEP IVIP E.V (2014). These change types were henceforth referred to as MCs and defined based on the definition for ECs (KOCH 2017, p. 23).

[3] Translated by the author. Original text: "[…] Beschreibung eines regelbasierten und planmäßigen Vorgehens, nach dessen Vorgabe bestimmte Tätigkeiten auszuführen sind, um ein gewisses Ziel zu erreichen" (LINDEMANN 2009, p. 57).

> A **Manufacturing Change (MC)** is an "alteration made to the factory or its elements that have been released for or are already in operations. An MC can be of any size or type, it can involve any number of people, and take any length of time".

The third change type describes changes to the "structure and organization" of a company (QUATTRONE & HOPPER 2001, p. 408). It is referred to as Organizational Change (OC)[4]. KOCH (2017, p. 24) defined the term OC based on several previous works as follows:

> An **Organizational Change (OC)** is "an alteration made to the overall structure or the operations of a company. An OC can be of any size or type, it can involve any number of people, and take any length of time".

In the literature, the term OC is often used synonymously with the general term *change*. In the context of this work, the term *change* is intended to conceptually unite the change subtypes EC, MC, and OC. It is explicitly specified if another change type is intended. The terms EC and MC are summarized in this thesis as Technical Change (TC), following the work of RÖßING (2007).

2.1.3 Management and planning of changes

The efficient and effective management of change is generally regarded as a fundamental prerequisite for the long-term success of companies (ELMARAGHY 2014). The Change Management disciplines are differentiated according to the change types as described in Section 2.1.2. Figure 8 presents an overview of the Change Management disciplines. The relevant terminology is explained below.

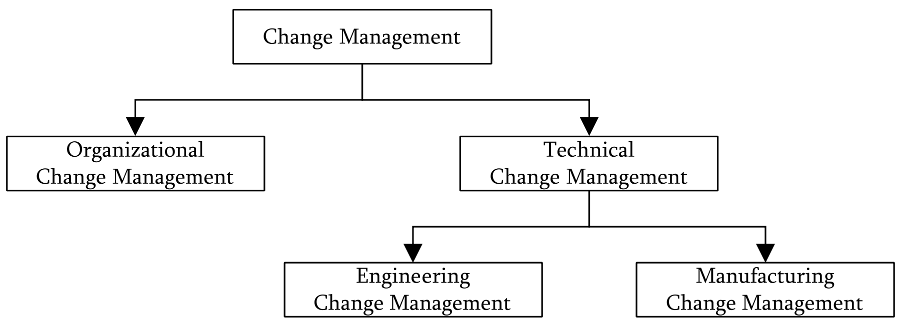

Figure 8. The hierarchy of the different Change Management types.

The basic term Change Management (CM) can be understood as an umbrella term describing the handling of all different change types. There are various definitions and descriptions for the general concept of CM, but none is universally utilized (KAUNE & WAGNER 2016, p. 10). Helmold (2021, p. 31) defines CM as "the sum of tasks, measures, and activities that are

[4] For further details on OCs please refer to TODNEM BY (2005) or HAYES (2014).

intended to bring about a comprehensive, cross-departmental, and far-reaching change in a company or organization". In contrast, VAHS (2020, p. 19) describes CM as "the preparation, analysis, planning, realization, evaluation and ongoing development of holistic change measures with the aim of developing a company from a specific current state to a desired target state and thus increasing the efficiency and effectiveness of all corporate activities"[5]. The generic term CM can be subdivided into specialized disciplines based on the change types (cf. Figure 8). Engineering Change Management (ECM) deals with product changes. In contrast, Manufacturing Change Management (MCM) addresses changes in the factory, and Organizational Change Management (OCM) changes in the organization. MCM and the ECM are often incorporated within the so-called Technical Change Management (TCM) (RÖßING 2007). Koch (2017, p. 26) defines OCM based on preliminary work (TODNEM BY 2005, BURNES 2009, LAUER 2014, AL-HADDAD & KOTNOUR 2015, GATTERMEYER & AL-ANI 2001), as follows.

> **Organizational Change Management (OCM)** "comprises all measures which are required to initiate, adapt, and implement new strategies, structures, organizational systems, behaviors and capabilities in a company".

In other words, OCM addresses "the people side of change" (HIATT & CREASEY 2003, p. 7) and no changes to the product or the factory.

Various definitions of ECM have been proposed during intensive research in this field. Among others, LINDEMANN & REICHWALD (1998), JARRAT ET AL. (2011), HUANG & MAK (1999), and ROUIBAH & CASKEY (2003) present independent definitions. KOCH (2017, p. 25) united their core aspects in the following definition, which is adopted in the context of this thesis:

> **Engineering Change Management (ECM)** refers to "organizing and controlling the process of making alterations to a product. This includes the totality of measures to avoid and specifically front-load as well as efficiently plan, select, process, and control Engineering Changes".

The term MCM can be defined in a similar way to ECM due to the similarity of the task, as outlined by Koch (2017). Only the different change objects (product versus factory) must be taken into account:

[5] Original text in german translated by the author. See reference for details.

> **Manufacturing Change Management (MCM)** refers to "organizing and controlling the process of making alterations to a factory. This includes the totality of measures to avoid and specifically front-load as well as efficiently plan, select, process, and control Manufacturing Changes".

2.1.4 The Manufacturing Change Management process

Several scientific contributions from the 2000s onward (e.g., AURICH ET AL. 2004, RÖßING 2007, STANEV ET AL. 2008) focused on the transfer of processes and methods for the procedural handling of ECs to the domain of MCM. Several process models with different foci have already been introduced. PROSTEP IVIP E.V. (2014) presented a two-phase MCM process that is strongly oriented towards the industrial status quo and requirements. KOCH (2017) combined the existing preliminary work from the fields of ECM, MCM, factory planning, and continuous factory planning with several industrial case studies. The result was a general model for MCM[6]. This model contains the most comprehensive and detailed MCM process, with 54 activities structured in eight different stages. It follows the basic concept of a stage-gate process, according to COOPER (1990). Koch's process describes the activities to be performed (stages) and the intermediate results (gates), which must be achieved so that the process can be continued. In addition, the author defines the process roles, relevant tools, and flexibilization measures. Therefore, Koch's MCM process serves as a reference for describing the point of application of the developed methods in this thesis.

KOCH (2017) divides the process of MCM into the overarching main phases of proactive, reactive, and retrospective action in analogy to the preliminary work in the field of ECM. In the proactive phase, "all activities are performed to identify, avoid, advance, create, and/or control a cause of change and a potentially resulting MC, rather than just reacting to it after it occurs" (KOCH 2017, p. 111). The goal of the reactive phase is to "prepare, evaluate, plan, process, and implement an MC after a confirmed need for action - i.e., confirmation of the occurrence of a defined cause of change" (KOCH 2017, p. 111). The final retrospective phase includes "all activities to look back at, review, and learn from a past MC" (KOCH 2017, p. 111). The lessons learned generated in this phase provide a critical foundation for improving the handling of future MCs to support continuous learning. Since the approaches to SI presented in this thesis aim to support the reactive phase, the sequence of activities in this phase is illustrated in Figure 9.

[6] The interested reader is referred to KOCH (2017, p. 203) for an overview of the preliminary work.

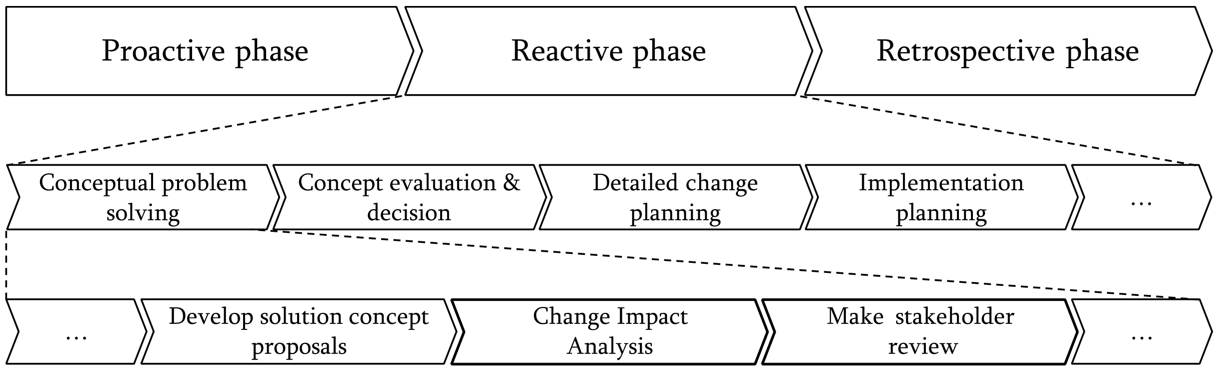

Figure 9. Overview of the MCM process.

The MCM process contains a multitude of tasks that need to be completed for the initiation, planning, implementation, and review of MCs. These tasks each require the involvement of persons and departments with matching skills and responsibilities. Therefore, process participants have to determine affected and relevant stakeholders at several points in the process. This applies, for example, to the transition from the upstream proactive phase to the reactive phase. In this process phase, it has been recognized that a deviation between the target and the actual state of the factory requires a MC. A suitable change manager has to be defined, who organizes the process for the new MC.

This thesis particularly focuses on supporting the identification of relevant stakeholders for Change Impact Analysis (CIA) (cf. activities on the third level of Figure 9). The objective of this step is to capture the potential impacts of proposed changes and, thus, solution alternatives. The knowledge generated in this step is decisive for the selection of the optimal change alternatives. Errors in this process step, i.e., the wrong assessment or the non-consideration of change impacts, can lead to the selection of non-optimal change alternatives. This includes the risk of increased time and financial expenditure, e.g., due to unplanned production stops or new changes requirements.

2.1.5 Change Impact Analysis

The CIA describes the systematic identification and evaluation of the consequences of a change. It has originally been intensively researched in the domain of ECM, as the effects of ECs on the overall product must be carefully analyzed before a change is implemented. This necessity is due to the diverse dependencies, e.g., mechanical or functional interactions, within a product (HAMRAZ ET AL. 2013). The same applies to the handling of MCs. The effects of a MC on a factory system must be carefully identified and evaluated before it is implemented (CICHOS & AURICH 2014, p. 395). The knowledge generated during CIA is considered crucial for selecting the best possible change alternative and the subsequent change implementation (BAUER ET AL. 2020, PLEHN ET AL. 2016). This underscores the necessity and the importance of integrating all relevant stakeholders in this step of MCM. A definition for the term change impact was provided by PLEHN (2017, p. 13):

> **Change impact** refers to „the cost incurred by a change in terms of money and time due to any activities as well any further direct or indirect impacts related to its planning and implementation".

This definition implies that determining change impacts requires knowledge of all activities necessary for and resulting from the change. The integration of a new energy-efficient machine could, for example, require special employee training. This training may result in additional financial resources and may be subject to time constraints, as it must be completed before the new machine is put into operation.
A major challenge in performing the CIA is the phenomenon of change propagation. It describes "the process by which a change to an existing system design triggers at least one additional change to the system or any associated activity, incident, or alteration within the system environment that would not have been required otherwise" (GIFFIN ET AL. 2009, p. 2). The handling of change propagation was initially researched with regard to ECs (e.g., CLARKSON ET AL. 2004) but also applies to the handling of MCs (HERMANN ET AL. 2022, BAUER ET AL. 2020) and the associated risk of causing unexpected changes to other parts of the factory.

2.2 Fundamentals of Stakeholder Management

This section introduces the topic of Stakeholder Management, as this thesis aims to support MCM through new methods for SI. First, the central concept of the stakeholder is introduced and then transferred to the field of MCM. Second, the concept of Stakeholder Management, its importance, and its procedures are explained.

2.2.1 Stakeholder

The term stakeholder is an artificial word that is composed of two parts. The word "stake" can be understood as "interest", "share", or "co-ownership" (MERRIAM-WEBSTER 2024c). The term "holder" can be considered as "owner", "possessor", or "proprietor" (MERRIAM-WEBSTER 2024b). The concept of stakeholder was first mentioned in an internal memo of Stanford University (HENTZE & THIES 2014, p. 12). In the meantime, the concept can be found in numerous management- and organization-oriented research papers, e.g., on strategic planning, organization theory, corporate social responsibility, or organization theory. Many definitions and interpretations have evolved throughout this extensive research (MILES 2017, STONEY & WINSTANLEY 2001). MILES (2017) compares and classifies over 500 definitions of the term stakeholder. A stakeholder can be defined, for example, as a “person, group or organization that has interests in, or can affect, be affected by, or perceive itself to be affected by, any aspect of a project” (ISO/TR 21506, p. 7).

This thesis follows the definition by FREEMAN (2010, p. 46) due to its widespread use. However, this definition has to be further specified to cover the focus of this thesis, i.e., the identification of relevant stakeholders in MCM. The stakeholder definition of FREEMAN (2010, p. 46) was combined with the definition of MCM (cf. Section 2.1.3). This results in a clear understanding of how stakeholders are conceived in the context of this thesis:

> **Stakeholders in MCM** are “any group or individual that can influence or is influenced by the avoidance, front-loading, selection, planning, implementation, and control of manufacturing changes”.

Stakeholders can be differentiated with regard to several dimensions (MILES 2017), whereby the resulting classifications can overlap. FREEMAN (2010) distinguishes between primary and secondary corporate stakeholders regarding their involvement. Primary stakeholders are a group “without whose continuing participation the corporation cannot survive as a going concern” (CLARKSON 1995, p. 106). Examples are employees, owners, or those stakeholders involved in MCM if it is assumed that no external partners, such as suppliers, are affected. In contrast, secondary stakeholders are defined “as those who influence or affect or are influenced or affected by the corporation, but they are not engaged in transactions with the corporation and are not essential for its survival” (CLARKSON 1995, p. 107). Examples are the society, the suppliers, and the customers. The literature provides further approaches for the classification of stakeholders. For example, a distinction can be made between core-fringe/peripheral (HART & SHARMA 2004), normative/derivative (PHILLIPS 2003), or moral/strategic (GOODPASTER 1991) stakeholders. In the context of this work, only the classification based on localization is used to specify the group of stakeholders. Primary (internal) stakeholders who can actively contribute to the evaluation of the planned change or who can be passively affected by this change are to be identified (cf. Figure 10).

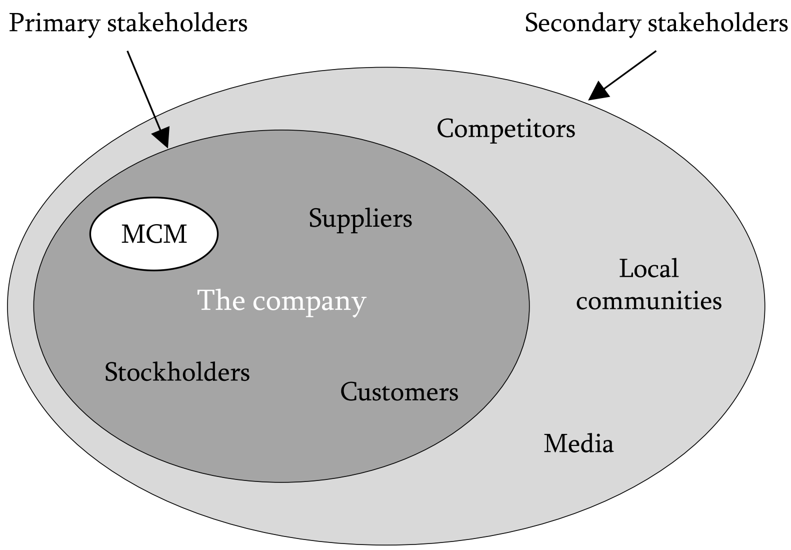

Figure 10. Primary and secondary stakeholders. Visualization adopted from COLLE (2005, p. 300).

2.2.2 Stakeholder Management

The discipline of Stakeholder Management has its roots in the field of Stakeholder Theory (PEDRINI & FERRI 2019), whose foundation was laid in the 1980s by FREEMAN (1984). Stakeholder Theory aims to "consider the needs of and the impacts on the various stakeholders of a corporation" (FASSIN 2012, p. 88). Building on this, SM can be understood as a "continuous and systematic process through which a firm establishes positive and constructive relationships with its stakeholders to integrate their expectations into business strategy and activity" (PEDRINI & FERRI 2019, p. 46, HABISCH ET AL. 2011, COLLE 2005). SM has been utilized in various disciplines since its emergence. Therefore, close connections with multiple domains, such as risk management, communication management, requirements engineering, or reporting, are recognized (HENTZE & THIES 2014). Different objectives and motivations can drive the application of SM. SM can, e.g., positively affect economic aspects, such as decision-making (e.g., COLLE 2005) or risk management (e.g., GODFREY ET AL. 2009). In general, it can be stated that the involvement of relevant stakeholders leads to increased knowledge and greater acceptance of the company's actions (ACCOUNTABILITY 2015, p. 7, HENTZE & THIES 2014, p. 23). This inclusion is especially essential in projects with technical complexity, such as product development or MCM. These tasks require "knowledge and expertise that is likely to be distributed geographically or virtually" (ZWIKAEL ET AL. 2012, p. 118). Numerous processes and methods for SM have already been presented in the literature. The models show different levels of detail depending on the application area. The phases of Stakeholder Identification and Stakeholder Analysis are common steps in most stakeholder models (MEREDITH & MANTEL 2010, CHEN & SACKETT 2007), with Stakeholder Identification usually being one of the first steps.

Following the approach of Karlsen (2002), the SM process begins with the definition of the purpose and the planning of the SM process. Afterward, the variety and multitude of relevant stakeholders are systematically identified. This is followed by the Stakeholder Analysis, in which the identified stakeholders are examined regarding their knowledge, interests, and relationships with each other. Their involvement is then planned and communicated. The involvement can take place at different levels (e.g., consultative, empower, collaborate) or with the help of several methods (e.g., surveys, workshops, or advisory boards) (Accountability 2015, p. 22). It is monitored during implementation so that countermeasures can be initiated in the case of deviations. In the end, a review is conducted to identify improvements potential for future projects based on the fundamental idea of continuous improvement.

The overall process of SM is visualized in Figure 11 following Karlsen (2002, p. 23). The phases after the Stakeholder Analysis appear in a multitude of scientific works. However, they often do not follow the same terminology, are structured differently, or are described with varying detail levels.

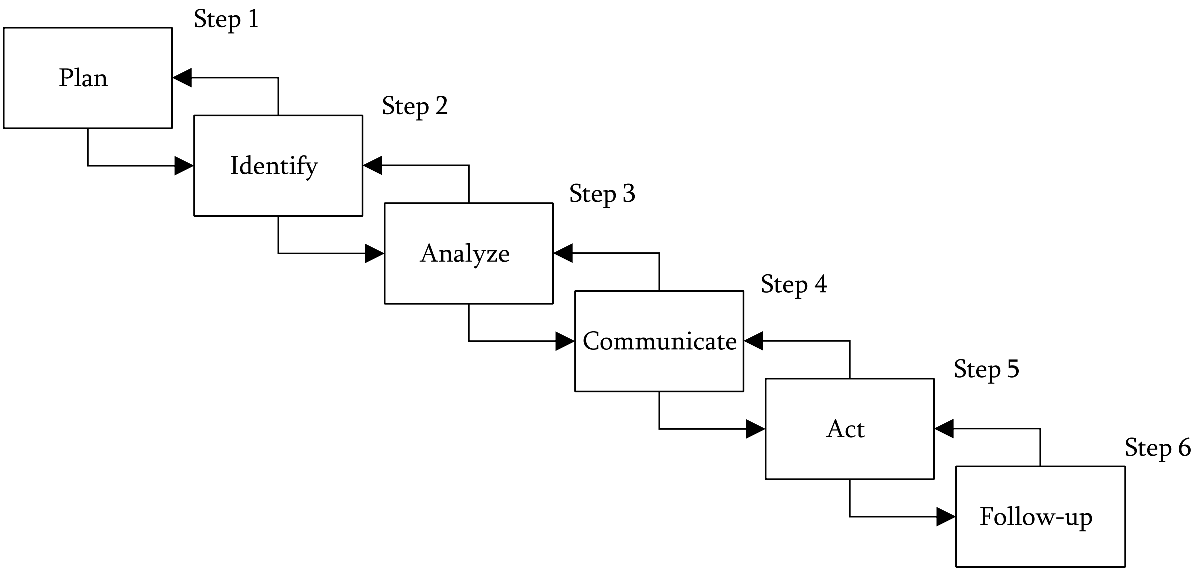

Figure 11. Phases of Stakeholder Management according to KARLSEN (2002, p. 23).

2.3 Relevant data-based approaches

The following two sections briefly explain the basics of Process Mining and Natural Language Processing. The increasing digitalization leads to the availability of process data and textual data, as described in Chapter 1. Process Mining and Natural Language Processing allow for an extensive analysis of these data types and thus play a vital role in the approaches developed for the identification of relevant stakeholders in MCM.

2.3.1 Process Mining

Process Mining (PM) represents the link between the disciplines of Data Science and Process Science. It "combines knowledge from information technology and knowledge from management sciences to improve and run operational processes" (VAN DER AALST 2016, p. 15). The goal of PM is to reconstruct and analyze business processes based on event and movement data (SIEPERMANN 2018). Processes can thus be "put under a microscope" to identify deviations and inefficiencies (VAN DER AALST 2016, p. 48). The motivation for PM can be summarized as follows (VAN DER AALST ET AL. 2012, p. 172):

> "The idea of **process mining** is to discover, monitor and improve real processes (i.e., not assumed processes) by extracting knowledge from event logs readily available in today's (information) systems."

The basis for the application of PM is event data. This data must be available in the form of so-called event logs and represent the input for the PM algorithms. Events logs include the process activities and in what order they appear (VAN DER AALST 2016, p. 58, PETERS & NAUROTH 2019, p. 15). Event logs from different IT systems of the company often have to be combined to map entire processes comprehensibly and correctly (VAN DER AALST 2016, p. 125). The structure of an event log for an individual process is shown in Figure 12, based on an example Change Management process.

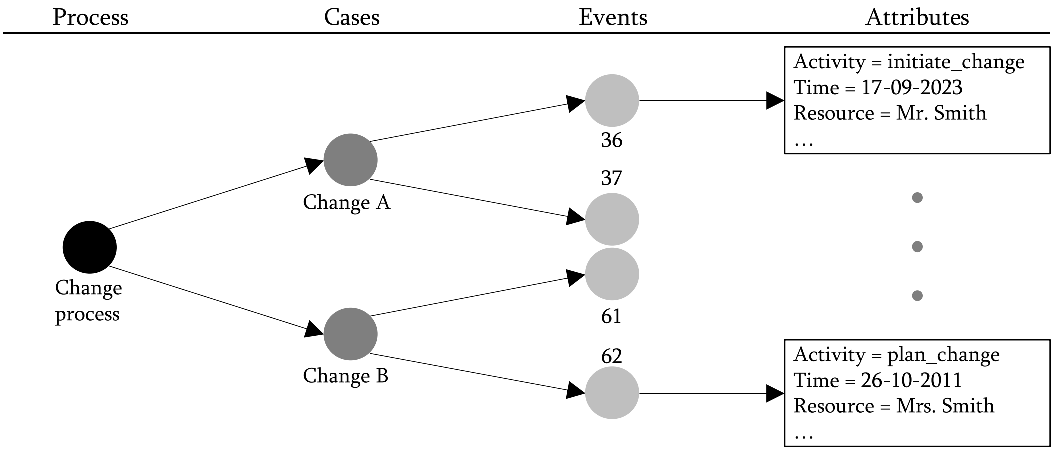

Figure 12. The structure of event logs adapted from VAN DER AALST (2016, p. 130).

The event log of the process, e.g., of the MCM, contains the instances of the process, e.g., the individual changes, which are also referred to as *cases*. *Cases*, in turn, consist of *events*, e.g., the approval of a change. They are ordered within a *case* and can be uniquely assigned to the *case* by means of an ID. Events can be enriched by additional *attributes*, such as the timestamp or the activity name, e.g., the approval of the change request. *Events* within an event log do not have to contain the same *attributes*. However, the same *attributes* are usually included if events refer to the same activity (VAN DER AALST 2016, p. 130).

Events logs are then used to derive process models that represent the dynamic behavior and the course of the processes under consideration as accurately as possible. A variety of process model notations have been proposed so far in scientific literature and industrial practice. Each of them has different characteristics and, therefore, has to be chosen depending on the application (VAN DER AALST 2016, p. 25). Examples are Process Trees (VAN DER AALST 2016, p. 78), Yet Another Workflow Language models (HOFSTEDE ET AL. 2010), Petri Nets (PETRI 1962), or models based on the Business Process Modeling Notation (BPMN) (OMG 2014). An example of a Petri Net is illustrated in Figure 13.[7] It is based on the BPMN.

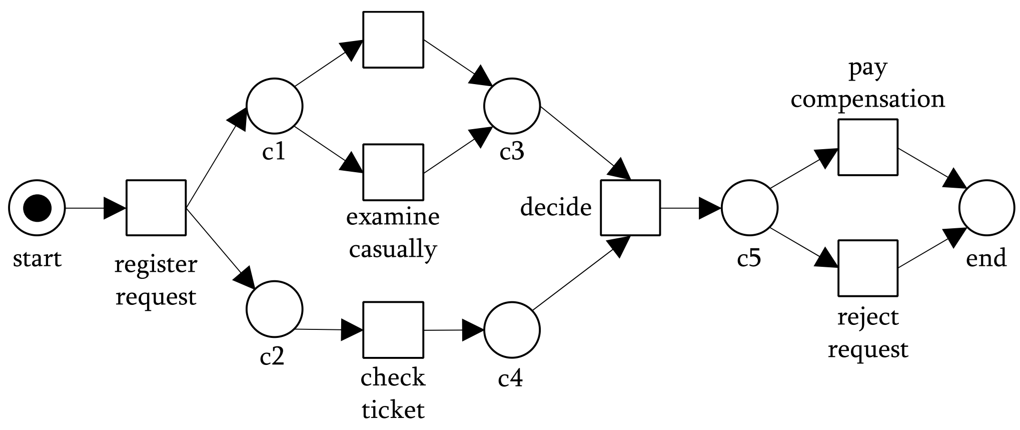

Figure 13. An example of a Petri net for a compensation process adopted from VAN DER AALST (2016, p. 27).

Types of Process Mining

VAN DER AALST (2016, p. 33) differentiates three Process Mining types that represent specific use cases and objectives. First, *Process Discovery* pursues the goal of creating a process model based on an event log without including additional prior information. Second, *Conformance Checking* evaluates the compliance of an actual process, which was identified through *Process Discovery*, with a target process model. It can be, for example, verified whether all necessary process steps have been carried out. Third, *Enhancement* enables the enrichment and extension of process models with additional information about the actual process flow, such as the average execution times (ACCORSI ET AL. 2012, p. 358). The resulting enriched process models allow deeper insights and an improved identification of improvement potentials.

[7] The readers interested in details about Petri Nets are referred to REISIG (2013).

2.3.2 Natural Language Processing

NLP is an umbrella term for a collection of approaches to automatically analyze, process, and represent the meaning of human language (CHOWDHARY 2020, p. 604). The objective is to enable computers to utilize this information (SHELAR ET AL. 2020, p. 1) for the purpose of performing useful tasks (DENG & LIU 2018, p. 1). NLP is an analysis technique of the Text Mining domain (SARKER 2022, p. 158), which pursues a similar objective. Text Mining aims for the "discovery and extraction of interesting, non-trivial knowledge from free or unstructured text" (KAO 2007, p. 1). The difference is that NLP tries to generate a deeper textual understanding, which can be described "as figuring out who did what to whom, when, where, how and why" (KAO 2007, p. 1). For this purpose, NLP takes into account the word types, the grammatical structure, and the dependencies in the text, e.g., the relationship between sentences or words (KAO 2007, p. 1). NLP is a strongly interdisciplinary discipline that combines methods and concepts from several fields. Examples include mathematics, psychology, computer science, information science, cognitive science, artificial intelligence, computational linguistics, and robotics (LIDDY 2001, DENG & LIU 2018, DIKSHAN N. SHAH & HARSHAD B. BHADKA 2017, p. 11).

The accurate preparation of the textual data is an essential prerequisite for the efficient exploitation of texts. The so-called part-of-speech tagging, or synonymously grammatical tagging, is used for "the automatic assignment of part-of-speech tags to words in a sentence" (DIVYAPUSHPALAKSHMI & RAMALAKSHMI 2021, LV ET AL. 2016). The individual words are categorized, e.g., whether they are nouns, adjectives, or verbs, with the goal of a better text understanding (CHICHE & YITAGESU 2022). The necessity of this step originates from the fact that a word or expression "can be understood in two or more possible ways" (MERRIAM-WEBSTER 2024a). A frequently used example is the word "bank", which can be part of a river, a financial organization, or the place where a financial organization operates (PYYSALO ET AL. 2004, YADAV ET AL. 2021). These word ambiguities must be resolved to enable precise text understanding. Therefore, word sense disambiguation aims "to determine which one among the several senses of a particular word to consider based on the instance" (YADAV ET AL. 2021, p. 1, LIU ET AL. 2005). It is considered an essential challenge and a "vital aspect" of NLP (YADAV ET AL. 2021, p. 1).

A wide variety of use cases can be pursued based on the prepared textual input data. Examples include dialog systems, lexical analysis, machine translation, knowledge graphs, information retrieval, question answering, sentiment analysis, social computing, natural language generation, and natural language summarization (DENG & LIU 2018, p. viii). The use case of text classification is of particular importance for this thesis. It "automatically assigns a given document to a set of pre-defined categories based on its textual content and extracted features" (DALAL & ZAVERI 2011). Categories, often called "labels", are assigned in this process to text documents. (DOGRA ET AL. 2022, p. 2). For example, the severity of a problem can be estimated based on the description of the problem, with the labels "Low", "Medium", and "High" (MALHOTRA ET AL. 2013).

3 State of Research

This chapter aims to provide a systematic overview of relevant preliminary work. This overview supports the researcher in developing a better understanding of the subject area, e.g., in terms of essential concepts and vocabulary (HART 2011). In addition, it enables him or her to acknowledge the contribution of the preliminary work to the progress of science. In other words, it is the "driving force and jumping-off point" of the research work (RIDLEY 2012, p. 3) and represents an essential part of the DSI of DRM (see Section 1.4.2). In the following, the relevant preliminary work is divided into the main categories of non-data-based and data-based approaches. A brief interim conclusion is drawn for both categories. The chapter ends with an overall summary and a description of the need for research.

3.1 Methodology for literature review

The literature search was based on JAHANGIRIAN ET AL. (2010). In the first step, clear inclusion (IC) and exclusion (EC) criteria were defined to focus transparently on the most promising preliminary work (cf. Appendix A.6). Attention was paid to ensuring that the criteria are "explicit and comprehensive enough so that any article that comes to light could be included or excluded solely based on those criteria" (RANDOLPH 2009, p. 6). Afterward, keywords were defined in German and English, which were then combined with Boolean operators (see Appendix A.7 for an overview of the keywords). As an example, the search string "Manufacturing Change Management" AND "stakeholder" AND "identify" was used. The databases *Scopus®*, *Web of Science,* and *Google Scholar* were considered as information sources. Separate searches were conducted for preliminary German and English work due to technical limitations. The initially identified publications were then filtered by checking the title and the abstract. The remaining publications were analyzed via full-text screening. Forward and backward searches were additionally used to validate the results and provide the reader with an extended overview of the current state of research. Parallel to this, the publications of research institutions that have dealt intensively with the field of ECM or MCM were specifically reviewed.

All relevant preliminary work is described in the following sections. The extent of the presentation was selected depending on the relevance for this thesis. The final objective was to analyze the identified publications, describe differences and similarities, and derive research opportunities. Figure 14 visualizes the applied procedure for literature research (LR) in an aggregated form.

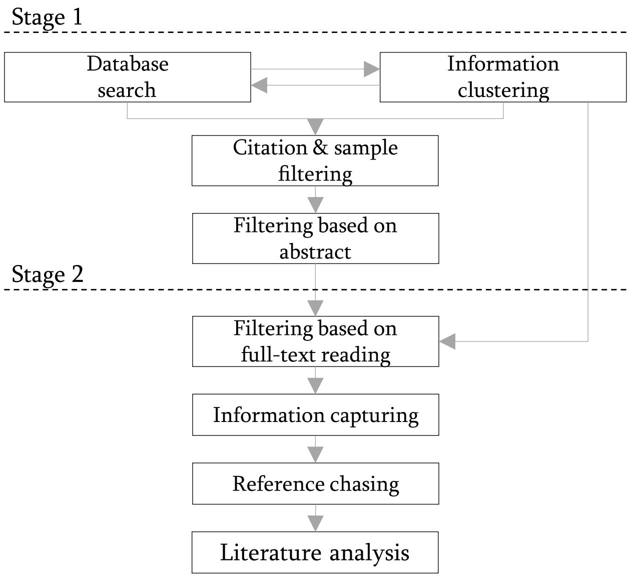

Figure 14. Overview of the procedure for LR (JAHANGIRIAN ET AL. 2010).

3.2 Non-data-based approaches for Stakeholder Identification

The following sections first provide an overview of relevant preliminary work in the field of ECM and MCM for Scenario 1 (Analog SI). An interim conclusion is drawn, and relevant findings are derived at the end.

3.2.1 Processes for ECM, MCM, and related disciplines

The identification, analysis, and management of stakeholders are essential success factors for different disciplines. Preliminary work can be found in the area of requirements management (e.g., HEßELER ET AL. 2004) and particularly in the area of project management (ACHTERKAMP & VOS 2008). Although the necessity of SI is mentioned in these preliminary works, no specific solutions are provided (e.g., HEßELER ET AL. 2004), which can be transferred to the field of MCM and cope with the characteristics of MCs.

Supporting the handling of ECs through structured processes has also already been intensively researched. Examples of early publications include DALE (1982), CONRAT (1997), and TERWIESCH & LOCH (1999). Dale (1982) presents a 33-step procedure for the handling of ECs and explicitly integrates the step of “Inform departments requiring information”. Relevant departments can be selected on a so-called change note in which the change is described in a standardized way. The concept of “Integrated Change Management” by LINDEMANN & REICHWALD (1998), KLEEDÖRFER (1999), and AßMANN (2000) combines the aspects of people, management, organization, methods, and tools, which is the reason for the integrative nature of this approach. The necessity of identifying and integrating affected stakeholders is mentioned several times in this work. For example, it is pointed out that relevant disciplines, such as production or sales, must be integrated depending on the situation (LINDEMANN & REICHWALD 1998, p. 175). LINDEMANN & REICHWALD (1998, p. 53) name both internal stakeholders (e.g., development or production) and external stakeholders (e.g., customers or suppliers) of a change. Although other approaches emphasize the importance of integrating all relevant stakeholders (JARRATT ET AL. 2005, TAVČAR & DUHOVNIK 2005, LEE ET AL. 2006), they do not address this task in their work. JARRATT ET AL. (2005, p. 281) state that information about new changes "should be communicated as soon as possible to all affected people and sections". However, this challenge is not addressed in the generic six-step procedure introduced, and the responsibility for identifying affected components and systems remains exclusively with the person who has issued the change request (JARRATT ET AL. 2005, p. 270). Other approaches present similar process-related support for ECM but neither directly nor indirectly address the challenge of SI (e.g., WICKEL ET AL. 2015, LI ET AL. 2022, SCHUH ET AL. 2018, HAN ET AL. 2015).

Several approaches for a structured and systematic handling of MC have been presented over time (e.g., CICHOS & AURICH 2015, CICHOS & AURICH 2014, AURICH ET AL. 2004, STANEV ET AL. 2008, PROSTEP IVIP E.V. 2015). However, these do not offer any support for SI although its necessity is repeatedly highlighted. For example, AURICH ET AL. (2004) specifically mention the need for "reviews and opinions on the change" (p.1) to be obtained from the affected departments for an upcoming change. A second example represents the work of PROSTEP IVIP E.V. (2015). The task "Clarification among the participants" is carried out during the phase of change evaluation. Therein, all relevant decision-makers should be identified and integrated to be able to start a "qualified decision-making process" (p.7). The task of the SI is again not systematically supported.

The work by KOCH (2017) represents an exception in this regard. It introduces the most detailed MCM process to date based on extensive literature reviews and expert interviews. The necessity of stakeholder involvement is formulated as a requirement before the conception of the process model and subsequently considered several times in the process flow. The task "Identify Stakeholders" is, for example, proposed at the beginning of the phase "Change reviews and approval". It pursues the goal of identifying relevant process participants and integrating them into the process. However, KOCH (2017, p. 135) also provides indications on which corporate functions should be included in which scenarios. These scenarios are differentiated based on change attributes, such as the change cause. The specific attribute values are linked to individual corporate functions using a matrix-based modeling approach (cf. Table 1). For example, it is stated that if the "Technology" element is selected as a change cause, the corporate function for "Operational Excellence" should be included in the change.

Table 1 Identification of relevant corporate functions in MCM following the approach by KOCH (2017).

	Department functions										
MC attributes	Production management	Shop floor	Quality management	Logistics	Technology planning	Product development	PLM & ECM	Management	HR	Purchasing	…
Cause											
Factory life cycle	X	X			X					X	
MC	X	X									
Complications	X	X	X								
Product life cycle	X	X			X	X	X	X		X	
EC	X	X	X			X	X				
…											

The guidelines presented are company-independent and do not allow for any company-specific adaptation. On the one hand, this shows that only a selection of change attributes is integrated and detailed. For example, the change location is not incorporated in the guidelines. It describes where the change takes place in the factory. On the other hand, this implies that the company-specific organizational structure is not considered. A mapping between the general department functions and the company-specific organizational units does not take place. This means that, e.g., the responsibilities of the function "Quality Management" can be subdivided into various departments, e.g., according to product families or production sites. Furthermore, Koch's (2017) approach only allows for the identification of relevant corporate functions but does not determine the actual stakeholders as departments or roles. The author confirms the necessity of knowledge about relevant persons. He emphasizes that "an MC to a certain manufacturing resource might require the selection of a specific, but different person within the department function" (KOCH 2017, p. 129).

3.2.2 Approaches for Change Impact Analysis and Stakeholder Identification

The CIA of ECs has already been analyzed in numerous previous works. Many of them, such as COHEN ET AL. (2000), CONRAD ET AL. (2007), OLLINGER & STAHOVICH (2001), YANG & DUAN (2012), OUERTANI (2008), LEE ET AL. (2010), CLARKSON ET AL. (2004), FLANAGAN ET AL. (2003), AHMAD ET AL. (2010), AHMAD ET AL. (2013), and KOH ET AL. (2012), are limited to modeling the interdependencies within a product. They do not take into account the communication in and the organization of the ECM process. Other approaches extend the analysis to include the effects of ECs on the underlying processes, such as the development process or the ECM (e.g., WYNN ET AL. 2014, LI & MOON 2012, CHUA & HOSSAIN 2012, TANG ET AL. 2010). However, they do not primarily address the case-individual identification of relevant process stakeholders.

Other publications allow for a change-specific SI but only consider ECM without taking into account MCMs and the associated stakeholders (ABRAMOVICI & AIDI 2015, TANG ET AL. 2010, ROUIBAH & CASKEY 2003, MARTIN ET AL. 2022). TANG ET AL. (2010) aim to increase product design efficiency by improving product design knowledge utilization. Three domains and their interactions are modeled in matrix form: Product, Development Process, and Organization. The organizational structures are represented in the latter domain. If necessary, they can be divided into working groups and individual employees. It is possible to determine which organizational domains are affected by product changes in the event of change propagation by linking the domains.
A similar approach is followed by ROUIBAH & CASKEY (2003). They focus on multi-company design efforts and establish a workflow for the engineering in a concurrent environment. A parameter network is utilized to model the dependencies between the domains Product, Documents, Persons, and Process. The identification of relevant workflow participants is based on parameter-specific responsibilities (e.g., supervisor or reviewer). MARTIN ET AL. (2022) present an approach for a model-based propagation and impact analysis of ECs in ECM to support product engineering. In addition to impact analysis, the approach focuses on demand-oriented communication, as product development "requires strong collaboration between individual developers" (p. 5). The relevant stakeholders are identified based on their associations with subsystems or functions of a product as well as their roles (Responsible, Accountable, Consulted, and Informed). Table 2 provides an example of allocating employee responsibilities to a product's subsystems and functions.

Table 2 Identification of relevant stakeholders as presented by MARTIN ET AL. (2022).

	Systems engineer	Validation engineer	Management	…
Subsystem A	responsible	informed	accountable	…
Function B	consulted	responsible	accountable	…
…	…	…	…	…

Manufacturing Change Management

Most approaches from the MCM domain focus on modeling dependencies between the factory's system elements. An example of this is the flow of materials or energy between machines or warehouses. Objectives of these approaches are the determination of affected factory elements, the consideration of change propagation (e.g., PLEHN 2017), or the evaluation and comparison of MCs (e.g., HERMANN ET AL. 2021, BERGS ET AL. 2020).

Bauer (2024) presents an approach for the modular design of CIA for MCM. The approach follows the basic ideas of process tailoring and modularization. The necessary analysis modules are selected, and application templates are provided based on the intended level of detail. The author indicates that the SI can only be indirectly supported based on the affected factory objects (p. 68). Rößing (2007) introduces an approach for the initialization, implementation, and post-processing of MCs. The approach presents a reference process model and a reference object model. The process model describes the sub-processes required to implement a MC (RÖßING 2007, p. 52). The object model represents all classes relevant to MCM, e.g., the technical change or the production object, as an UML class diagram. This knowledge base is used to identify affected factory elements if a change proposal is submitted. The affected stakeholders are in turn identified by specifying the responsibilities for each production object. This approach does not provide a detailed consideration of the distribution of responsibilities between employees. For example, no cross-sectional aspects (e.g., material flow) are considered, and the class of the production object is only differentiated into the sub-classes production unit, assembly system, inspection unit, and logistics unit (RÖßING 2007, p. 49). In conclusion, the approach of Rößing (2007) does not allow for a detailed specification of responsibilities to support SI in the area of MCM.

MALAK (2013) presents a software-based approach for evaluating, planning, implementing, and reviewing ECs impacting factories. Once the need for a technical change is recognized, its effects are analyzed using predefined categories, such as layout or process chain. The change implementation is then planned based on a database of standardized solution steps. All solution steps are described in a standardized profile with the help of various attributes, such as costs, duration, or risk. The profile additionally specifies the necessary personnel resources, such as one person from facility management. Therefore, the approach supports the SI during implementation planning. However, it does not allow for the identification of stakeholders in earlier MCM process phases as the necessary implementation steps are not yet known.

3.2.3 Cross-case findings

The literature review shows that numerous approaches for the procedural handling of ECs and MCs, as well as for the CIA, have already been introduced. However, few preliminary works address the SI at all or consider it in detail. It is apparent that process-oriented approaches with a high level of detail mention the SI task. Explicit support for SI is only provided in very few cases. In conclusion, the analysis of the state of research yielded several findings, which are presented below.

Change types

Most of the preliminary works explicitly and exclusively focus on ECs (e.g., MARTIN ET AL. 2022, TANG ET AL. 2010) without addressing MCs specifically. The transferability to the MCM domain cannot be ensured as the underlying change objects (product vs. factory) and the processes for ECM and MCM differ significantly. Differences exist, for example, in terms of information availability, stakeholders, and change description models.

Stakeholder levels

Following the basic idea of task distribution, the larger the company, the greater the distribution of tasks is. Therefore, SI is necessary at different levels, such as individual employees, roles, and departments. Existing preliminary work is often limited to identifying individual corporate functions (e.g., KOCH 2017) or individuals in ECM (e.g., MARTIN ET AL. 2022). The identification of relevant stakeholders in MCM at different levels, such as employees, roles, and departments, has not been sufficiently addressed so far.

Adaptability

The identification of relevant stakeholders has to consider the characteristics of the MC under consideration as well as the underlying organizational structures. The existing preliminary work does not allow a sufficient and company-specific description of the MC with the aim of SI. It is limited to considering abstract change groups or using simplified models for change description. The same applies to the mapping of organizational structures and, thus, the responsibilities of the stakeholders. These are either not considered at all (e.g., ROUIBAH & CASKEY 2003) or only depicted in a highly simplified form. KOCH (2017), for example, describes the need to integrate individual corporate functions based on a one-dimensional relationship between change attributes and corporate function. A multi-dimensional division of responsibilities (e.g., based on the factory area and the production technology) was previously not considered.

Table 3 is structured on the basis of the findings just described. It illustrates the extent to which the preliminary work from Sections 3.2.1 and 3.2.2 addresses these aspects. The degree of consideration is represented by three-stage Harvey balls.

Table 3 Overview of relevant preliminary non-databased work.

	Change type		Stakeholder levels				Adaptability	
	EC	MC	Corporate functions	Organizational unit	Roles	Employees	Change-specific perspective	Modeling of responsibilities
Abramovici & Aidi 2015	●	○	○	◑	◑	◑	◑	◑
Koch 2017	○	●	●	○	○	○	◑	○
Martin et al. 2022	●	○	○	○	○	●	◑	◑
Rouibah & Caskey 2003	●	○	○	○	●	●	◑	◑
Rößing 2007	○	●	○	○	◑	○	●	○
Tang et al. 2010	●	○	○	◑	◑	◑	◑	◑

Legend: ○ Not fulfilled ◑ Partly fulfilled ● Fulfilled

3.3 Data-based approaches for Stakeholder Identification

The digitalization of manufacturing companies and the resulting availability of data has opened up new opportunities for the digital support of ECM and MCM. A selection of the preliminary work relevant to scenarios 2 and 3 (cf. Section 1.3), i.e., “Descriptive SI” and “Predictive SI”, is therefore presented below.

3.3.1 Approaches for Change Similarity Assessment

Only a few preliminary works present specific approaches for Change Similarity Assessment (CSA). Some methods require additional information not contained in the change data (Rößing 2007, Mehta 2010, Do 2018) and whose availability is therefore not given in the MCM domain. For example, Rößing 2007 assumes that it is known which production objects are affected how intensively by changes. Mehta (2010) uses STEP files to determine the similarity of changes. Both approaches are, therefore, not suitable for evaluating the similarity of MCs based on change data. Other approaches explicitly focus on the use of change data from ECM but limit the analysis to textual data without including additional data features.

Sharafi (2013) derives general potentials for improvement in the ECM process of an automotive manufacturer. The applied similarity assessment is based solely on textual change data. The procedure for CSA (cf. Figure 15) includes the standardization and tokenization of the text, the text filtering using stop word lists, the subsequent stemming, and the final vector transformation using the Term Frequency-Inverse Document Frequency approach

(TF-IDF). The similarities are then determined using various clustering algorithms and the metric cosine similarity.

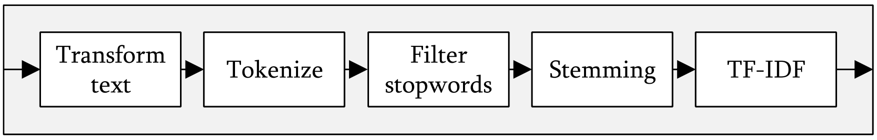

Figure 15. Procedure for the word vector creation based on SHARAFI (2013, p. 208).

GRIECO ET AL. (2017) apply the same procedure for data preparation as SHARAFI (2013) and use the approach of unsupervised learning utilizing Self-Organizing Maps (SOM) to identify similarities in the data set. The SOM function creates a map on which similar changes are positioned close to each other[8]. The k-means algorithm is subsequently applied to identify clusters of similar changes. The approach was evaluated based on a data set containing information about 54 ECs from a company in the railway industry. Like SHARAFI (2013), GRIECO ET AL. (2017) focus on the analysis of ECM data and use exclusively textual data for CSA.

3.3.2 Approaches for Change Impact Analysis

Multiple approaches have already explored the possibilities of exploiting ECM data. Some approaches support ECM through a data-based analysis of the product structure (e.g., GIFFIN ET AL. 2009, MEHTA 2010, DO 2015, KOCAR & AKGUNDUZ 2010, WICKEL & LINDEMANN 2015), the prediction of the financial efforts (e.g., RIESENER ET AL. 2021) or the identification of general process improvements potentials (ELEZI ET AL. 2011, GIFFIN ET AL. 2009, SHARAFI 2013). However, they either do not consider the organizational or social perspective of the ECM and MCM process or do not support the involvement of relevant stakeholders.

Other approaches explicitly address the identification of relevant stakeholders (e.g., DO 2018, WICKEL 2017, PASQUAL & WECK 2012) but rely on additional data sources, such as the Product Data Management (PDM). Therefore, these approaches are not applicable in the MCM domain. For example, Pasqual & Weck (2012) present a promising approach for product development analysis. The authors use a three-layer network model that draws on various information sources, such as staffing records or design documents. This model considers the layers Product, Change, and Social. It describes the relationships between and within the layers (cf. Figure 16). The social layer represents the organization and, thus, the association of persons or organizational units with changes and product components. This

[8] For details on SOM the interessted reader ist reffered to HUANG ET AL. (2001).

approach focuses primarily on an a-posteriori identification of improvement potentials for product development. An a-priori SI for a specific process phase is not addressed.

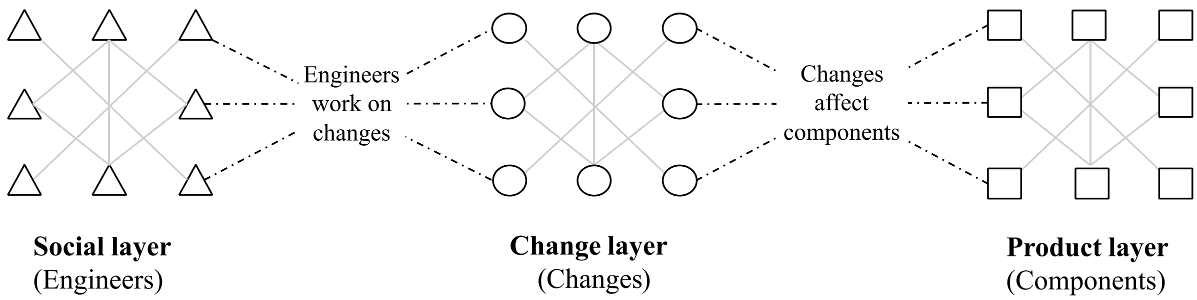

Figure 16. The multilayer network model of ECM adapted from PASQUAL & WECK (2012).

3.3.3 Cross-case findings

Sections 3.3.1 and 3.3.2 described relevant preliminary work for scenarios 2 and 3, i.e., descriptive and predictive SI. Multiple overarching findings were obtained, which are presented in detail below.

Change types

The data-based preliminary works also show a clear focus on the handling of EC in analogy to the preliminary work discussed in Section 3.2. The transferability of these approaches from the ECM to the MCM area cannot be assumed due to the different framework conditions. Examples include the data availability and the relevant stakeholders. It can, therefore, be stated that none of the approaches explicitly focus on MCM or the handling of individual MCs. Only RÖßING (2007) presents an approach for CSA of MC. However, it does not exploit actual change data, as it is based on impact matrices filled in by experts.

Stakeholder levels

The data-based approaches either do not address SI (e.g., GRIECO ET AL. 2017, MEHTA 2010) or do not consider it in detail (e.g., SHARAFI 2013, WICKEL 2017). Other approaches concentrate on individual stakeholder levels (e.g., DO 2018). ABRAMOVICI & AIDI (2015) basically address all three stakeholder levels in detail, limiting themselves to determining the necessary activities in ECM. At this point, there is no approach that claims to support SI in MCM.

Data basis

The availability of textual change data (e.g., change description), non-textual change data (e.g., change costs), and change process data can be assumed in the MCM domain. Therefore, it should first be noted that the preliminary work in the field of CSA (Section 3.3.1) is based exclusively on textual data (e.g., GRIECO ET AL. 2017, SHARAFI 2013). The option of integrating additional non-textual change attributes is not considered although this is considered a promising option (ARNARSSON ET AL. 2019). Furthermore, it became clear that the approaches for data-based process analysis and impact prediction (Section 3.3.2) from the ECM domain are, in most cases, dependent on additional information, e.g., from PDM systems. The availability and relevance of this information are not given in MCM. Finally, it can also be noted that the analysis of change process data in the area of MCM has not yet been considered.

Detail level of textual data analysis

Multiple preliminary approaches already exploit textual change data (e.g., (GRIECO ET AL. 2017, SHARAFI 2013, WICKEL 2017) but rely on simple Text Mining approaches driven by word frequencies. The possibilities of the NLP approaches introduced in recent years have not yet been explored in the field of ECM and MCM. These approaches enable a better understanding of semantic relationships in textual information (e.g., YANG ET AL. 2016). Only MEHTA (2010, p. 83) uses a taxonomy to capture similarities based on groups of specific terms with similar meaning.

Time perspective

Most data-based approaches from the fields of ECM and MCM take an a-posteriori perspective, aiming at a general analysis and improvement of change processes (e.g., SHARAFI 2013, PASQUAL & WECK 2012). A-priori support, i.e., before the analysis, selection, and implementation of a specific change, is often not provided. However, approaches that explicitly offer a-priori support (e.g., WICKEL 2017) either do not focus on SI (e.g., RIESENER ET AL. 2021) or only as a secondary aspect (e.g., WICKEL 2017).

Table 4 summarizes the extent to which the publications presented in Sections 3.3.1 and 3.3.2 consider the aforementioned criteria. The degree of fulfillment is again represented by the three-stage Harvey balls.

Table 4 Overview of relevant data-based preliminary work.

		Change type		Stakeholder levels			Data basis			Time perspective		Text analysis	
		Engineering Change	Manufacturing Change	Organizational unit	Roles	Employees	Change process data	Textual change data	Non-textual change data	A-priori	A-posteriori	Word frequencies	Semantic contexts
Change Similarity Assessment (3.3.1)	ABRAMOVICI & AIDI 2015	●	○	◐	◐	◐	○	○	○	●	○	○	○
	GRIECO ET AL. 2017	●	○	○	○	○	○	●	○	○	●	●	○
	MALAK 2013	○	●	○	○	◐	○	○	○	●	○	○	○
	MEHTA 2010	●	○	○	○	○	○	○	●	●	○	○	◐
	RÖSSING 2007	○	●	○	○	◐	○	○	○	●	○	○	○
Change Impact Analysis (3.3.2)	DO 2018	●	○	○	○	●	◐	○	◐	●	○	○	○
	PASQUAL & WECK 2012	●	○	◐	◐	●	●	○	◐	○	●	○	○
	SHARAFI 2013	●	○	◐	○	○	●	●	○	○	●	●	○
	WICKEL 2017	●	○	◐	○	○	●	●	○	●	●	●	○

Legend: ○ Not fulfilled ◐ Partly fulfilled ● Fulfilled

3.4 Facit: need for research

Sections 3.2.3 and 3.3.3 already presented interim conclusions for the analysis of the state of research. The following pages summarize the findings and present the research opportunities addressed in this thesis in detail.

First, it can be noted that the large amount of preliminary work demonstrates the high relevance of dealing with ECs and MCs. Second, although SI is described as relevant in many process-related models, hardly any preliminary work explicitly deals with this task. Explicit approaches originate primarily from the field of ECM. No approach for the MCM domain was found that goes beyond the specification of general guidelines. With regard to the data-based approaches, it can be stated that the large number of successful use cases illustrates the potential of data-based approaches in ECM. However, the transfer of these approaches to the field of MCM needs to be addressed. The high availability of change and change process data (SIPPL ET AL. 2021) offers current and future potential for supporting change management. In particular, the rapid developments in the field of NLP (VASWANI ET AL. 2017) provide new opportunities for increased text understanding.

The research opportunities (ROs) addressed in this thesis are explained below. The presentation is structured according to the three SI scenarios.

Research Opportunities Scenario 1 – Analog SI:
Two central ROs were identified with regard to SI scenario 1, i.e., the determination of relevant stakeholders without using change data. Following the principle of task and responsibility distribution in companies (KOSIOL 1976), clear criteria are required to define the responsibilities for MCs. The established description models (e.g., KOCH 2017, RÖßING 2007, AßMANN 2000) can serve as a basis for this, as this information has already been proven to be relevant within the MCM. Building on this, the attributes that indicate the relevance of stakeholders in MCM must first be determined and detailed. This information can then be used to provide support for the SI. The resulting approach must consider company-specific framework conditions, as existing work offers little support in this regard.

> **Research Opportunity 1:** Defining and detailing change attributes relevant to the identification of stakeholders in MCM
>
> **Research Opportunity 2:** Enabling Stakeholder Identification in MCM by modeling the responsibilities of stakeholders for MCs

Research Opportunities Scenario 2 – Descriptive SI:
Two ROs were also identified with regard to Scenario 2, i.e., the descriptive analysis of the stakeholders. Existing approaches for data-based CSA have so far focused on ECs and utilize exclusively textual data (e.g., GRIECO ET AL. 2017, SHARAFI 2013). This offers the opportunity to transfer these approaches to the MCM domain and enhance them with the option of flexibly integrating additional information. The resulting knowledge about similar past changes can be utilized in a descriptive SI method in MCM. This method should combine this knowledge with a systematic analysis of change process data, as this approach has already been successfully applied in the field of ECM (WICKEL 2017).

> **Research Opportunity 3:** Enabling the data-based similarity assessment of MCs
>
> **Research Opportunity 4:** Supporting the identification of relevant stakeholders in MCM through systematically analyzing change process data

Research Opportunities Scenario 3 – Predictive SI:
Preliminary data-based work often takes an a-posteriori perspective (e.g., PASQUAL & WECK 2012, SHARAFI 2013), providing no support for new changes. For the use case of SI, this implies that no direct prediction of relevant stakeholders based on textual and other change data is enabled. Preliminary work that already incorporates textual information but without the objective of SI is limited exclusively to basic, e.g., frequency-based Text Mining

approaches. The new NLP techniques introduced in recent years (JIAO & ZHANG 2021, YANG ET AL. 2016) significantly improve text understanding.

> **Research Opportunity 5:** Utilizing advanced methods of NLP for predicting stakeholder relevance in MCM

4 Requirements and Solution Concept

This chapter first describes the requirements (Section 4.1) identified as relevant for the support of SI in MCM. These requirements are considered during the presentation of the developed approaches (Section 5) and the final evaluation (Section 6). The chapter ends with an overview of the solution concept and the author's associated publications.

4.1 Requirements

The importance of defining requirements is emphasized in the DRM, as it is essential for guiding the research work and evaluating its success. (BLESSING & CHAKRABARTI 2009, p. 26). Requirements are an important influencing factor in the prescriptive phase, i.e., during the development of the solution approach. They are structured in this thesis according to HAMRAZ ET AL. (2013, pp. 771-772). These authors presented a broad overview of relevant requirements for the domain of ECM based on a literature analysis and industrial case studies (cf. Figure 17). This initial set of requirements was expanded based on relevant preliminary work, particularly WICKEL (2017). In her work, she specified requirements for the data-based support of ECM. The identified requirements were additionally discussed with the industrial partners supporting the research described in this thesis. Furthermore, general requirements were added to ensure scientific quality (HELFRICH 2016, pp. 95-96).

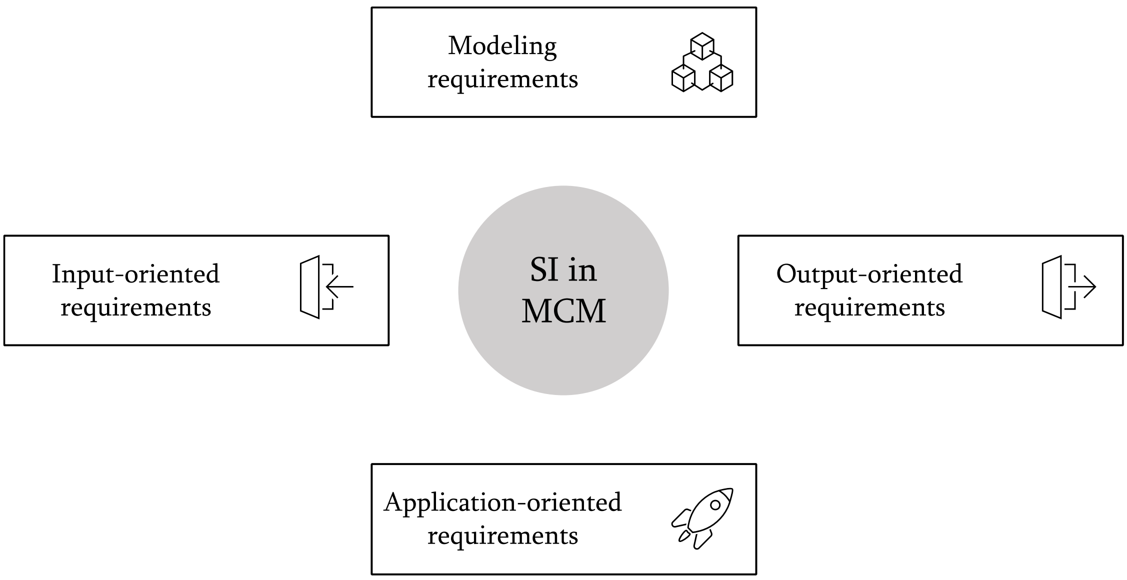

Figure 17. Requirements categorization based on HAMRAZ ET AL. (2013) and illustrated based on WICKEL (2017).

Input-oriented Requirements

R1. ***Use of available data:*** The approaches use available information, particularly change and change process data, and do not require additional data.

R2. ***Suitability for different change types:*** The SI approaches are applicable to a wide range of ECs and MCs and are not limited to specific change categories.

R3. ***Different stakeholder levels:*** The different levels and types of stakeholders (individual, role, group/department) can be considered.

Modeling Requirements

R4. ***Selection of additional attributes:*** Additional change data features can be exploited, and their selection is based on an objective procedure.

R5. ***Consideration of semantic information:*** Semantic relationships and contexts are considered when analyzing textual change data.

R6. ***Integration of expert knowledge:*** The procedures provide explicit opportunities to incorporate expert knowledge to make efficient use of the knowledge already available in the companies.

R7. ***Adaptability:*** The procedure can be adapted with low effort during preparation and implementation, e.g., to company-specific constraints.

Application-oriented Requirements

R8. ***Open-source software:*** The applied software is freely available, and its functionality is transparent.

R9. ***Industrial applicability***: The developed approaches can be easily applied in industrial use cases.

R10. ***Economic efficiency:*** The economic added value justifies the efforts required to introduce and apply the approaches.

Output-oriented Requirements

R11. ***Quantitative statements about the relevance of individual stakeholders:*** Quantitative statements are made to enable a systematic comparison of the stakeholders' relevance.

R12. ***Objectivity:*** The methods deliver the same results regardless of the person carrying them out when applied in identical circumstances. This “requires a precise description of the methodological procedure (transparency) and a certain level of standardization” (BORTZ & DÖRING 2006, p. 326)[9].

[9] Translated by the author. Original text in German: “(…) eine genaue Beschreibung des methodischen Vorgehens (Transparenz) und eine gewisse Standardisierung” (BORTZ & DÖRING 2006, S. 326).

R13. ***Reliability:*** The outcomes of the methods remain unchanged when applied repeatedly in the same circumstances (HELFRICH 2016, p. 96).

R14. ***Validity:*** The methods provide valid statements and thus prove the intended capability of the methodological procedures (HELFRICH 2016, p. 96).

The requirements apply to all scenarios with a few exceptions. Scenario 1 (analog SI) excludes R1, R4, and R5 as no change data is available. R5 is also not applicable to scenario 2 (descriptive SI), as there is no sufficient amount of change data for an in-depth text analysis.

4.2 Solution concept and publications

The following solution concept supports the Stakeholder Identification in MCM across the three defined scenarios (Section 1.3), addressing the ROs from Section 3.4 and the requirements from Section 4.1. It describes the steps and objectives for each SI scenario and the corresponding publications. Figure 18 provides an overview of the solution concept. The concept is split between the information preparation and the actual identification of relevant stakeholders in the three SI scenarios. The numbers represent the affiliation to the publications described in Chapter 5. Appendix A.2 contains a detailed overview of the author´s contributions to the publications.

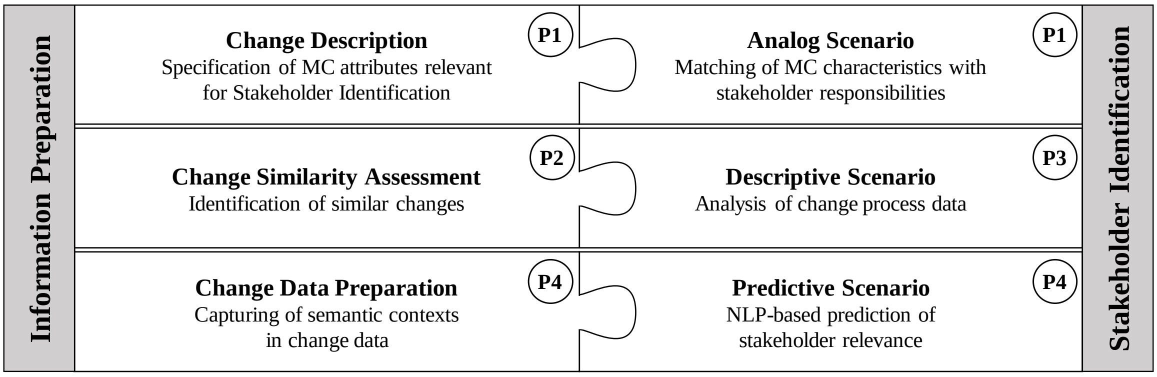

Figure 18. Overview of the solution concept.

MC attributes that indicate the relevance of stakeholders in MCM are identified during the information preparation for analog SI. The attributes are further detailed through a systematic literature review in different domains, including MCM and ECM. The identified attributes are confirmed and extended in interviews with change management experts from industry (RO1). Based on these attributes, an approach is to be developed to allow the SI in a change- and company-specific manner (RO2). The basic idea is to exploit the existing distribution of tasks and responsibilities within the company (KOSIOL 1976). Therefore, the modeling of stakeholder-specific responsibility profiles must be supported. An approach should support the SI by a systematic comparison of these responsibility profiles and the MC attributes. The complete approach is to be applied by Change Management experts in several realistic industrial use cases. The expert assessments of the result quality and the applicability are to be collected via a standardized questionnaire. All obtained results are detailed in Publication 1 (Section 5.1.1).

The information preparation for Descriptive SI aims to establish a method for assessing the similarity of MCs based on change data (RO 3). The necessary understanding of the available database should be generated through relevant literature from the fields of ECM and MC, as well as dialogs with industrial companies. The method for similarity assessment should be structured and conceptualized following the Cross-Industry Standard for Data Mining (CRISP-DM) of SHEARER (2000). The individual method components should be selected on the basis of the formulated requirements and relevant preliminary work. The method is intended to identify clusters of similar MCs. This knowledge should serve as a basis for introducing an approach for the descriptive support of SI (RO4). The SI should be based on the systematic analysis of change process data. The approach's structure should follow the L* methodology, as this is a common choice for the analysis of process data (RO4). Both solution components, i.e., the CSA and the PM-based SI, are to be tested in realistic use cases in an industrial environment. Change Management experts should evaluate the approach by using a standardized questionnaire. Publication 2 (Section 5.2.1) addresses the CSA (RO3), and Publication 3 (Section 5.2.2) focuses on the descriptive support of SI (RO4).

The predictive SI in scenario 3 relies on an in-depth analysis of textual change data and the flexible integration of additional change attributes. The aim is to directly predict the relevance of stakeholders for individual changes. The prerequisite is a data preparation, which allows the capturing of detailed semantic relations in the change data. This knowledge should be combined with a suitable prediction model for stakeholder relevance. Therefore, an overall methodology for the data selection and preparation, as well as for the training and application of the prediction models, is required. The SI approach structure should be based on the CRISP-DM methodology again to ensure a systematic approach (RO5). The quality of the prediction models is to be tested in realistic industrial use cases and quantified using suitable metrics. The results achieved are presented in Publication 4 (Section 5.3.1).

5 Approaches for Stakeholder Identification in MCM

This chapter presents the author´s publications and, thus, the main results of the research work. In the following Sections 5.1 - 5.3, summaries of the respective publications are presented. The sections' structure follows the considered SI scenarios.

5.1 Scenario 1: Analog SI

5.1.1 Publication 1: responsibility-based SI

Approach for Stakeholder Identification in Manufacturing Change Management

Fabian Sippl, Bernardo del Rio, Gunther Reinhart

This publication presents a SI method based on the principle of task analysis and synthesis (KOSIOL 1976), which refers to the fact that the overall task of a company is decomposed until manageable and clear task and responsibility profiles are established. These profiles can be defined for individuals, roles, or organizational units. The method supports the SI by comparing the responsibility profiles of the stakeholders with the change characteristics.

First, an initial set of change attributes that influence the selection of stakeholders was identified based on a literature review in the fields of MCM, ECM, and organizational theory. Second, the initial set was verified and supplemented in nine semi-structured interviews (GALLETTA 2013) with change management experts from five companies (cf. Appendix A.9). This type of interview follows a predefined structure, e.g., by using a guidline or a questionnaire, but also offers the flexibility to discuss further topics if considered relevant by the interviewees. In the end, eight superordinate attribute dimensions were considered relevant, as e.g., the Change Cause and the Change Complexity.

In the first step of the method, the users select the attributes relevant to their company from the catalog of change attributes. In the second step, each change attribute is further specified by adding quantitative or qualitative values or value ranges. The resulting morphological box represents the basis for modeling the responsibility distribution and it is then used to create Change Responsibility Profiles (CPRs) for relevant stakeholders (cf. Appendix A.8 for an example CRP). This allows stakeholders to explicitly specify in which change cases they want to be involved. If necessary, the stakeholders have the opportunity to create several profiles to account for the RASCI (Responsible, Accountable, Support, Consulted, Informed) role distribution.

During the application of the SI method, the morphological box is utilized to systematically describe a new MC in a Change Profile (CP). The stakeholder relevance is then quantified by assessing the match between the CP and the stakeholders' CRPs. The matching is quantified using path coverage metrics. These metrics are commonly used for quality assurance in the software sector (KLEUKER 2019, pp. 105-192). A complete overview of the workflow for method introduction and application can be found in Appendix A.10.

The application and evaluation were conducted in collaboration with an international mechanical engineering company. Experts in production engineering, manufacturing development, and work preparation provide 75 profiles of 15 employees. The method was applied in five specific change scenarios, including the introduction of a new production technology. A success and application evaluation was carried out with the help of a questionnaire. The result quality and the ease of application were rated positively. In contrast, the initial effort required to determine the relevant attribute dimensions was viewed critically. It was also noted that it can be challenging for stakeholders to define their CRP correctly.

5.2 Scenario 2: Descriptive SI

5.2.1 Publication 2: Change Similarity Assessment

Data-based Similarity Assessment of Engineering Changes and Manufacturing Changes

Fabian Sippl, Yosr Cheikh, Gunther Reinhart

The approach to support scenario 2 (cf. Section 4.2) is based on an analysis of the stakeholder involvement in similar past changes. Therefore, Publication 2 introduces an approach for data-based similarity assessment of technical changes. The operational goal is to automatically obtain a cluster of similar changes for a new change.

The approach was structured according to the CRISP-DM (SHEARER 2000), as it is “the defacto standard and an industry-independent process model for applying data mining projects” (SCHRÖER ET AL. 2021, p. 526). For the step of data preparation, existing approaches were first identified from literature (Section 3.3.1). Sharafi's approach (2013) was selected as a basis and then adapted based on the formulated requirements.

The first step of data preparation deals with the textual input data, such as the change description. Spelling errors and special characters are removed. Tokenization is applied, which breaks the text into individual components (“tokens”). The resulting text still contains word forms that are only comparable to a limited extent, such as conjugated verbs. Therefore, lemmatization is applied to convert all words to their basic form. Lists of stop words are used to explicitly remove words that are generally irrelevant to the meaning of the sentence, such as “an” or “the”. The user has the option of specifying additional irrelevant words. Individual word categories can also be excluded based on the part-of-speech tagging (CHICHE & YITAGESU 2022). This method identifies the word types, e.g., nouns, or adverbs. Subsequently, the Yet Another Keyword Extractor (CAMPOS ET AL. 2020) is used to focus the text corpus on the most important words. In the last step of data preparation, the Term Frequency Inverse Document Frequency[10] technique, whose underlying concept was introduced by SPARCK JONES (1972), is used to convert the text into vector form. This form is necessary for the application of ML algorithms. The data basis is then enriched with categorical and continuous data features, and their weighting is specified. This is followed by the actual clustering of the past MCs. It is advised to test several clustering algorithms to identify the most suitable option for the specific use case. The resulting change clusters are then used to train a classification model based on the k-nearest neighbor algorithm. New changes can be automatically sorted into existing change clusters with the aid of this model. A Python-based interface was developed to facilitate easy application of the method.

The application and evaluation were carried out in cooperation with a medical technology company, which provided a data set of 2.892 changes. Ten ECs and ten MCs were then tested in nine semi-structured interviews with change management experts. The changes had previously been randomly selected and not integrated into the training process of the clustering and classification models. The experts rated for each EC and MC on a Likert scale whether the identified clusters and the assignment of the new changes to these clusters was accurate. In the end, each expert answered a questionnaire to gain an overall success and application evaluation. The results indicated that both the quality of the clustering and the classification for ECs and MCs were perceived positively. However, in both cases, the values for MCs were slightly lower than those for ECs. According to experts, this effect was caused by the more structured description of ECs in the data set.

[10] The interessted reader is referred to ROBERTSON (2004) for more details.

5.2.2 Publication 3: Process Mining-based SI

A Process Mining-Based Approach for Stakeholder Identification in Manufacturing and Engineering Change Management

Fabian Sippl, Tim Moriz, Gunther Reinhart

Publication 3 builds on the similarity assessment of publication 2 to complete the approach for descriptive SI. The identified change clusters serve as a basis to analyze the process data of similar changes. This analysis has the objective to allow quantitative statements about the stakeholder relevance for a new change.

The SI approach was structured according to the L* model (VAN DER AALST ET AL. 2012, p. 6), which guides the analysis of process data. The first step of the method addresses the preparation of the change process data. The approach explicitly takes into account the change of MCM processes over time to enable a data basis that is as comprehensive as possible. The correction of this data inconsistency requires the synchronization of different process versions to a reference process.

The data extracted from the source systems is then converted into the *XES* format (eXtensible Event Stream). This format is a standard for the application of PM algorithms (VAN DER AALST 2016, p. 127). The result of this data transformation is an event log. The publication details which information must be provided at which event log level. The levels of *event log*, *case*, and *event* are differentiated. An *event log* consists of *cases*, which in turn contain *events.* At the *event log* level, it must first be clearly defined which process version is involved. *Cases* refer to individual ECs and MCs. These must be identifiable with the help of an *ID*. The change status must also be stored at the *case* level, e.g., whether it is in progress or already completed. At the *event* level, the *Activity*, the *Timestamp*, the *Resource*, the *Department,* and the *Synchronous Activity* are then stored. The *Activity* describes the name of the process phase, and the timestamp represents the time at which an event occurred. *Resource* specifies the employees or roles involved in the process, and the *Department* contains the assigned organizational unit. The *Synchronous Activity* describes the names of the same activity in the reference process to enable synchronization between different process versions. Data records of incorrect or incomplete change processes are removed during data preparation.

The prepared database is then used to conduct process analyses using Process Mining. This allows the process models of similar past changes to be created. The relevance of the stakeholders is then quantified by the frequency of their participation in similar past changes, as by WICKEL (2017). For the purpose of a practical application, the interface of the CSA tool was extended to enable an easy application of the descriptive SI approach (cf. Appendix A.12 for an exemplary user interface). The resulting SI tool was then tested during semi-structured interviews with eight Change Management experts of a medical technology company (cf. Appendix A.13 for details). At the beginning of the interview, the topic was introduced, and the tool was explained. The change management experts then had the opportunity to test the tool for eight different changes. They rated the accuracy of the quantified stakeholder relevancies at the employee and department level on a Likert scale from 1 to 5. It can be stated that the support of the SI was rated very positively at both the employee and department levels. In addition, most respondents agreed with the statement that the method has the potential to improve the efficiency and effectiveness of TCM.

5.3 Scenario 3: Predictive SI

5.3.1 Publication 4: NLP-based SI

Data-Based Stakeholder Identification in Technical Change Management

Fabian Sippl, Renè Magg, Carla Paulina Gil, Steffen Düring, Gunther Reinhart

Publication 4 introduces an approach for predicting the relevance of individual stakeholders for new changes. It incorporates methods of text classification and other advanced NLP approaches. In the first step, the data preparation, it is necessary to determine which previous changes were relevant for the stakeholder under consideration. This information is crucial as it represents the target value for the later prediction. The transformation of textual data into a numerical form is then carried out with the help of the Word2Vec approach (MIKOLOV ET AL. 2013). It was identified as suitable based on relevant NLP literature (YANG ET AL. 2016, BARONI ET AL. 2014). The resulting vector-based representation, the so-called word embedding, offers the advantage of considering the word context. The next step in the method is feature selection. It determines the relevant non-textual data features for the subsequent modeling. For this purpose, a correlation-based approach for feature selection was adopted due to its simplicity and successful applications (GUYON 2008). The approach utilizes the correlation of a feature with the target value to assess the feature's importance.

Hierarchical Attention Networks (HANs) (YANG ET AL. 2016) are then applied as classification models, as they allow the exploitation of semantic contexts. Multiple classification models are trained, and their accuracies are compared. The objective of the comparison is to identify the combination of textual and non-textual data features, allowing the highest classification accuracy. The metric recall was primarily used to evaluate the model quality. This metric incentivizes the model to reduce the number of stakeholders incorrectly classified as non-relevant. In the final step of the method, the prediction models are fine-tuned by integrating expert knowledge. For this purpose, workshops were identified as a suitable approach to discuss the FN cases of the prediction model with the considered stakeholders. In these workshops, text elements that indicate the relevance of the stakeholders are identified. These words and word combinations are then categorized based on their meaning, and all possible cross-category word combinations are generated. Each word combination is then assessed to determine whether its occurrence justifies the overwriting of the previous classification model with regard to the overall model quality. Word combinations with an overall positive impact are then permanently integrated to adjust the classification results.

The approach was applied in cooperation with an international car manufacturer. The objective was to predict the relevance of a change request for the assembly department. The trained classification models delivered positive results. However, the integration of additional attributes significantly further improved the result quality in terms of recall and other considered metrics. A workshop was then organized with 14 experts from the assembly department to determine potentially relevant word combinations (cf. Appendix A.15 for examples). The result quality was again slightly improved by adjusting the predictions based on these word combinations. The overall quality of the prediction model was better than a purely manual SI.

6 Critical Reflexion

This chapter reflects on the approaches developed for the identification of relevant stakeholders in MCM. The following sections discuss the fulfillment of the requirements formulated in Section 4.1, the economic viability, and the existing limitations.

6.1 Fulfillment of requirements

The sections' structure is aligned with the requirements categories introduced in Section 4.1. Table 5 presents an overview of the fulfillment of the requirements, which is again illustrated by three-stage Harvey balls. It is followed by more detailed explanations. R10 "Economic Efficiency" is discussed in detail in Section 6.2., but is also included in Table 5 to provide a complete overview.

Table 5 Overview of requirements fulfillment.

	Input-oriented requirements			**Modeling requirements**				**Application-oriented requirements**			**Output-oriented requirements**			
	R1: Available data	R2: Change types	R3: Stakeholder levels	R4: Additional attributes	R5: Semantic information	R6: Expert knowledge	R7: Adaptability	R8: Open-source software	R9: Industrial applicability	R10: Economic efficiency	R11: Quantitative statements	R12: Objectitivy	R13: Reliability	R14: Validity
Analog SI	●	●	●	n/a	n/a	●	●	◑	●	●	●	◑	●	●
Descriptive SI	●	◑	●	●	n/a	●	●	●	●	●	●	●	●	●
Predictive SI	●	●	◑	●	●	●	●	●	●	●	●	●	●	●

Legend: ○ Not fulfilled ◑ Partly fulfilled ● Fulfilled n/a Not applicable

Input-oriented Requirements

The first requirement (R1) demands that the SI approaches only rely on data that can be assumed to be available in MCM. All presented approaches do not require the integration of additional data sources or IT systems. They only rely on data attributes that are commonly collected in MCM, as proven by current surveys. Therefore, R1 can be considered fulfilled for all approaches.

The second requirement (R2) states that all approaches should be applicable to a wide change variety. This applies in principle to all approaches. However, one limitation was identified during the industrial evaluation of the descriptive approach. It refers to the change property novelty. The descriptive approach requires the identification of similar changes. Therefore, the method provides no support if this is not possible. The predictive approach offers an advantage in this regard. The generalization of semantic correlations between changes and stakeholders although also based on historical data, can provide indications on new MCs. No limitations were noted during the application of the analog SI approach. The established description model allowed the sufficient classification of all tested MCs. In conclusion, the analog and the predictive approaches fully met R2, while the descriptive approach only reached partial fulfillment.

The third requirement (R3) demands the applicability at the different stakeholder levels of employees, organizational units, and roles. The analog and the descriptive approaches allow the consideration of all stakeholder levels. Although applying the predictive approach at the employee level is possible, it requires high effort. This effort results from the need to create individual classification models for all stakeholders. In summary, the analog and the descriptive approaches fulfill R3 completely, while the predictive approach only reaches partial fulfillment.

Modeling Requirements

The requirement R4 calls for a systematic procedure to integrate additional data attributes. This requirement is not applicable in the analog scenario, as no data is utilized in this case. The descriptive and predictive approaches introduce a step-by-step method for selecting and integrating additional attributes that positively impact model quality. Therefore, R4 was completely fulfilled by both approaches.

The integration of semantic contexts represents the fifth requirement (R5), which was only intended for the predictive scenario. The approach for this scenario incorporates advanced NLP techniques, such as Word Embeddings and HANs. These techniques were specifically developed to enable a deep text understanding. R5 was completely fulfilled due to this fact and the positive results of the industrial application.

The sixth requirement (R6) addresses the utilization of expert knowledge, and the seventh requirement (R7) focuses on the adaptability. All three approaches explicitly facilitate the capturing and integration of Change Management knowledge. In the analog scenario, users can add further description dimensions and their weighting. In the descriptive scenario, the experts have the possibility to adjust word weightings or explicitly exclude words. In the predictive scenario, the experts can influence the classification model's fine-tuning by specifying relevant words and word combinations. In summary, all approaches allow the integration of expert knowledge and company-specific adaptation. This shows that R6 and R7 can be considered completely fulfilled.

Application-oriented Requirements

Requirement R8 demands the exclusive use of open-source software. The software of the descriptive and the predictive approach only incorporates freely accessible Python software codes and libraries[11], such as pm4py (BERTI ET AL. 2023) or NumPy (HARRIS ET AL. 2020). In contrast, the template for the change description used in the analog SI approach was implemented in Microsoft Excel. This software was selected at the request of an application partner although it cannot be classified as open-source software. However, the VBA code is accessible at any time and can be easily adapted and transferred to open-source alternatives with little effort. In summary, the descriptive and predictive approaches fully comply with R8, while the analog approach only partially fulfills this requirement.

The ninth requirement (R9) addresses the industrial applicability. It was ensured that all use cases tested during the evaluation of the approaches were a realistic representation of industrial practice. The positive results initially confirm the industrial applicability of all three approaches (R9).

Output-oriented Requirements

A quantitative assessment of stakeholder relevance is demanded by requirement R10. All SI approaches presented in this thesis explicitly consider this aspect. The analog approach quantifies the relevance by matching the change characteristics with the stakeholders' responsibilities. The descriptive approach uses the participation in similar past changes as a reference. The predictive approach utilizes a text classification model that incorporates a softmax function as an output layer to evaluate the classification reliability (BRIDLE 1989). Therefore, all approaches fully comply with R10.

The eleventh requirement (R11) addresses the avoidance of subjective influences. First, it has to be noted that all three SI approaches rely on expert knowledge, albeit to varying

[11] For a complete overview of the used Python libraries see Appendix A.19

extents. A high risk of subjective influences is associated with the stakeholder-individual filling of the CRPs in the analog scenario. The individual CRPs are based exclusively on the self-defined responsibilities of the stakeholders. Therefore, a mode for joint reviews of the profiles should be agreed on. In the descriptive scenario, expert knowledge is required in two steps: the selection and weighting of data features during the change clustering and the final stakeholder selection. Quantitative statements are provided in both steps, allowing for more objective decisions. During change clustering, relevant data attributes are initially defined on expert basis, but suitable metrics measure their impact on the clustering quality. The final stakeholder selection is still the responsibility of the change manager. However, the decision is supported by a quantified assessment of the stakeholders' relevance based on their participation in past changes. For the predictive approach, a subjective risk has to be reported concerning the fine-tuning of the classification model. In this step, experts specify words and word combinations that, in their opinion, indicate the relevance of stakeholders. These statements' validity and the suggestions' influence on the overall model quality are quantitatively assessed. In the end, only words and word combinations with an overall positive effect are integrated into the stakeholder prediction. Subjective influences are eliminated during the application as the SI is fully automated. In summary, the analog approach only partly fulfills the requirement of objectivity, as it still relies on expert knowledge during the CRP and CP creation. In contrast, the descriptive and predictive approaches fully comply with R11 as quantitative assessments back all expert inputs.

R12 addresses the approaches' reliability. All approaches have a deterministic behavior after the training or the creation of the models. This applies to the classification models of the descriptive and predictive approaches as well as the matching of MC characteristics with stakeholder responsibilities in the analog scenario. Therefore, all three approaches completely fulfill R12.

The last requirement (R13) demands for the validity of the approaches. In the case of the analog and descriptive approaches, the usefulness and the accuracy of the results were assessed positively in expert-based evaluations. In the case of the predictive approach, the validity could be proven by a data-based comparison indicating that the resulting quality of the classification model exceeds that of the expert-based prediction. Therefore, all three approaches fully comply with R13.

6.2 Cost-benefit ratio

The economic viability of the SI approaches is evaluated in this section in comparison to a purely manual SI. It should be noted that the primary aim of this work was to support the SI to avoid errors. In contrast, an effort reduction per SI was not a primary objective.

Therefore, this section describes the necessary efforts and compares them with the opportunities to avoid the risks associated with incorrect SI.

The aim is to reduce errors late in the MCM process, following the fundamental idea of the rule of ten for the increase of failure costs over time (CLARK & FUJIMOTO 1991). This would avoid high financial and time risks, e.g., during change implementation. Table 6 presents the initial and ongoing economic efforts. The latter is split into change-independent (e.g., software maintenance) and change-dependent efforts (e.g., time required to check the relevance of a stakeholder for a specific change). The four scenarios (manual, analog, descriptive, predictive) are compared based on an example company. This company was inspired by the medical technology company that has already participated in the evaluation of the descriptive approach. Based on this knowledge, it is assumed that 300 MCs take place per year and that three change managers, together with 30 potential stakeholders, participate in MCM. The efforts are calculated for an observation period of three years, and the personnel costs are set to 900 €/day for an engineer (HÖLLTHALER 2022, p. 154). Additional assumptions and limitations underlying the calculations are listed in Appendix A.17. Appendix A.18 shows a detailed breakdown of the efforts.

Table 6 Efforts of the introduced approaches for SI in MCM compared to a manual SI.

Efforts	Manual SI	Analog SI	Descriptive SI	Predictive SI
Initial effort	0 €	9.900 €	11.700 €	19.800 €
Ongoing effort (change-independent)	0 €	6.300 €	5.400 €	5.400 €
Ongoing effort (change-specific)	10.800 €	8.100 €	8.100 €	0 €
SUM	10.800 €	24.300 €	25.200 €	25.200 €

The results show that all developed approaches have significantly increased financial efforts compared to a manual SI. This difference results from the fact that the latter only causes direct efforts for a purely subjective and unstructured SI with no initial or change-independent ongoing efforts. In contrast, high initial and ongoing manual efforts can be reported for the analog scenario. They are required to create and maintain the CRPs. Compared to the other approaches, a significantly higher number of persons is involved, as all change managers and stakeholders have to participate. The descriptive SI has similar initial efforts due to the necessary data preparation and programming. However, the ongoing efforts are lower, as only the maintenance of the ML models and the software is required. The predictive approach has significantly higher initial efforts. They are caused by the high complexity of the data preparation and the model training, as well as the necessary fine-tuning of the ML models in expert workshops. The change-independent ongoing costs are similar to those of the descriptive approach. However, the predictive approach entirely avoids the change-dependent costs due to the complete automation of SI.

A break-even analysis is often applied to evaluate the profitability of investments. This method compares the financial efforts of the investment alternatives over time. The objective is to determine the point at which the total efforts of the investment alternatives are below the currently used status quo. In the case of this thesis, this would imply that the efforts for SI are below those of a purely manual scenario. It must be acknowledged that the ongoing change-independent efforts of the descriptive and analog SI exceed the effort savings in the change-dependent efforts. Therefore, no break-even point is reached with a purely effort-focused perspective. In the case of predictive SI, a positive effect can be observed after the high initial efforts, namely the complete avoidance of change-dependent efforts. However, this effect is weakened by the ongoing expenses that are independent of changes. This implies that the break-even point is reached in this scenario, but only after 11 years. Consequently, it must be concluded that a purely effort-based analysis does not directly support the introduction of the developed approaches.

However, a purely effort-based assessment of the economic viability disregards the main objective of the introduced approaches. This objective was to avoid missing relevant stakeholders and, thus, reduce the risk of high follow-up costs. These risks can hardly be quantified precisely, but the resulting costs for production downtimes indicate the consequences of incorrect SI. The scientific and industrial literature provides a variety of statements on the financial damage of downtimes, depending on the cost categories considered. The cost of one hour of unplanned production downtime in the automotive industry was estimated in 2022 at 2 million dollars (SIEMENS AG 2023). Other sources estimate the costs to be 1.32 million dollars per hour (RAVANDE 2022). An expert interview[12] with an employee of an environmental technology manufacturer revealed costs of 15.000 €/h, albeit with a purely sales-based calculation and a focus on a single production line. A survey in the Swedish manufacturing industry in 2016 revealed an average value of 980 €/h. The authors of the study themselves stated that the actual costs are probably significantly higher and that this survey result is caused by a lack of awareness of the actual costs (SALONEN & TABIKH 2016).

These values must be set in relation to the costs for the introduction and application of the developed SI approaches. The additional costs are between 4.500 € (analog SI) and 4.800 € (descriptive and predictive SI) per year in the first three years[13]. The break-even point is

[12] The interview was conducted on 19.01.2024. The interviewee worked as a project manager for a global environmental technology company.

[13] Calculation of the additional costs based on Table 6: The difference between the total costs of the proposed SI approaches and a manual SI are divided by the evaluation period (three years). Example for the analog approach: (24.300 € - 10.800 €) / 3 = 4.500 €.

reached after less than one minute of prevented downtime, assuming the highest damage per downtime hour of 2 million dollars. Even if only a loss of 980 € per downtime hour is assumed, an added value is already achieved after around five prevented downtime hours per year. In addition, applying the methods could lead to further cost savings, such as avoiding rework.

The results indicate that introducing the developed SI approaches can quickly become cost-effective and thus increase the company's profitability. However, the approaches are generally more suitable for companies with a high change volume and a high number of potentially relevant stakeholders. Conventional approaches can also be a reasonable alternative for small companies with a simple distribution of responsibilities. An example of a conventional approach is a change board, in which representatives of all potentially relevant departments discuss upcoming changes at fixed intervals.

6.3 Limitations

The presented approaches offer the potential to improve SI in MCM, as described in previous sections. However, their limitations and weaknesses must also be considered for a holistic assessment. The most relevant aspects are presented below.

1. Necessity for a flexible application of methods

The developed approaches address three different scenarios, which consider both company-specific and change-specific conditions. Therefore, a careful method selection is necessary, depending on the use case under consideration. This applies in particular to the predictive approach, as it aims for a SI without the intervention of a human change manager. For example, an additional review of the identified stakeholders could be appropriate in the case of expensive or critical changes. However, this thesis does not provide indications on which method should be applied in which change cases. Therefore, the economic evaluation did not consider the flexible method selection (cf. Appendix A.17). A change-specific selection of methods would reduce the number of MCs per method and, therefore, influence the economic viability.

2. Changes to the organization

The SI approaches are based on the modeling of stakeholder responsibilities, either directly through the recording of responsibility profiles or indirectly through the analysis of dependencies in change data. Large-scale changes in the organizational structure, e.g., splitting departments into several groups, can cause the available change data and the responsibility profiles to no longer fully reflect the current dependencies. In the case of analog SI, this requires an adjustment or recreation of the responsibility profiles. In the case of data-based approaches (descriptive and predictive SI), the data has to be corrected manually, which is time-consuming despite the provided data preparation template. A holistic specification of the organizational change cases and their implications for the change data was not in the scope of this work.

3. Criticality of expert knowledge for analog SI

It was demonstrated for all three SI approaches that integrating MCM experts' knowledge can positively affect the creation or fine-tuning of the necessary models. The effect and correctness of integrating expert knowledge can be quantitatively assessed and validated in the descriptive and the predictive scenario. However, the approach for analog SI relies primarily on the responsibility profiles created by individual stakeholders. A manual consistency control is not directly possible due to the high number of necessary profiles when applied in an industrial environment. This consistency control should, for example, detect overlaps or unaddressed areas of responsibility. Therefore, the significant influence of expert knowledge leads to the risk of systematic errors in the analog SI.

4. Criticality of data reliability for descriptive and predictive SI

The approaches to descriptive and predictive SI require the change data to correctly reflect the characteristics of the MCM, such as the implicit way to textually describe changes. However, the behavior of the MCM stakeholders might change over time, e.g., due to the hiring of new employees or a change in the corporate culture. It is necessary to review the data reliability critically at regular intervals to detect these changes. Otherwise, there is a risk that the ML models gradually change their behavior over time. This problem is a well-known phenomenon in the field of ML and is referred to as concept drift (TSYMBAL 2004).

5. Criticality of data availability for descriptive and predictive SI

The descriptive and predictive SI approaches require the availability and accessibility of the necessary amount of change and change process data. Current surveys show that an absolute majority of manufacturing companies support MCM digitally and thus record data. However, the actual availability of high-quality change data is estimated to be lower. One reason for this is that around one-fifth (21%) of companies support the change process with Microsoft Excel (SIPPL ET AL. 2021). This software only partially ensures compliance with a structured process and, thus, systematic data recording. Furthermore, the accessibility of the change management data poses a challenge for many companies. Change data is easily accessible in roughly 50% of companies, while change process data is accessible in only 32%

of companies. This limits the industrial applicability of the approaches for descriptive and predictive SI.

6. Industrial application and evaluation

All SI approaches were tested in realistic application scenarios in manufacturing companies. However, each method was only applied in one company, and the application was carried out in three different industries (mechanical engineering, medical technology, and automotive). Therefore, the evaluation is based on company-specific conditions, such as the available data set or the Change Management experts. A general transferability of the findings, e.g., regarding the result quality, can therefore not yet be confirmed. The validity of the findings for other industries should be evaluated in the next step. Industry-specific requirements must be identified and their fulfillment by the developed SI approaches reviewed for this purpose. The SI approaches should then be used in everyday industrial practice with a concluding application and success evaluation. The transferability, the potential, and any possible needs for adaptations can only then be described for specific industries. Furthermore, the author's assumptions regarding the assessment of economic viability are based directly on the experiences gained during the industrial application. For example, using open-source software was included as a cost reduction. The programming effort would be significantly higher if companies refused to integrate this software type.

7 Summary and Future Perspectives

7.1 Summary

The fundamental motivation behind this thesis is to increase the efficiency and effectiveness of dealing with MCs, offering theoretical and practical implications for research and industry. This objective should be accomplished through the facilitation of Stakeholder Identificiation in MCM. There is a risk of errors and inefficiencies during change implementation if relevant stakeholders and their change assessments are not considered during CIA. This can lead to high follow-up costs or the necessity for new changes. Therefore, supporting SI contributes to a more efficient and effective handling of changes through better communication during change preparation, which is generally seen as a problem in MCM and ECM. The thesis differentiates between three SI scenarios. The scenarios consider the availability of change data, both with regard to the specific change and the company under consideration. This is followed by the introduction of three separate SI approaches for these scenarios with different levels of support and automation.

First, a SI approach is presented for a scenario without the availability of change data. The approach is based on a systematic comparison of the change characteristics with the responsibilities of the stakeholders. For this purpose, the change characteristics with an influence on the SI were first identified and structured based on a systematic literature research and expert interviews.

The second scenario addresses the case of a limited database in the company, e.g., due to a low change volume. A similarity assessment approach of the ECM domain was adapted and enhanced to demonstrate that MC and EC can be clustered with similar quality. An SI approach was presented to prepare and use change process data to prioritize the stakeholders based on the identified groups of similar changes.

The third scenario assumes a high availability of change data. The developed approach exploits the semantic relationships in the change data and aims for a direct prediction of stakeholder relevance. Therefore, this thesis introduced a methodology for data selection and preparation and training of prediction models. The methodology combines NLP approaches with the knowledge of Change Management experts.

All three approaches were applied and evaluated in realistic industrial use cases. Either an expert- or a data-based assessment was undertaken to rate the applicability and the resulting quality. The results show that the systematic support of SI is achievable in all scenarios while indicating further opportunities to improve the SI and the overall MCM.

7.2 Future perspectives

Current surveys (RAMMO & GRAF 2023, SIPPL ET AL. 2021) highlight MCM's high and further growing industrial relevance. This industrial need, combined with current trends, such as digitalization, artificial intelligence, and decarbonization, results in numerous research potentials. Four potentials for the further enhancement of Stakeholder Identification in MCM, as well as for MCM in general, are briefly proposed in the following.

A) Flexibilization of MCM

The variety of MCs requires a flexible approach to organizing the MCM efficiently. This thesis incorporates this idea by differentiating between three SI scenarios. However, a holistic concept for increasing the flexibility of MCM should be developed in the future. Multiple flexibilization dimensions have to be considered and efficiently combined. Examples include the change-dependent adaptation of the MCM process (process tailoring), the selection of methods and stakeholders, and the integration of suitable digital tools. A prerequisite for change-specific flexibilization is a clear understanding of the intended change. A data-based change characterization could support this. For example, a risk assessment regarding financial expenses or delays could be provided on the basis of the experience gathered from similar past changes. From an industrial perspective, it also seems necessary to strive for the flexibilization of general MCM processes. The modeling and flexibilization of industrial MCM processes should also be enabled.

B) Opportunities for Natural Language Processing and Generative AI

This thesis demonstrates the potential of advanced NLP approaches. However, the domains of NLP and Generative AI are undergoing rapid developments, especially since the introduction of the Transformer models in 2017 (VASWANI ET AL. 2017). This development has already resulted in new possibilities to support SI and facilitate the entire MCM process. The emergence of Large Language Models (LLMs) is a crucial building block in this respect. They enable a deep language understanding by default. Future research should build on LLMs and provide indications on how these models can be fine-tuned for specific tasks in MCM. This would significantly reduce the required training data and allow more, especially smaller companies, access to these advanced approaches.

C) Digital Twins for MCM

Increasing digitalization and the availability of corresponding data have stimulated extensive research in the field of Digital Twins in recent years. The application has already been investigated for different factory levels, such as individual production processes (CHEN ET AL. 2021), order processing (WAGNER ET AL. 2021), and production networks (BENFER ET AL. 2021). The linkage of these models offers great potential for increasing the understanding of interdependencies in production systems. Such a consolidating model could, for example, support the determination of the change impacts at a new level of detail or also facilitate the early identification of change necessities by simulating future scenarios.

D) The human side of MCM

Research in the field of MCM often focuses on procedures for planning and implementing MCs or supporting individual tasks within MCM with tailored methods or tools. However, it should be acknowledged that the success of change projects heavily depends on the acceptance and cooperation of all affected employees. This is especially relevant for the introduction of new digitalization solutions, which is currently a challenge for many manufacturing companies. The affected employees must accept the new solutions and recognize the intended benefits. This human side of change management has so far been considered more explicitly and methodically in OCM. Future research should, therefore, focus on the transfer and the integration of methods and paradigms from OCM into MCM. This has the potential to reduce employee resistance and, at the same time, increase motivation for change projects.

Manufacturing companies should acknowledge MCM as a key enabler for a resilient and future-proof production system. Current developments such as the increasing digitalization, the integration of AI, or the efforts to create a climate-neutral industry require permanent changes in factories. Therefore, both research and industry should collaborate to advance the MCM further. The efficient and effective handling of changes will continue to be a decisive factor for manufacturing companies' existence and long-term success.

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Wynn, D. C.; Caldwell, N. H.; John Clarkson, P.: Predicting Change Propagation in Complex Design Workflows. Journal of Mechanical Design 136 (2014) 8.

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Zwikael, O.; Elias, A. A.; Ahn, M. J.: Stakeholder collaboration and engagement in virtual projects. International Journal of Networking and Virtual Organisations 10 (2012) 2, p.117-117.

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Appendix

A.1 Integrated publications

Sippl, F.; Moriz, T.; Reinhart, G.: A process mining-based approach for stakeholder identification in manufacturing and engineering change management. Procedia CIRP 107 (2022), S. 978-983.

Sippl, F.; Del Rio, B.; Reinhart, G.: Approach for stakeholder identification in Manufacturing Change Management. Procedia CIRP 106 (2022), S. 191-196.

Sippl, F.; Magg, R.; Gil, C. P.; Düring, S.; Reinhart, G.: Data-Based Stakeholder Identification in Technical Change Management. Applied Sciences 12 (2022) 16, S. 8205.

Sippl, F.; Cheikh, Y.; Reinhart, G.: Data-based similarity assessment of engineering changes and manufacturing changes. Procedia CIRP 120 (2023), S. 422-427.

A.2 Confirmation of author contributions

The publications integrated in this cumulative dissertation are the result of a trusting and successful collaboration with several co-authors. The author's contributions were confirmed by the co-authors and are specified in Table 7 below. The author would like to take this opportunity to thank all co-authors.

Publication 1 (P1):
Sippl, F.; Cheikh, Y.; Reinhart, G.: Data-based similarity assessment of engineering changes and manufacturing changes. Procedia CIRP 120 (2023), S. 422-427.

Publication 2 (P2):
Sippl, F.; Del Rio, B.; Reinhart, G.: Approach for stakeholder identification in Manufacturing Change Management. Procedia CIRP 106 (2022), S. 191-196.

Publication 3 (P3):
Sippl, F.; Moriz, T.; Reinhart, G.: A process mining-based approach for stakeholder identification in manufacturing and engineering change management. Procedia CIRP 107 (2022), S. 978-983.

Publication 4 (P4):
Sippl, F.; Magg, R.; Gil, C. P.; Düring, S.; Reinhart, G.: Data-Based Stakeholder Identification in Technical Change Management. Applied Sciences 12 (2022) 16, S. 8205.

Table 7 Overview of the author's contributions.

Task	P1	P2	P3	P4
Overall Idea	90%	90%	90%	70%
Data Preparation	35%	n.a.	35%	n.a.
Development of the Methodology	70%	70%	70%	65%
Implementation	40%	n.a.	50%	30%
Preparation and Conduction of the Evaluation	50%	60%	60%	60%
Project Management	90%	90%	90%	90%
Writing the Manuscript	80%	60%	65%	70%
Correction and Improvement of the Manuscript	90%	90%	90%	90%

A.3 Publications of the author

The author was involved in the following publications either in a leading role or as a co-author during his work as a research associate.

BAUER ET AL. 2020
Bauer, H.; Haase, P.; Sippl, F.; Ramakrishnan, R.; Schilp, J.; Reinhart, G.: Modular change impact analysis in factory systems. Production Engineering 14 (2020) 4, S. 445-456.

BERNHARD ET AL. 2024
Bernhard, O.; Sippl, F.; Zäh, M. F.: Augmented Reality in der kollaborativen Fabrikpla-nung von KMU. Zeitschrift für wirtschaftlichen Fabrikbetrieb 119 (2024) 3, S. 120-125.

CAPISTRANO BURGOS ET AL. 2022
Capistrano Burgos, R.; Sippl, F.; Radisic-Aberger, O.; Weisser, T.: Data-Based Method for the Implementation Planning of Engineering Changes in the Automotive Industry. Proceedings of the Design Society 2 (2022), S. 343-352.

MILDE ET AL. 2021
Milde, M.; Sippl, F.; Reinhart, G.: Simulation of order processing in global production networks. Procedia CIRP 104 (2021), S. 8-13.

SIPPL ET AL. 2020
Sippl, F.; Haghi, S.; Wagner, S.; Reinhart, G.: Flexibilisierung des Änderungsmanage-ments. Zeitschrift für wirtschaftlichen Fabrikbetrieb 115 (2020) 6, S. 394-398.

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Sippl, F.; Schellhaas, L.; Bauer, H.: Umfrage zum Änderungsmanagement in der Produktion Status quo, industrielle Anwendung der Änderungsauswirkungsanalyse und Stand der Digitalisierung. Zeitschrift für wirtschaftlichen Fabrikbetrieb 116 (2021) 4, S. 208-212.

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Sippl, F.; Moriz, T.; Reinhart, G.: A process mining-based approach for stakeholder identification in manufacturing and engineering change management. Procedia CIRP 107 (2022), S. 978-983.

SIPPL ET AL. 2022b
Sippl, F.; Del Rio, B.; Reinhart, G.: Approach for stakeholder identification in Manufacturing Change Management. Procedia CIRP 106 (2022), S. 191-196.

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Sippl, F.; Reinhart, G.: A Framework for Data-Based Change Impact Analysis in Manufacturing. Procedia CIRP 104 (2021), S. 247-252.

WONSAK ET AL. 2021
Wonsak, I.; Bauer, H.; Sippl, F.; Reinhart, G.: A scenario-based approach for translating strategic perspectives into input variables for production planning and control. Procedia CIRP 104 (2021), S. 429-434.

A.4 Supervised student research projects

The author of this thesis supervised multiple student research projects during his work as a research associate at the Institute for Machine Tools and Industrial Management (*iwb*) at the Technical University of Munich (TUM). Some results have been directly or indirectly incorporated into this thesis. The author would like to thank all students for their dedication and commitment.

Table 8 Overview of the supervised student research projects.

Student	Jahr	Title	Contribution to chapter(s)
Paulo Montijo Bandeira	2019	Framework for the Company-Specific Selection of Data-Driven Methods for Evaluating Technical Changes	1, 2
Sarah Wagner	2020	Process Flexibilisation of Technical Change Management	2, 3
Tim Moriz	2020	Potential of Process Mining for Indirect Production-Related Areas: A Systematic Literature Review	2
Lukas Schellhaas	2020	Survey on Change Management in Manufacturing- Status Quo and Application of Change Impact Analysis	1
Raquel Capistrano Burgos	2021	Data-Based Method for the Implementation Planning of Engineering Changes in the Automotive Industry	2, 3
Tim Wrede	2021	Data Analysis and Complexity Assessment of Technical Change Processes using Process Mining	2, 3
Bernardo Del Rio	2021	Development of a Method for Stakeholder Identification in Technical Change Management	1, 3, 4, 5
Tim Moriz	2021	A Process-Mining-Based Method to Identify Relevant Stakeholders within Technical Change Management	2, 3, 4, 5
Yosr Cheikh	2021	Data-based Similarity Assessment of Technical Changes	3, 4, 5
Lukas Jünger	2022	Data-Based Support for Change Characterization	2, 3
René Magg	2022	Data Analysis in Change Management for Digitalised Stakeholder Identification	3, 4, 5

A.5 Literature references of the initial impact model

An initial impact model for an improved Stakeholder Identification in MCM was presented in Section 1.3 as part of the application of the Design Research Methodology. The impact relationships were justified based on the literature. Table 9 provides an overview of the references in the literature.

Table 9 Overview of the literature reference for the initial impact model.

Literature reference	Literature source(s)
1	FRICKE ET AL. 2000, MALAK 2013, PLEHN 2017, BAUER 2024, SHARAFI 2013
2	PROSTEP IVIP E.V. 2015, PLEHN 2017, POHL 2014
3	RAMMO & GRAF 2023, KOCH 2017, PROSTEP IVIP E.V. 2015, JARRATT ET AL. 2005
4	KOCH 2017, KARL & REINHART 2015
5	WIENDAHL ET AL. 2007, NYHUIS 2010, STANEV ET AL. 2008, CISEK 2005
6	PLEHN 2017, BAUER 2024, TERWIESCH & LOCH 1999
7	PROSTEP IVIP E.V. 2015, BAUER 2024, KOCH 2017

A.6 Inclusion and exclusion criteria for literature analysis

The following inclusion (IC) and exclusion (EX) criteria were applied to focus the literature analysis on the most promising preliminary publications.

IC 1: publications in German or English

IC 2: conference articles, journal articles, dissertations, and books

IC 3: publications issued before 31.11.2023

EC 1: publications issued before 01.01.2000

EC 2: non-peer-reviewed publications

EC 3: grey literature, reviews, and newspaper articles

A.7 Literature analysis: overview of keywords

Three word categories were defined as relevant for the systematic literature review. These are shown in Table 10 below. The categories and the corresponding terms were then linked by Boolean operators. The categories were connected with the help of AND operators and the words with OR operators. The search was carried out in German (GER) and English.

Table 10 Keywords for literature analysis.

Category 1	Category 2	Category 3
Technical Change Management	Stakeholder	Identify
Manufacturing Change Management	Department	Analyze
Engineering Change Management	Group	Determine
Change Impact Analysis	Role	(GER) identifizieren
(GER) Änderungsmanagement	Employee	(GER) analyiseren
(GER) Änderungsauswirkungsanalyse	Group of interest	(GER) bestimmen
	(GER) Abteilung	(GER) ermitteln
	(GER) Team	
	(GER) Mitarbeiter	
	(GER) Rolle	
	(GER) Interessensgruppe	

A.8 Analog SI: example of a Change Responsibility Profile

The analog SI approach aims to identify relevant stakeholders based on a systematic comparison between the MC attributes and the responsibilities of potentially relevant stakeholders. Table 11 presents an example of a Change Responsibility Profile. The RASCI roles are used to represent different role profiles. The Accountable role was not selected by the example stakeholder. The roles are illustrated in Table 11 by the color coding:

- Responsible: green
- Support: orange
- Consulted: blue
- Informed: green

The colored fields represent the critical dimensions, which trigger an immediate involvement of the stakeholder when selected. The lines illustrate combinations of MC attributes.

Table 11 An example Change Responsibility Profile.

Dimension	Granularity								
Manufacturing process	Turning	Welding	Grinding	Gear hobbing	Gear cutting	Broaching	Heat treatment		
Logistic process	Goods receipt	Repacking	Storage	Commissioning	Transport	Packaging	Shipping		
Change impact	Product			Manufacturing process			Employee		
Change costs	Low			Medium			High		
Department	Engineering	Work preparation	Purchasing	Assembly	Production	Quality	Service	Logistic	
Change complexity	Low			Medium			High		
Requirements	Customer requirements		Spatial requirements		Technical requirements		Employee requirements		
Risk	Low			Medium			High		
Product	A	B	C	D	E	F	G		
Workstation	100-199	200-299	300-399	400-499	500-599	600-699	700-799	800-899	900-999

A.9 Analog SI: details about the expert interviews

Nine semi-structured interviews were conducted via Mircosoft Teams to verify and extend the selection of MC attributes that influence the SI. Prior to this, an internal trial run was carried out with a research assistant from the Institute for Machine Tools and Industrial Management at the Technical University of Munich in order to check the procedure, e.g., with regard to the comprehensibility of the task or the expected duration of the interview. The motivation, objectives, and interview procedure were presented after a brief introduction and a request for consent to record the interview. The developed SI method was then applied in the form of a software prototype and finally evaluated by the experts with the aid of a questionnaire.

Table 12 Details about expert interviews (analog SI).

Date	Company	Role	Duration [h:min]
08.03.2021	Mechanical Engineering	Project Leader Production Engineering	1:22
09.03.2021	Automotive Supplier (Electronics)	Project Leader Technical Construction	1:05
09.03.2021	Engineering Service Provider (Automotive)	Technical Construction and Project Management Assistant	1:11
10.03.2021	Mechanical Engineering	Process Planning Engineer	0:59
11.03.2021	Automotive OEM	Technical Change Management	1:13
11.03.2021	Automotive Supplier (Electronics)	Technical Construction and Change Manager	1:11
15.03.2021	Mechanical Engineering	Director Production Engineering	0:47
17.03.2021	Mechanical Engineering	Project Leader Production Engineering	1:07
17.03.2021	Medical technology	Head of Process Development and Change Management	1:12

A.10 Analog SI: workflow for introduction and application

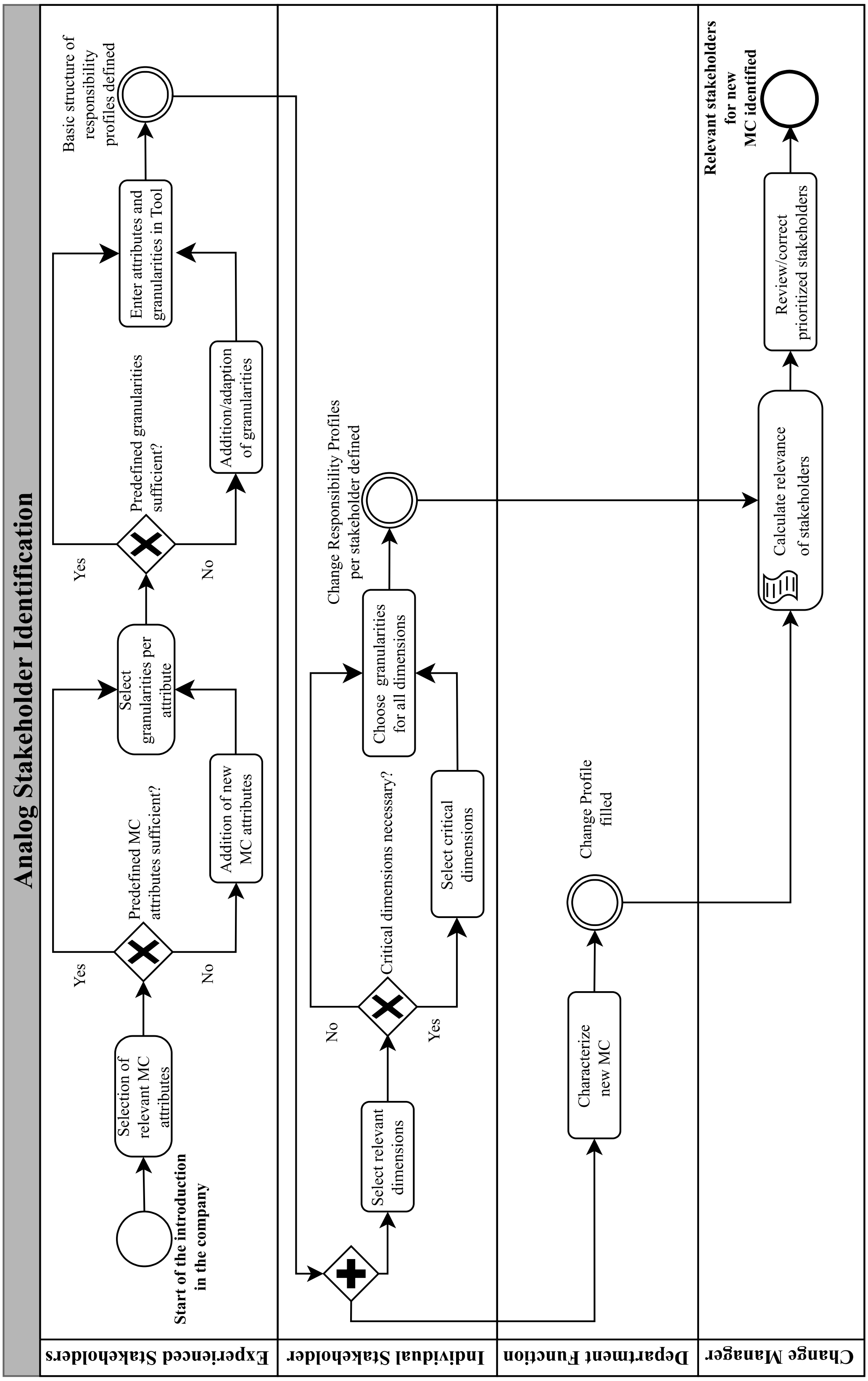

Figure 19. Overview of the procedure for the introduction and application of the approach for analog SI modeled based on BPMN (OMG 2014).

A.11 Descriptive SI: interviews for the evaluation of CSA

Nine semi-structured interviews were conducted via Mircosoft Teams to evaluate the developed approach for Change Similarity Assessment. Prior to this, an internal trial run was carried out with a research assistant from the Institute for Machine Tools and Industrial Management at the Technical University of Munich in order to test the procedure, e.g., with regard to the comprehensibility of the task or the expected interview duration. After a brief introduction and a request for consent to record the interview, the motivation, objectives, and procedure of the interview were presented. All interviewees were employees of the medical technology company involved in the research for this thesis. The outliers in the duration of the interviews can be explained by the fact that these people were already familiar with the research objective, allowing the description of the motivation, problem, objective, and task to be significantly reduced.

Table 13 Expert interviews for the evaluation of the CSA approach.

Date	Company	Duration [h:min]
04.05.2021	Medical technology	00:43
04.05.2021	Medical technology	01:08
04.05.2021	Medical technology	00:38
04.05.2021	Medical technology	00:49
05.05.2021	Medical technology	01:04
05.05.2021	Medical technology	00:57
06.05.2021	Medical technology	00:30
06.05.2021	Medical technology	00:45
06.05.2021	Medical technology	00:27
10.05.2021	Medical technology	00:33

A.12 Descriptive SI: user interface

An user interface was developed to enable a realistic evaluation of the approach for descriptive SI. As part of the evaluation, the experts had the opportunity to control the tool themselves. In the interface, it is possible to specify which phase of the CM and which role is to be analyzed. The user then receives a quantified and prioritized overview of persons or departments frequently involved in the past.

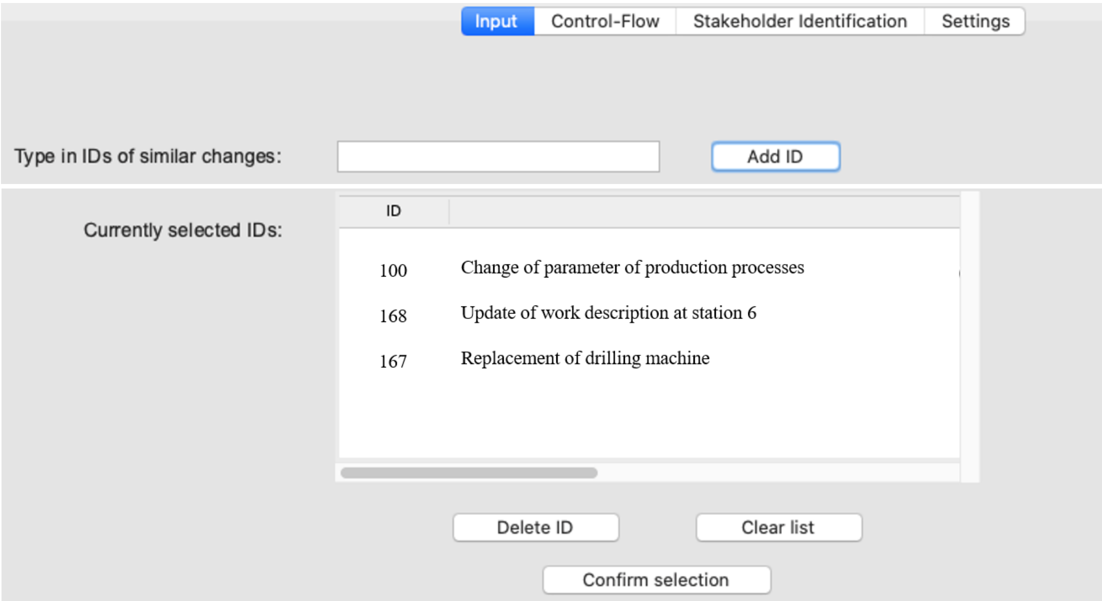

Figure 20. User interface of descriptive SI: selection of relevant similar changes.

Figure 21. The interface for descriptive SI.

A.13 Descriptive SI: details about the evaluation

Seven semi-structured interviews were conducted via Mircosoft Teams to evaluate the developed approach for descriptive SI. Prior to this, an internal trial run was carried out with a research assistant from the Institute for Machine Tools and Industrial Management at the Technical University of Munich to test the procedure, e.g., with regard to the comprehensibility of the task or the expected interview duration. After a round of introductions and a request for consent to the interview recording, the motivation, objectives, and interview procedure were presented. All interviewees were employees of the medical technology company involved in the research for this thesis. Participants had the option of skipping the assessment of the result quality for individual changes if they did not have the necessary knowledge. This led to a significant proportion of the questions being skipped in the case of one participant. Accordingly, no ratings were recorded by this respondent in these cases.

Table 14 Expert interviews for the evaluation of the descriptive SI.

Date	Company	Role	Duration [h:min]
04.10.2021	Medical technology	Life Cycle Manager	1:10
05.10.2021	Medical technology	Engineering	0:59
05.10.2021	Medical technology	Process Engineer	1:14
07.10.2021	Medical technology	Product Manager	0:56
12.10.2021	Medical technology	Purchasing	1:01
12.10.2021	Medical technology	Quality Management	1:08
13.10.2021	Medical technology	Quality Management	0:22
14.10.2021	Medical technology	Change Manager	1:01

A.14 Descriptive SI: workflow for introduction and application

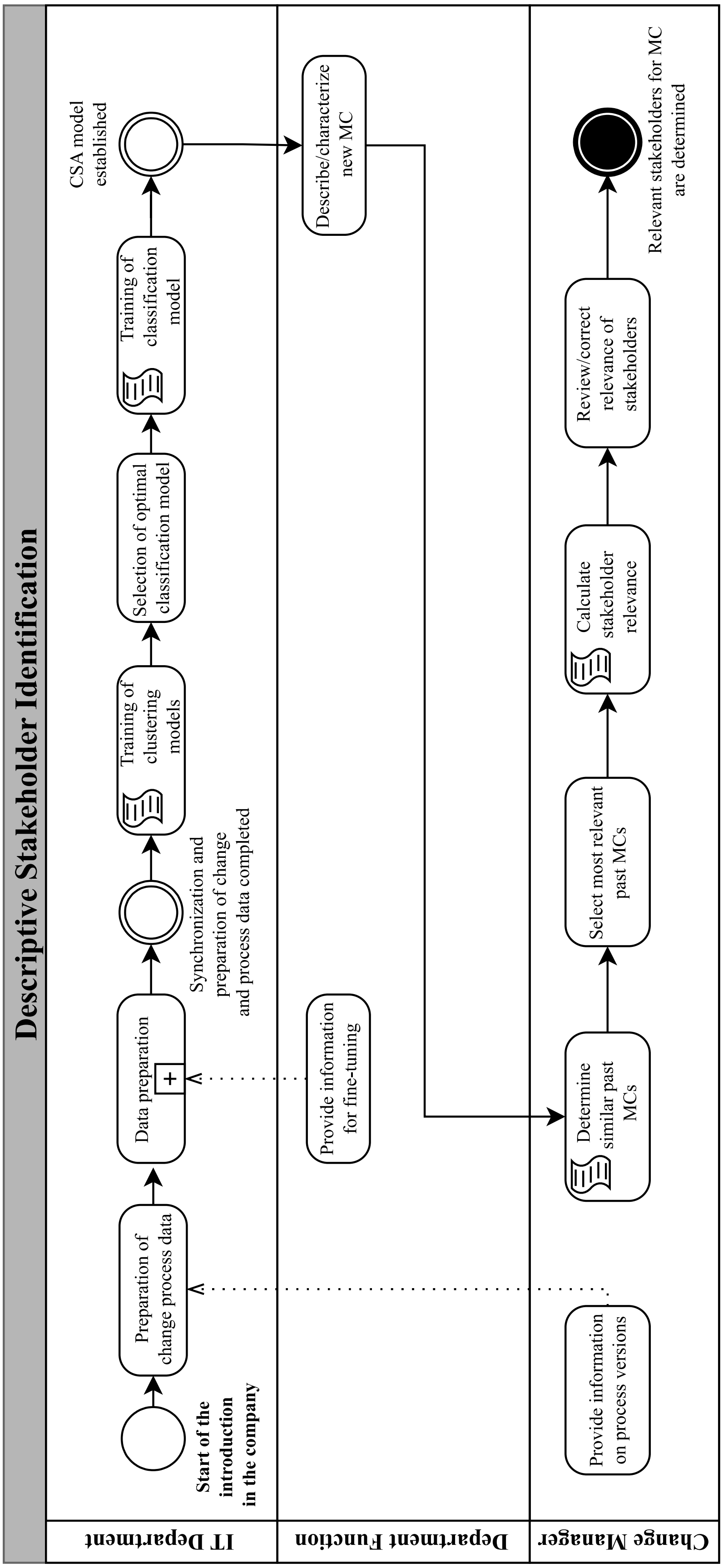

Figure 22. Overview of the procedure for the introduction and application of the approach for descriptive SI modeled based on BPMN (OMG 2014).

A.15 Predictive SI: details on the use case assembly

Table 15 Exemplary word combinations identified during the workshop with assembly experts.

Category	Examples
Component	wiring harness, wiring, locking bracket, sealing film
Assembly	clip-on, fixing point, scan, assembly variant, pre-assembly
Mounting part	edge clip, protective cover, clinch nut, plug, screw
Plant	plant A, plant B

A.16 Predictive SI: workflow for introduction and application

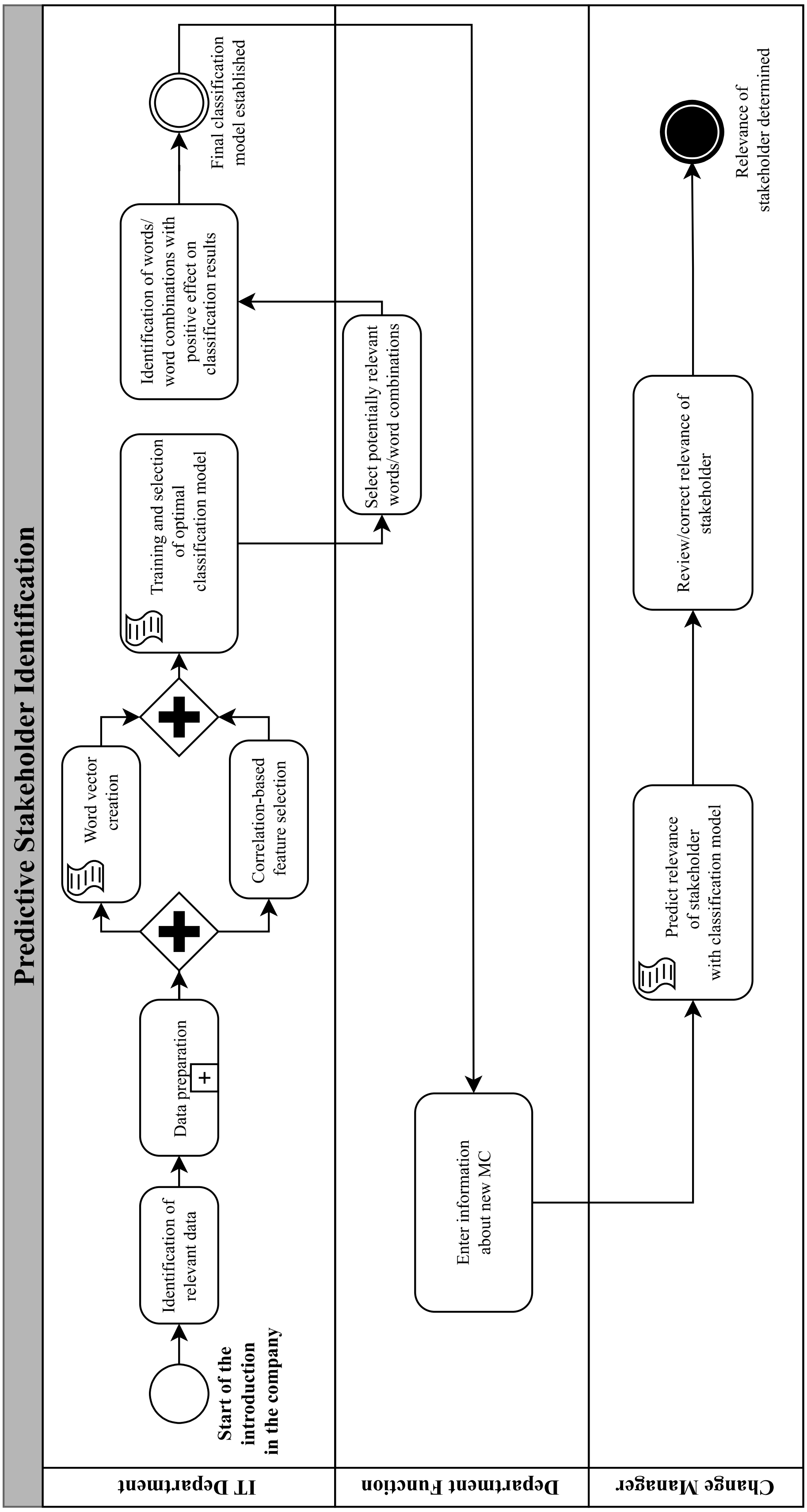

Figure 23. Overview of the procedure for the introduction and application of the approach for predictive SI modeled based on BPMN (OMG 2014).

A.17 Assumptions regarding the assessment of economic viability

Table 16 Assumptions concerning economic viability.

Assumption	Description
Training effects	Training effects of change managers, i.e., a reduction in the time required to carry out the SI per MC, are not taken into account, nor is the training process of new employees over time in the event of personnel fluctuation.
Staff turnover	The change managers and stakeholders do not change during the observation period. This means, for example, that layoffs and new hires or the addition of new stakeholders are not taken into account.
Competence level	It is assumed that all change managers have a similar level of competence and that, therefore, there are no time differences in the time required to carry out the SI.
IT infrastructure	The costs for the necessary IT infrastructure (e.g., computers, additional computing capacity, screens) and their amortization are not taken into account.
Method selection	The SI for all MCs occurring in the period under consideration are each carried out using one method.
Data availability	The necessary change and change process data is available and accessible. Therefore, no additional effort is required.
Utilization of the preparatory work	The templates and open-source codes created in the course of this work are utilized.
Effort reduction	It is assumed that the use of analog and descriptive methods reduces the effort for an individual SI by a constant rate of 20 %, as the change manager directly receives a prioritized overview of relevant stakeholders but still has to review the results and operate the provided tools.

A.18 Breakdown of financial efforts

Table 17 Detailed overview of the financial efforts.

Effort	Manual SI		Analog SI (Scenario 1)		Descriptive SI (Scenario 2)		Predictive SI (Scenario 3)	
Description	**Quantity Person Days**	**Economical Effort**	**Quantity Person Days**	**Economical Effort**	**Quantity Person Days**	**Economical Effort**	**Quantity Person Days**	**Economical Effort**
Initial Economical Effort								
Definition of the basic structure of the CRP	0	0,00 €	2	1.800,00 €	0	0,00 €	0	0,00 €
Stakeholder-specific definition of the CRP	0	0,00 €	2	1.800,00 €	0	0,00 €	0	0,00 €
Workshop for fine-tuning of ML-models	0	0,00 €	0	0,00 €	1	900,00 €	8	7.200,00 €
Data preparation	0	0,00 €	0	0,00 €	5	4.500,00 €	6	5.400,00 €
Employee training	0	0,00 €	2	1.800,00 €	1	900,00 €	0	0,00 €
Programming	0	0,00 €	5	4.500,00 €	6	5.400,00 €	8	7.200,00 €
Current Economical Effort (Change-Independent)								
Reviewing the CRP structure	0	0,00 €	3	2.700,00 €	0	0,00 €	0	0,00 €
Reviewing the stakeholder CRP	0	0,00 €	4	3.600,00 €	0	0,00 €	0	0,00 €
Maintenance of the ML-models	0	0,00 €	0	0,00 €	3	2.700,00 €	3	2.700,00 €
Maintenance of the software	0	0,00 €	0	0,00 €	3	2.700,00 €	3	2.700,00 €
Economical Effort per MC								
Identification of relevant stakeholders	12	10.800,00 €	9	8.100,00 €	9	8.100,00 €	0	0,00 €
Sum	**12**	**10.800,00 €**	**27**	**24.300,00 €**	**28**	**25.200,00 €**	**28**	**25.200,00 €**

A.19 Utilized Python libraries

Table 18 Overview of utilized Python libraries.

Name of Python library	Reference
Pm4py	https://pm4py.fit.fraunhofer.de/
os	https://docs.python.org/3/library/os.html
pandas	https://pandas.pydata.org/
Matplotlib	https://matplotlib.org/
Seaborn	https://seaborn.pydata.org/
gviz_api	https://pypi.org/project/gviz-api/
NLTK	https://www.nltk.org/
NumPy	https://numpy.org/
platform	https://docs.python.org/3/library/platform.html
Tkinter	https://docs.python.org/3/library/tkinter.html
scikit-learn	https://pypi.org/project/scikit-learn/
spaCy	https://spacy.io/
Langid	https://pypi.org/project/langid/
Googletrans	https://pypi.org/project/googletrans/