Analytical Business Process Modeling Language

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Gutachterinnen/Gutachter

Prof. Dr. Gunter Saake
Prof. Dr. Klaus Turowski
Prof. Dr. Juan J. Cuadrado Gallego

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Abstract

Global socio-economic changes and technological developments bring new opportunities and threats for enterprises. In this competitive environment, business process management and improvement are crucial for enterprises. For this purpose, business process modelling is widely used for graphical representation of processes and communication between different stakeholders. Process understanding and its evaluation are crucial steps for process improvement.

Business process models can be annotated with performance information which in turn can be used to identify deficiencies. In practice, annotation-based models are used, however, they are not designed for this purpose and do not sufficiently support the post execution analysis and improvement of business processes. Performance evaluation with business process model is undermined research area. Our goal is to address this challenge and focus on the relationship between evaluation of business processes and their representation at the process level.

For this purpose, we specify an analytical framework for post execution analysis and improvement of business processes. We focus on the representational part of the framework and discuss the limitations of modelling languages in post execution analysis context. By doing so, we define the characteristics of analytical modelling languages. We also provide patterns to extend modelling languages for post execution analysis and improvement purpose. These analytical characteristics and patterns are modelling language independent.

We extend a business process modelling language to demonstrate the usage of our proposed patterns. Furthermore, we evaluate the proposed extension empirically and analytically as well. We discuss how these extensions solve the evaluation challenges of business processes. We emphasize the benefits of extended business process models for expressiveness and understanding to improve business processes.

Zusammenfassung

Globale sozioökonomische Veränderungen und technische Entwicklungen bergen neue Möglichkeiten und Risiken für Unternehmen. In diesem Wettbewerbsumfeld sind Geschäftsprozessmanagement und -verbesserung entscheidend für Unternehmen. Zur grafischen Darstellung der Prozesse und Kommunikation zwischen verschiedenen Stakeholdern, ist die Verwendung von Geschäftsprozessmodellierung weit verbreitet, denn das Verständnis und die Evaluierung von Prozessen sind Schlüsselfaktoren des Verbesserungsprozesses.

Geschäftsprozessmodelle können zusätzlich mit Informationen zur Leistung versehen werden, welche wiederum verwendet werden, um Mängel zu identifizieren. Auch wenn solche kommentierten Geschäftsmodelle in der Praxis Verwendung finden, so sind sie nicht dafür geschaffen und unterstützen die Post-Execution-Analyse und die Verbesserung der Geschäftsprozesse nur unzureichend. Die Leistungsmessung mit Geschäftsprozessmodellen ist ein vernachlässigter Forschungsbereich. Unser Ziel ist es daher, diese Problematik anzugehen und den Fokus auf die Beziehungen zwischen Geschäftsprozessevaluierung und deren Repräsentation auf Prozessebene zu legen.

Hierfür erstellen wir ein Framework zur Post-Execution-Analyse und Verbesserung der Geschäftsprozesse. Wir konzentrieren uns dabei auf den repräsentativen Aspekt des Modells und erörtern die Anwendungsgrenzen der Modellierungssprache im Kontext der Post-Execution-Analyse. Wobei wir auch die Merkmale der analytischen Modellierungssprachen definieren. Außerdem stellen wir Muster zur Erweiterung der Modellierungssprachen für die Post-Execution-Analyse sowie der Verbesserung zur Verfügung. Diese analytischen Merkmale und Muster sind jedoch Modelliersprachen-unabhängig.

Wir erweitern dafür eine Geschäftsprozessmodellierungssprache, um den Nutzen unserer vorgeschlagenen Vorlagen zu demonstrieren. Des Weiteren führen wir eine empirische und analytische Evaluierung der vorgeschlagenen Erweiterung durch und erörtern, wie sie die Evaluierungsproblematik der Geschäftsprozessmodelle lösen. Dazu konzentrieren wir uns auf die Vorteile der erweiterten Geschäftsprozessmodelle, damit deren Ausdruckskraft und Verständnis die Geschäftsprozesse zu verbessern.

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1. Introduction

The business world is competitive and fierce competition exists between companies due to globalisation, emerging technologies, and digitalisation. Even small companies with niche characteristics give competition to well-established companies and have a reach to broader international markets. Research in 2014 indicated that in 14 years (since 2000), 52% of companies in the Fortune 500 had been disappeared from the list (either gone bankrupt, been acquired or ceased to exists) [Wan14]. Only 12% of companies (60 in total) are still in Fortune 500 list since 1955 as analysed in [Per17]. Old products are replaced by new products and services (e.g. camera films with digital cameras) and traditional business models with new business models.

Consider an example of a customer purchasing a product from a company. She has many options like purchasing from an online store or a physical store and from big brand companies to small manufacturers. In the past three decades, significant technological development has been made and reached broader society. The competition between organisations is not only increased but also raised the expectation of customers. Therefore, enterprises seek new strategies to provide innovative and quality services to satisfy customers' needs. Enterprises attract and involve customers with digital experiences. These new ways also paved the way for new business models and services to generate more revenue and serve different customer segments.

In order to respond to the changes in business world with existing infrastructure, enterprises continuously try to streamline their organisational structure and processes [KT21]. The streamlining helps to provide new and better services for customers. However, before making any changes to existing operations, first, we need to understand and analyse how processes are executed in an enterprise.

Recent technological developments open new horizons for products and services in business sectors. These changes affect business process management research, like satisfying stakeholders' requirements from different perspectives. Changes bring up several challenges for the business process modelling domain as well. These challenges need to be addressed for better management of business processes. For example, data about business process executions are stored in different tables and logs. This type of data facilitates the analysis of business processes in deep detail and helps in making business decisions [TW20].

Business processes (BP) are represented in a graphical way for easy communication between stakeholders. The intuitive nature of business process models and explicit representation of business objects improve the overall understanding of business processes. Business process modelling is fundamental for understanding, managing, and improving business processes [Rei21]. Most of the research in business process modelling is focused on the alignment of information technology with business processes [LKS11d]. However, limited research is carried out to represent process knowledge through business process models for improvement [ETDRORRC21, ZBGD19, VTM08].

The remaining part of this chapter is structured as follows. In Section 1.1, we provide the research motivation by discussing data and process-oriented approaches in correspondence to performance representational support. In Section 1.2, we formulate the research questions of the thesis. In Section 1.3, we elaborate on the research contributions of the thesis. In Section 1.4, we present the research methodology followed by the thesis. We outline the structure of the thesis in Section 1.5. At the end of the chapter in Section 1.6, we summarise this chapter.

1.1 Motivation

Management of business operation undergoes in various research disciplines. Specific terms have been introduced to describe the focus of research disciplines like controlling in the early twenty century by Henri Fayol [FS16]. In the 1970s, the storage of business records in databases started where data was used to keep in operational and analytical databases. Later, these databases were used in decision support systems to answer business questions for decision makers. Different reporting dashboards are made on these databases. These databases were also used to find interesting relationships and patterns between data.

Data mining approaches were proposed and applied in various fields in the mid-nineties. However, mere data perspective is not enough for operational improvements. Therefore in practice, data scientists work closely together with business experts to gain knowledge about processes and to relate the discovered knowledge with operations for better application. Visualisation techniques and methods have been proposed to represent the knowledge. We represent these two types of analytics are represented as descriptive and predictive analytics in Figure 1.1 and often known as business intelligence technologies. Figure 1.1 is adopted from [DH07, Eck07, LDJD10] and put in the manufacturing context in [BL20].

In data-oriented approaches, the provision of IT support (software/service) to business functions and its analytics is primary focus of research, e.g., data models,

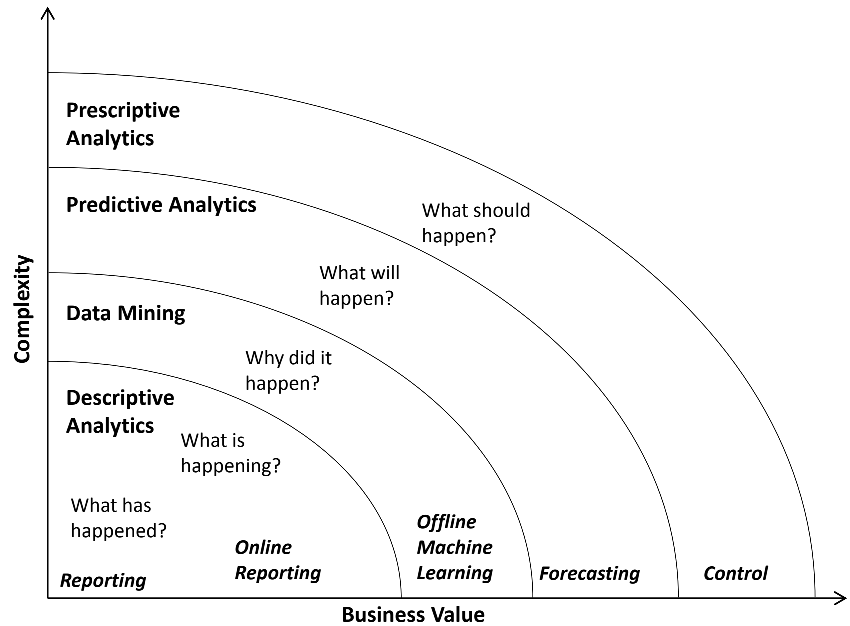


Figure 1.1: Business Analytics with Value

dimensional modelling, and database systems. With the maturity of research on data-oriented approaches, the focus shifted to higher levels where processes are the main focus of research to provide better analytics [vdAvH02]. In the start of 1990's, methods focusing on processes were proposed like process modelling (EPCs), process mining [vdAW04] and process management systems, i.e., workflow management systems [Mue04], process aware information systems [DvdAtH05]. The field focusing on process analysis is known as business process intelligence [vdA16, GCC+04].

Process Mining techniques [vdARW+07] provide excellent opportunities to extract knowledge from business process executions (including operational data, events and logs). Process mining fits between the business process models and business executions. Most of the research in process mining is focused on process model discovery, alignment between information technology and business processes, and social networks in operations [vdARS05].

The knowledge extracted by descriptive and predictive analytics have to be applied in business operations. Process mining techniques help further to extract knowledge about running processes. Prescriptive analytics as represented in Figure 1.1, attempts to address the question which changes should be carried out to get the desired results. The changes are carried out by an enterprise's business experts (process managers). In order to carry out such changes, they are interested in performance details of processes in an organisation. These details are necessary in order to identify deficiencies and improve processes. A deep understanding of processes is required for improvement purposes [KT21, DDB05].

Different phases of process management (from initial setting to optimisation) require different models [AS04, Mac93, Pha98, Alo16]. Phalp and Shepperd distinguish the usage of business process models into two types [PS00]. On the one side, software development is in focus, whereas on the other side, restructuring business processes is a priority. Diagrammatic notations are used for software development where a focus is on a certain perspective. Different models and views are required to restructure and analyse business processes [AS04]. Most of the modelling methods address only the needs of information system development purposes.

Limited research is carried out to represent process knowledge through business process models for improvement. Currently, information is represented with key performance indicators (KPIs), statistics, or visualisations (e.g., pie charts or histograms) which are abstract and does not provide process details to business analysts. Business process modelling has to be investigated for adequate representations of business processes, especially after execution. Similarly, different cognitive studies show that users read and perceive the information in a particular order. The order in which information is presented is an important factor. Elements essential for business process improvement should be presented in a definite position to get the attention of an analyst.

The motivation for this thesis is to represent business processes in a way where deficiencies can be easily identified for improvement. In addition to this, we propagate the need for an analytical business process modelling language for post-execution analysis by discussing the limitations of business process modelling and its focus. Furthermore, we also propagate the need for the specification of a business process improvement framework. According to this view, a process model should be enriched with performance details for business process improvement. In the following, we formulate them as our research questions.

1.2 Research Questions

Business process improvement is challenging because of the complexity of carrying out the changes in processes. Enterprises find it difficult to decide where to start and what changes should be implemented for improvement. Complexity in the business process is due to various factors like inter-dependencies between activities, stakeholders, involved elements, their attributes, and applications. Research in business process improvement needs to address these complex issues and provide support to decide which action should be taken for business process improvement. We address the main research challenge in this thesis to provide representational support for business process improvement. In order to address the research challenges, the research question (RQ) is as follows.

RQ: *How to represent the performance of a business process for its improvement?*

This research question is further subdivided into detailed questions. We divide it into three parts. In the first part, we want to investigate existing methods to represent business processes. We also want to evaluate, how well they are used for post-execution analysis. The following research questions are related to the first part.

RQ1.1: *Which novel contributions exist in the business process modelling domain?*

RQ1.2: *How business process modelling is used in different phases of a business process lifecycle?*

In order to address the above research questions, we discuss the research in the business process modelling domain. We also discuss the usage of business process modelling artefacts in the context of a business process lifecycle. We represent some of the modelling languages according to their usage in a business process lifecycle and also discuss the lack of modelling languages in post-executional analysis.

Decision makers want to know the actual situation of processes and involved objects in order to make a decision about processes. The representation of the actual situation also helps to process managers to identify and improve the deficiencies in processes. In the second part, we want to address the challenges related to performance evaluation and post-execution analysis of business processes. The research questions related to this part are as follows.

RQ2.1: *How are business processes evaluated in an organisation? Which perspectives and dimensions are used for this purpose?*

RQ2.2: *Which components are involved in the evaluation of a business process?*

RQ2.3: *How the performance of a process is represented after execution? Which type of methods and techniques are available?*

RQ2.4: *What are the current challenges to represent performance in a business process model?*

In order to answer these research questions, we discuss different perspectives for evaluating business and provide corresponding dimensions for evaluation. We also introduce a framework to collect, compute and then represent the data about business operations. The challenges of business process models in post-execution are discussed to answer these research questions.

For process improvement, process managers are interested in more details for process performance analysis. Therefore, new detailed graphical models are required for this purpose. These approaches go beyond typical applications and usage of process models [Rei21]. However, existing representational techniques of evaluation do not adequately fulfil the requirements. Given this context, further questions are also raised. These questions compliment the third part of our research questions which is related to post-executional representation of process with performance details.

RQ3.1: *What are the requirements for process performance representation in post-execution context?*

RQ3.2: *Is it possible to analyse the performance of a process with existing modelling languages?*

RQ3.3: *How business process modelling languages are adapted to improve the performance representation?*

We discuss the characteristics of an analytical modelling language. Being able to identify characteristics, we also propose an analytical modelling language that is generic enough to use as a basis to extend other modelling languages for post-execution analysis. We also extend an existing modelling language for demonstration purposes. This extension is evaluated and compared with traditional methods from experimental and analytical perspectives with the help of a case study.

In the following section, we describe the contribution of our thesis in detail.

1.3 Contribution of the Thesis

This thesis propagates the need for representational support for post-execution analysis and improvement. Representational support dedicated to business process intelligence is missing. Existing methods focus only on the data perspective (business intelligence). The main focus of this thesis is to provide representational support for business process improvement after business process execution. With this motivation, first, we provide the context and meta-model of business processes with its management techniques. We also discuss business process lifecycle, different stakeholders and their level of participation in processes. The context and meta-model provide the basis for understanding the influencing factors of business processes.

We investigate the first part of the research questions by investigating the business process modelling domain and its usage in business process lifecycle. We categorise the research in business process modelling and discuss the current challenges. We also position some modelling languages with their usage in different phases of a business process. By doing so, we find that limited research is carried out in the phases of post-execution analysis of business processes.

For the evaluation of business processes, data from different sources are collected and used for computation. Quantitative and qualitative measurements are made for performance evaluation of business processes. In order to get the required data, an analytical framework has been proposed in this thesis which addresses the issues in different areas. These areas include the collection of data from information systems, its computation, and representation in business process models. We also discuss the challenges for existing modelling languages in post-execution analysis context.

We see the scope of an innovative artefact to solve the problems related to business process analysis and improvement. Therefore, our objective is to provide a new representation of business processes for performance analysis and help managers to make decisions. Focusing on the third part of the research questions, we provide the characteristics of an analytical modelling language. We also propose language-independent constructs and patterns of the analytical modelling language. We extend an existing modelling language with the proposed constructs and patterns as

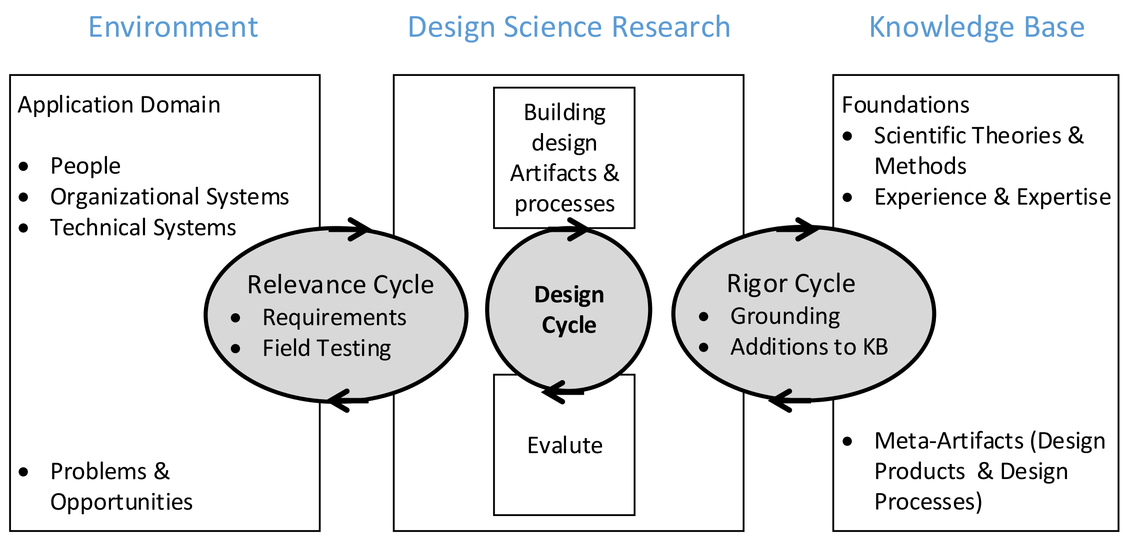


Figure 1.2: Design Science Research Framework and Cycles by [Hev07]

example. The extended modelling language is further evaluated from experimental and analytical evaluation methods. The extended modelling language enhances the user's understanding of business processes, execution environment, and help them make improvement decisions.

1.4 Research Methodology

Two science paradigms are mostly discussed in information systems research. One is a design science research paradigm (as discussed in [MS95, HMPR04]) which focuses on problem-solving and extending the artefacts. Another approach is the behavioural science paradigm which focuses on developing and verifying theories that explain or predict the behaviour of human and organisational elements [PTRC07, HMPR04]. Behavioural science follows the natural science research methods where principles and laws are observed in the environment. In [HMPR04], the authors present a conceptual framework by combining both paradigms. This framework and guidelines are further extended with three design science research cycles in [Hev07] and shown in Figure 1.2.

Design science is a problem-solving paradigm seeking for ideas, practices, technical capabilities, and artefacts through which problems can be effectively and efficiently solved [MS95]. The new artefacts attempt to extend the boundaries of human and organisational capabilities. In [HMPR04], authors broadly define IT artefacts defined as constructs (symbols and vocabulary), models (abstractions and representations), methods (algorithms and their practices), and instantiations (prototype systems and implementations). In this thesis, we follow the design science paradigm and acknowledge the work presented in [HMPR04, PTRC07, Hev07].

In [Hev07], the authors discuss three cycles of design science, as shown in Figure 1.2. These are relevance cycle, design cycle and rigour cycle. We introduce these cycles from [Hev07] and discuss their corresponding implementation in our research.

The relevance cycle of design science provides the context or reason for the research. It provides the requirement for the research and also the acceptance criteria. The output of the design cycle is provided in the application environment for testing. The result of the field test will decide whether additional iterations are needed in design science or not.

The rigour cycle provides the knowledge base of scientific theories and methods that provide the foundation for a research project. It also provides the experience, expertise and existing artefacts in a domain. Thus providing the state of the art in the domain and sometimes referred to design science as a search process. The result of the design cycle is included in the knowledge base that includes an extension to the original theory or method.

The design cycle is the central part of design science research and iterates between the core activities of artefact construction, evaluation and other research processes. The requirements from the relevance cycle are investigated by taking the foundations from the rigour cycle (design and evaluation theories). In this phase, a design artefact is developed and evaluated until a satisfactory design is achieved.

Our objective is to provide process models enriched with performance details for better analysis of business processes in the context of improvement. In this regard, we analyse the requirements of post-execution analysis of business processes [LKS10]. We also conducted interviews with experts to know their expectations from such models. We found that the community welcomes such business process models as they will help users to make decisions for process improvement.

We started our research by seeking more expressive business process models to analyse and improve the business process (Chapter 3). We identify different methods and modelling languages used to represent the performance of elements in practice and research. However, they fulfil the requirements only at an abstraction level and do not identify deficiencies in processes. To the best of our knowledge, modelling languages are not devised for performance analysis of business processes. The research process compliments the problem relevance part and rigour cycle (design science as a search process).

Our objective is to provide a new representation of business processes for performance analysis and to help managers in making decisions. The result of design as a search process and relevance part initially helped in designing the artefact. In design science, a language specification includes constructs, models, methods, and an instantiation part. Therefore, we address these parts to specify our proposed artefact. In order to explain the artefact, we also provide patterns for the use of the modelling language. These patterns help users to gain actionable insights about their processes for business process improvements.

The artefact introduced in this paper is an innovative artefact. Therefore, we used the descriptive and analytical evaluation method as suggested in [HMPR04]. For this purpose, we introduced an example and constructed scenarios using existing methods and our proposed artefact. We compare them with each other and show the benefits of our proposed artefact.

The following section gives an overview of our thesis and its structure.

1.5 Structure of the Thesis

We follow the design science research framework and its cycle (discussed in Section 1.4) to present the contents of the thesis. At the start, we go into the relevance cycle to provide the motivation and environment for this work. Afterwards, we go into the knowledge base and investigate the existing methods for the evaluation and representation of business processes. This also compliments the design as a search process. In order to solve the problem, we propose constructs and patterns in design cycle part. We also evaluate the proposed artefacts in this part. The detailed structure of the thesis is as follow.

In Chapter 2, we describe the basics of a business process. We discuss the overall business context and business challenges. We also provide different definitions of a business process and discuss its management techniques with different meta-models. We also elaborate on different characteristics of the business process and classify them by their participation role in its execution. In order to provide better background about the business process, we present different phases of a business process lifecycle in detail. We also present different organisational levels and stakeholders involved in a business process.

Chapter 3 provides an overview of research in the business process modelling domain. Active research areas of business process modelling are discussed from different perspectives. This state of the art helps us to identify current challenges in the business process modelling domain and provides directions for future research. We also discuss the usage of different business process modelling languages in the phases of a business process lifecycle and their focus. In this chapter, we also present a standard modelling language and its meta-model.

In Chapter 4, we describe business processes from post-execution analysis context. We discuss the evaluation of business processes from different perspectives. We present an analytical framework for business process improvement. This framework includes the components from data collection till its representation. We also differentiate between business intelligence and business process intelligence. By this differentiation, we discuss the limitation of modelling languages in post-execution analysis context.

In Chapter 5, we present the characteristics of an analytical business modelling language for analysis and improvement of the business process. In this chapter, we also propose modelling constructs and patterns for a modelling language. We explain the proposed modelling constructs and patterns by extending an existing modelling language for post-execution analysis and improvement. The meta-model of modelling language is extended for performance analysis. We also discuss the related work in this domain.

Chapter 6 provides the evaluation part of our proposed artefact. In this chapter, we perform the empirical evaluation of the proposed modelling language with the help of a case study. We compare between proposed modelling language and traditional methods into two independent groups. The results of these groups are discussed in detail followed by the limitations of empirical study.

In Chapter 7, we also evaluate the proposed modelling language from the analytical perspective. For this purpose, we build on the work of existing analytical evaluations and compare the proposed languages. Different analytical queries and the benefits of our modelling languages are also discussed in this chapter followed by the related work.

In Chapter 8, we conclude the thesis by discussing the contribution of the thesis. We also discuss how the overall research question and its subsequent research questions are addressed in the thesis. We also provide an outlook for future research in this field.

1.6 Summary

In this chapter, we have provided the motivation for our research. We have briefly discussed the research fields and the challenges for business process improvement. We also described the main research question and its further detailed research questions. The contribution of the thesis is also described. We also present the research method followed by our research. Following the same research method, we present the contents of our thesis and provide the structure of this work.

In the following Chapter 2, we present the basics of a business process and its context.

2. Business Process

This chapter shares material with the IS-Conf'2018 "Streamlining Processes for digitalisation" [LKST18], IHCI'2011 "Business Process Improvement Framework and Representational Support" [LKS11c], FIN Tech. Rep.'2011 "Business Process modelling: Active Research Areas and Challenges" [LKS11d] and FIN Tech. Rep.'2010 "Post-Execution Analysis of Business Processes: Taxonomy and Challenges" [LKS10].

Customers' demands are fulfilled by enterprises that do business for several reasons, like monetary gain, satisfying stakeholders (executives, employees, and customers), or increase in reputation. To maintain the competitive position in the market, enterprises provide new products and services. This trend of competitiveness triggers other enterprises to provide better services in order to keep or strengthen their position in the market.

We discuss the business context and its management perspectives in Section 2.1 followed by the business process definitions in Section 2.2. Different techniques are used for management of a business process during its lifecycle. These techniques are briefly discussed in Section 2.3. Data generated during business process executions are discussed in Section 2.4. The characteristics of business processes and its lifecycle are discussed in detail in Section 2.5 and Section 2.6 respectively. In Section 2.7, we discuss different organisational levels and involved stakeholders with business processes. At the end of this chapter, we summarise this chapter in Section 2.8.

2.1 Business Context

Executives set enterprises' goals and objectives that support a company's vision. Vision is developed by its stakeholders, followed by the strategy to fulfil it, whereas business model plays a vital role in the implementation of the strategy. Business

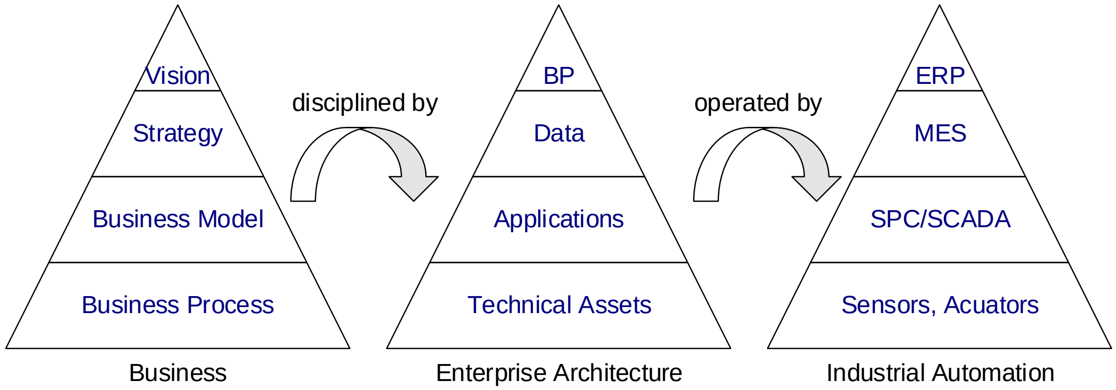


Figure 2.1: Relationship between Management Perspectives of an Enterprise

processes (BP) are defined to carry out the operations of an enterprise. We referred to this as a business perspective which is represented in Figure 2.1 (on the left). Different aspects have to be investigated on the business level due to digitalisation, such as business models and their respective business patterns, business process management practices and their impact on supporting information technology (IT).

Organisational resources execute business processes. During the execution of business processes, data is generated and used for processing. The execution of processes is supported by different applications and managed by technological entities. This view is referred as an enterprise architecture perspective and is represented in the middle of Figure 2.1. Enterprise Architecture is a renowned field of research. Information and communication technology (ICT) is a critical enabler in digitalisation. Often a holistic view of relevant processes, data, applications, and technological infrastructure is missing in the organisations. This gap is due to the fact that sometimes processes are complex and long that includes automated and manual process steps.

On the right side of Figure 2.1, the industrial automation perspective is shown. It shows how different technological systems interact with each other during industrial operations [LKST18, Api22]. On an enterprise level, orders are received and planned for manufacturing. Manufacturing Execution System (MES) [ISA00, Kle10] monitors and controls the execution of orders supported by Supervisory control and data acquisition (SCADA) and programmable logic controller (PLC) components. On the lowest level, actuators perform actions on the raw material and turn it into the products. Different sensors are used to collect the data during this process like quality attributes, machines and environmental conditions.

Enterprise architecture is disciplined by business perspective. This business perspective is at the end realised by industrial automation which is operated with enterprise architecture on a wider scale. The relationship between these perspectives is shown in Figure 2.1.

In order to achieve these goals and objectives, business operations are carried out in a specific way. This specific way is called business process and is discussed in the following Section 2.2 from different researchers' viewpoints.

2.2 Business Process Definitions

Business process is the central part of an organisation's operations, and different techniques are devised to manage processes like business process management [vdAtHW03, Wes07], business process re-engineering (BPR) [HC93], or business process improvement (BPI) [Har91]. There are several definitions of a business process in the literature where authors define a business process in the scope of their management techniques. These definitions are a starting point for understanding the business process and its context for further research in business process management. In [HC93], author defines business process as follow.

> "A business process is a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer."

Similarly, Davenport defines business process from process innovation [Dav93, p. 5] point of view as follows:

> "...a structured, measured set of activities designed to produce a specific output for a particular customer or market. It implies a strong emphasis on how work is done within an organisation[...]. A process is thus a specific ordering of work activities across time and space, with a beginning and an end, and clearly defined inputs and outputs: a structure for action."

The above definitions focus on the analysis and design of business processes with inputs and involved objects. Hence outputs are generated for potential customers. Business process re-engineering and business process innovation are responses to a competitive and changing environment, where existing processes are no longer effective. Therefore, processes must be redesigned from scratch to address customers' demands.

From the perspective of business process improvement (BPI), in [Har91, p. 9] Harrington defines business processes:

> "A business process consists of a group of logically related tasks that use the resources of the organisation to provide defined results in support of the organisation's objectives."

In this definition, an organisation's resources and related tasks are focused on fulfilling the organisation's objectives. The effective utilisation of resources and the structure of tasks are important for the improvement in products and services. In BPI, specific goals are defined, which are supposed to be achieved by process improvements like cost reduction or quality improvement. These goals are propagated in concrete steps of the processes. Thus, attempts are made to improve existing processes in different aspects.

In [Wes07, p. 5], the author defines a business process from the management perspective with organisational resources as follows:

> "A business process consists of a set of activities that are performed in coordination in an organisational and technical environment."

This definition of business processes is related to the management perspective where organisational and technical resources are used to execute business processes effectively. These resources include information systems, machines, and effective resource allocation. Several other definitions of business processes and their meta-models are discussed in [HB95, GK06]. Here, we describe a business process and its related context for discussion of business process lifecycle phases and research in business process modelling.

Enterprises provide new services or improve the existing ones in response to market forces (customer demands and the events happening in the market) for customer satisfaction. This is because old services are no longer efficient or do not fulfil new requirements. The changes in markets and customer demands must be reflected in enterprise objectives, processes, and the overall organisation.

Processes are governed by policies where inputs are transformed into outputs through actions performed by resources. Policies are defined by enterprises, markets (like standards), and government (e.g., environment-friendly). Based on this description, a new abstract meta-model of a business process and its context is represented in Figure 2.2. We further elaborate on the meta-model of Figure 2.2 to provide more details on the involved elements of business processes and relationships with management techniques.

2.3 Business Process Management Aspects

Customers demand products or services for consumption in their context. The major changes in customers' demands and the market must be reflected in the enterprise's objectives. Changes in markets are due to specific events, for example, legislations imposed by the government, new standards defined by organizations, or demands of certain items due to specific reasons like environmental and pandemic conditions and cost. The research addresses different aspects of such changes, and we discuss them in Chapter 3. In Figure 2.3, we show a meta-model with more details of involved

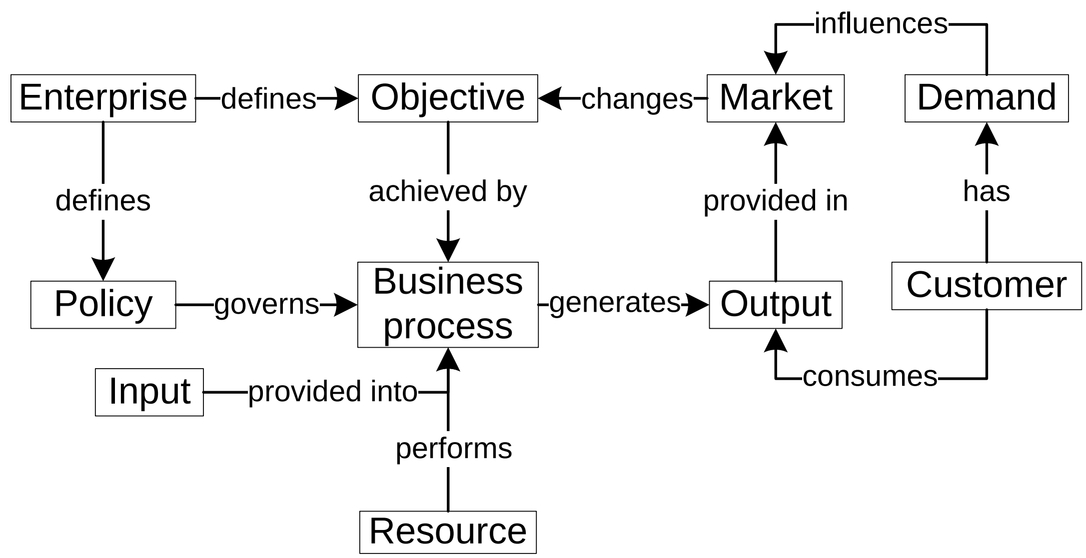


Figure 2.2: Business Process Meta-model

elements in business processes and their related techniques for managing business processes.

The objectives of an enterprise are realised through processes which itself composed of different activities. Resources perform operations in these activities according to a specific set of rules to transform inputs into outputs. The enterprise defines these specific sets of rules following its policies. Inputs, activities, processes, rules, outputs, policies, and resources provide the operational view of a business process. Resources of business processes are further divided into different types, such as humans, machines, and organisational structures. These various resources collaborate with each other to complete the execution of business processes. These management techniques are shown in Figure 2.3. Focusing on particular entities of Figure 2.3, different perspectives are provided in models such as control flow, cultural impact, employee's collaboration, and organisational perspective (resources usage, branches). Business processes are supported by workflow management systems that automate business processes [Wes07, p. 50].

An efficient process step or an overall performance improvement requires an evaluation of business processes after execution. Similarly, the feedback from customer and changes in the market are also analysed to devise a strategy for improvement or redesign of business processes. We further discuss these concepts in the following subsection.

2.4 Business Process Data

Computers are widely used in business as they range from hand-held devices to main servers to run businesses. Human interacts with business objects (physical materials), organisational resources (machines), and computer applications to carry out

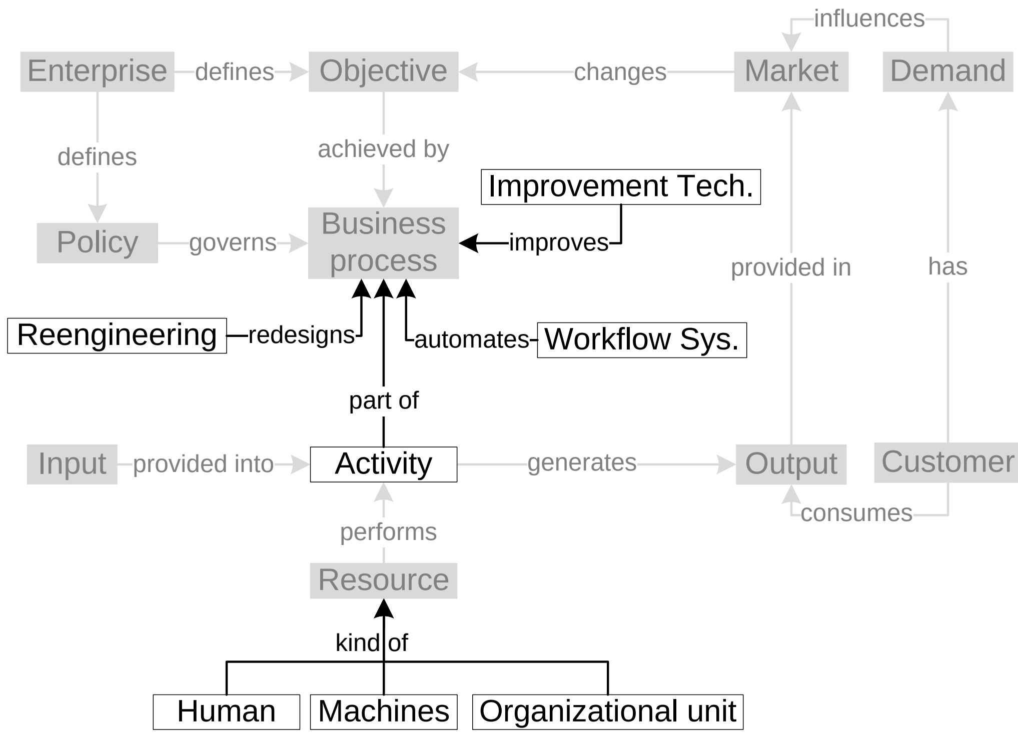


Figure 2.3: Business Process Context and Management Techniques

enterprises' processes. Different Information Technology systems play an important role in business process execution like ERP (enterprsie resource planing) systems and MES (manufacturing execution system). These systems record the interaction between humans, business objects (materials), organisational elements (machines) and also store other data (like process/product quality) during process execution. These interactions are stored in the form of databases tables, log files, and different messages. This data is helpful to improve overall business operations like business process structure, organisational resource structure, or human-computer interaction (HCI).

Consider a simple scenario where a customer orders a product for manufacturing. At the enterprise level, data about orders and customers are managed. Data about the organisational resources, suppliers and materials are also managed on this level. On the manufacturing level, data about manufacturing processes are maintained in an MES system. This data includes when the product is manufactured with which machine and quality characteristics. In this data, other details are also maintained like how much raw material was used, which organisational resources (building location, machine, persons) were involved, how much time it took (from the start of activity till the end), and about its quality characteristics. This data is vital for post-execution analysis from different perspectives.

2.5 Characteristics of Business Processes

A business process is characterised by involved business objects, their characteristics, and flow of activities. Different business objects are involved in a business process execution. The operations of a business process are carried out on these business objects according to a specific set of rules. The attributes of business objects are modified during business process execution. Analysing the processes with involved objects, their attributes, and rules are considered as breaking down the process into details that provide the opportunity to think creatively and to perform a better individual analysis. These details help business analysts to improve existing processes and services for customers.

The challenging question is to decide which objects and their attributes should be included in the analysis and correspondingly represented in analytical models. In order to address this challenge, we provide a classification of business objects, their attributes, and rules (flow of business processes). Objects are classified based on their participation in execution and the type of the object itself. We classify attributes of objects based on their contribution or role in analyses. In the following sections, we provide further details on this classification.

2.5.1 Classification of Objects

Business objects are classified based on their participation in operations. A classification of business objects helps analysts to understand which kind of objects are involved in the execution of processes. The concept of business objects is primarily used in the software development lifecycle like objects discovered in the analysis phase. Afterwards, these are converted into classes in software development's design and implementation phases. Therefore, these are discussed in the software development perspective in the literature [Sut97, ES98]. In [Nic02], Four kinds of business objects (people, places, things, and events) are described for business object modelling purposes. The author also presented the collaboration patterns for clear communication of business requirements about the product. In Figure 2.4, we classify business objects based on their participation in the executions. In the following, we discuss these types of objects briefly.

2.5.1.1 Operational Objects

Operational objects are involved in the execution of tasks in business processes. Different operational objects interact with one another to complete the execution. These operational objects can be further classified. These object types are highlighted in the following:

Resources perform operations on **inputs** and transform them into **outputs** which can be further taken as input for other operations or as a final output of the process.

Functional objects are related to the operation of tasks; these objects help in transforming input into an output like operational guidelines, checklists, and an invoice of products.

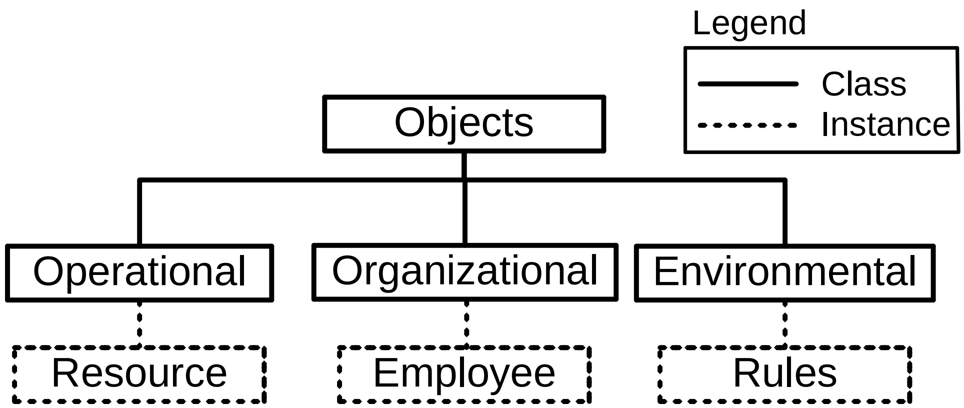


Figure 2.4: Classification of Business Objects

Derived objects are informational objects derived from other objects and fulfil information needs of the processes, for example, quantity in stock, total quantity, invoice total, customer history profile, and available capacity. These depend on the execution of business processes that modify the objects from where these objects are derived.

Categories of operational objects are flexible because one object can belong to different categories depending on participation in a business process. Like outputs of one process are input for another process, e.g., the customer order is the output of an order receiving process and input for the production department.

2.5.1.2 Organisational Objects

Organisational objects perform operations in business processes by making interactions with other objects. Resources discussed earlier in (operational objects) are also organisational objects and further classified into different types. Examples of organisational objects are humans (employees), machines (operating machines, vehicles), and organisational units (buildings, departments, and organisational roles).

2.5.1.3 Environmental Objects

These objects are related to the environment of a business process where executions occur. These objects may reside outside the control of an enterprise. We classify the objects based on the perspective under which it occurs. Different objects affect the execution and operations of a business process. Some examples of such factors are business markets (changes in customers' demands, technologies, currency rates, shipping rates), governmental issues (taxes and legislation rules), and natural conditions (weather and disasters).

2.5.2 Classification of Rules

Enterprises define their policies according to which operations of the organisation are carried out. These policies are further specified in a set of business rules. Business rules are also implemented as conditions. These conditions are evaluated and based on their result certain activities are executed in business processes. Conditions are of different types, like **pre-conditions** and **post-condition**.

Before performing any operation, an activity of a process checks whether the pre-conditions are fulfilled or not. Examples of pre-conditions are the completion of previous activity in sequence and the availability of resources. Once pre-conditions are fulfilled, then operations of activity are carried out. Conversely, post-conditions ensure that the system is stable and all related elements' attributes are updated. Pre-condition and post-condition concepts can be applied to any granularity level of detail, like at an abstract level or detailed level. Depending on the context, pre and post-conditions can be optional for activities.

Several other types of business rules and conditions also exist like logical, event or time-specific, and probabilistic. For example, if the weight of the product is greater than a certain value, then a particular shipping method is used. An example of an event-oriented rule is that when a customer payment is received then the product is dispatched to the customer. For time specific example, a salary is transferred at the end of a month or insurance deducted from an account at a specific time. Rules and conditions are applied and sometimes relaxed (waived-off) based on events and characteristics of instances. For example, handling of particular customer types (platinum, premium partners) in which certain conditions are relaxed for a certain time like confirmation of payment.

2.5.3 Business Process Flow

Business rules, events, and involved business objects affect the flow of business processes. The flow of business processes is investigated under various perspectives like control flow, organisation flow, and information (data) flow. Control flow focuses on the execution of activities and addresses what activities should be performed and in which order (for example, sequential, parallel, and iteration). Organisational flow investigates which organisational objects perform actions over activities and where these activities will be carried out. Information (data) flow focuses on which information (data) elements are consumed or produced in activities and what are their interrelationship.

2.6 Business Process Lifecycle

Different techniques are used in a business process lifecycle to effectively manage business processes. Business process management (BPM) is a cyclic methodology in which business processes are investigated from several perspectives during its phases. The business process lifecycle consists of several phases: plan, design, implement, execute, evaluate, analyse (post-execution) and recommend. This business process lifecycle is recursive, meaning each phase can have similar phases during its lifecycle. The business process lifecycle with entry points of different business process management (BPM) techniques is shown in Figure 2.5. Entry points of business process

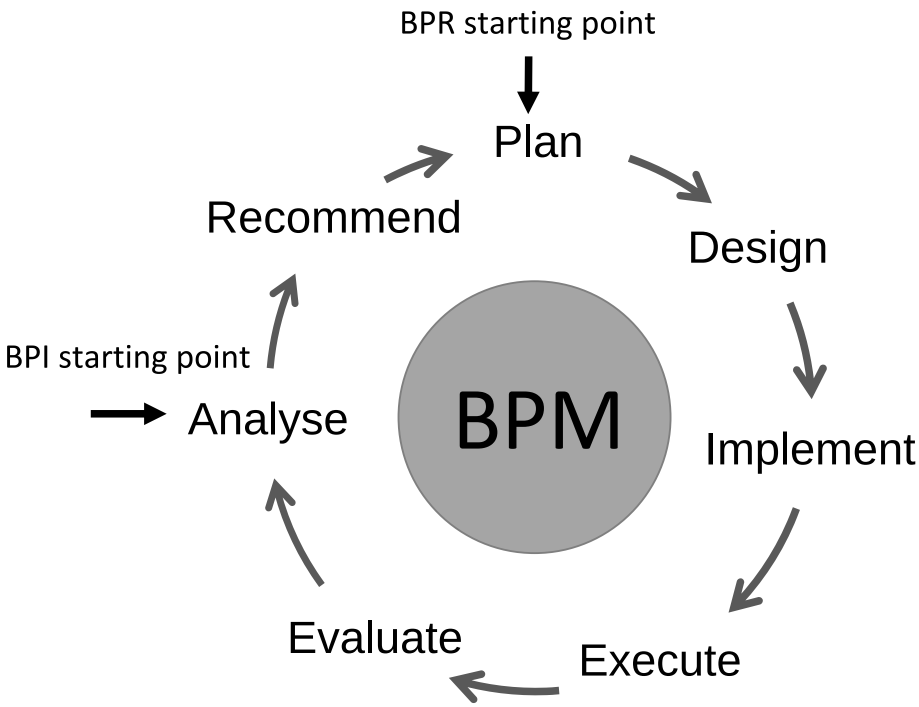


Figure 2.5: Business Process Management Lifecycle

management techniques (such as BPR or BPI) into phases depend on the context and usage of those techniques in enterprises. Activities carried out in business process management phases with respect to its techniques are briefly discussed as follows.

In the planning phase, analysts define which business processes are required to perform in order to achieve the desired objectives, like providing products and services. In this phase, the objectives and goals of a business process are described in detail. Therefore, processes are conceptualised in this phase, and design characteristics are specified at an abstract level. The desired output of a business process is also defined in this phase.

From a process improvement and change management perspective, a detailed plan is prepared about the changes to be carried out in business processes. These changes are due to process improvement or accommodating the new requirements. The scope and kind of changes are defined as which operations, organisational elements, and procedures should be changed. The target (TO-BE) design characteristics are provided to the design phase. The planning phase is also a starting point for the business process re-engineering, where processes are conceptualised from scratch. However, experts' domain knowledge and knowledge about previous processes creep back in.

In the design phase, different aspects of processes are considered in detail. Business processes are analysed from different perspectives like functional (which activities), behavioural (conditions, parallel, and iterations), organisational (where and by whom), and informational (requirements to perform) [CKO92]. In this phase, different involved elements are specified explicitly like inputs, operations, conditions, the flow of the process, and resources. The target values of different objects are also specified for the evaluation phase. Therefore, a detailed design model is prepared for the implementation phase.

The target design characteristics are investigated in detail from the process improvement and change management viewpoint. The impact of changes on other objects is evaluated by analysing it from different perspectives. Afterwards, the required changes and modifications are specified in the design model.

Once business processes are designed, then these are implemented in an organisation. The transformation from design to implementation depends on the description of language and the granularity level of models. For efficiency, business processes are supported with information technology (IT). The implementation phase of business processes with IT can have similar phases of BP lifecycle because business needs and requirements have to be mapped into IT services to provide the IT support. Activities carried out for Business-IT alignment are further discussed in Section 3.2. Before execution, the enactment of processes is carried out. Enactment of processes means that resources are allocated to process operations, and thus an execution environment is created.

Business processes are executed in order to fulfil the requests of customers (internal and external). Different instances are executed through a business process based on a defined event. Resources carry-out operations on inputs and transform the input into outputs. In this way, business processes are executed in enterprises. The execution of business processes is recorded with the help of information systems. Information systems are used to evaluate, analyse, and control business processes. The controlling part allows business managers to manage business processes which include measurement, monitoring and analysis of the business process to make real-time changes. After execution, the processes are evaluated for performance analysis. Customer and market demands are compared to the generated output. Different quantitative and qualitative measurements are made in this phase, like statistics and process mining [vdARW+07]. The actual values of objects are compared with the target values, and the planned process behaviour is compared with the actual behaviour.

The post-execution analysis of business processes uses the results of the evaluation phase and analyse the performance of business processes in a broader context. The achievement of the enterprise's objectives is analysed from customer, process and organisational performance aspects. In this phase, the AS-IS process model is built from execution logs (data perspective) to understand the current execution of business processes. In case of discrepancies between plan and target values or behaviour, the deficiencies in business processes are investigated. Different analyses are carried out to find the root causes of problems identified in this phase. The post-execution analysis of business processes is a starting point for business process improvement techniques.

Table 2.1: Business Process Lifecycle

Phase	**Activities**	**Input**	**Action**	**Output**
Plan	Process identification	Enterprise business objectives, change or improvement objective	Process identification, goal definition of BP, defining desired output, defining scope and kind of changes	Abstract BP description, design characteristics, plan for changes, To-Be design characteristics
Design	Detailed design of business process	Brief business process description, objectives, policies, org. info, output of plan phase	Defining inputs, procedure, rules, resource allocation, role mapping, and required changes	Detailed design model for implementation
Implement	IT implementation, simulation, and deployment	Output of design phase (detailed design model)	IT services, simulation, enactment and deployment of business process	Ready to execute environment
Execute	Execution	Defined event, instance execution request	Execution of business processes	Output result, product or service
Evaluate	Measure and monitor	Execution logs and other details	Taking Q&Q measurements, Comparison of plan and actual values	Statistics about performance of business objects
Analyse	AS-IS analysis, finding deficiencies	Performance statistics, execution details	AS-IS analysis, comparisons, mining, root cause analysis	Deficiencies, areas for improvement, new changes
Recommend	Defining change/ improvement objective	Deficiencies, areas for improvement or change	Defining the change or improvement objective	TO-BE concept and objective for changes

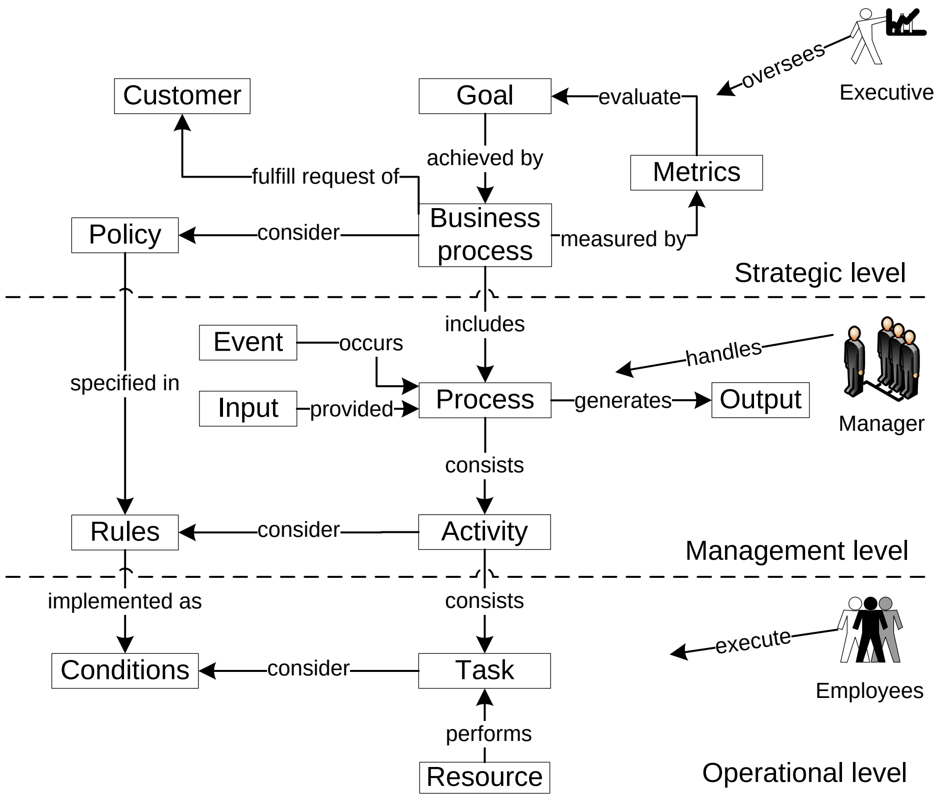


Figure 2.6: Business Process Meta-model in Different Layers

The identified deficiencies are tried to be avoided in further executions. The purpose of this phase is to define the objective for the planning phase in order to carry-out the changes for improvement in subsequent phases. Therefore, in recommend phase, the TO-BE concept is prepared. In this way, business processes are improved. For an overall view of the business process lifecycle, we summarise business process lifecycle phases in Table 2.1 with possible inputs, actions, and outputs.

2.7 Business Process Levels and Stakeholders

Different events occur (something "happens") in processes that usually have a cause (trigger like a request or demand from the customer) or an impact (the result of an activity) [OMG11]. In response to these events, organisational resources perform operations on inputs and transform them into defined outputs. In this way, the final output is generated in an enterprise. The achievement of an enterprise's goal is measured by metrics that evaluate the performance of a business process and its involved elements. This context of a business process is abstractly represented in Figure 2.6.

Different stakeholders are involved in business processes in an organisation. These stakeholders work on a business process at different levels. Therefore, they have different requirements, tasks and interactions with business processes. In the following, we list some levels, stakeholders, and their interaction with business process elements.

- Levels: Strategic level, management level, operational level
- Stakeholders: Executive, manager, employee
- Process: Business process, process, activity, task

At a strategic level, executives define the goals and objectives of an enterprise. They view a business process as a black box and are concerned with overall output, profits, new acquisitions, and mergers. From a human-computer interaction (HCI) viewpoint, aggregated reports and statistics on hand-held devices would be sufficient in case of remoteness. Product managers, domain or process experts, and line managers are concerned with enterprise operations and business process management. Tabletops, smart boards and other extended displays would be helpful in analyses. Employees execute business process operations with a view of taking inputs, performing defined actions based on certain conditions using organisational resources, and then forwarding the result of those actions to other activities. We show some of the involved stakeholders at different levels in a business process (BP) context meta-model in Figure 2.6.

Elements defined at one level are propagated to the other levels as well. For example, the goal of an enterprise is propagated as a process goal at the management level and continued as an activity and task goal to the lower levels. Similarly, metrics are computed on operational and management levels as well. Therefore, these stakeholders, levels, and their expectations are important for business process modelling and evaluation.

2.8 Summary

In this chapter, we provided the context of business processes starting from the vision to its industrial automation. We also discussed business processes from researchers' perspectives and provided its meta-model along with different management techniques. We also elaborated on the difference between business data and business process data which is important for analysis. We presented different business process characteristics and classified them into various classes. This classification is important from the analysis and improvement aspects. We have also discussed the business process lifecycle and its phases in detail. We discuss the lifecycle phases with activities, describing input and output elements of activities. In the end, we discussed different stakeholders, their levels and their role in business processes.

This chapter provides the basics to the reader and sets the context for our next chapter, where we discuss the method for communication between stakeholders and its (method) usage in different phases of a business process lifecycle.

3. Business Process Modelling

> This chapter shares material with the journal paper "An Extension of BPMN Meta-model for Evaluation of Business Processes" [LKS11b], FIN Tech. Rep.'2011 "Business Process modelling: Active Research Areas and Challenges" [LKS11d], and ACM FIT 2010 "Building AS-IS Process Model from Task Descriptions" [LKKS10a].

The communication of concepts related to the business process is very important between stakeholders. Different techniques are used for this purpose, like textual descriptions and graphical representations. Graphical techniques are used to visualise the concepts for better communication and analysis. Being graphical, they provide an intuitive understanding of concepts. Different graphical models are built to manage a company's business operations. The field that addresses the issues related to management of business operations and graphical models is called business process modelling.

In Section 3.1, we discuss different approaches of business process models followed by Section 3.2 where different research contributions and modelling languages are discussed briefly concerning business process lifecycle. A standard in business process modelling domain is also discussed with its meta-model and examples in Section 3.3. We also position some of the modelling language based on its focus and usage in different phases in Section 3.4. At the end of the chapter in Section 3.5, we summarise this chapter.

3.1 Business Process Models

Business process modelling is considered as the first and the most important step in BPM [vdAtHW03]. Business process modelling is used to visualise operations of a business process for better understanding and analysis. Being graphical nature of business process models, they are used as a medium of communication between stakeholders (e.g., executives, developers, and employees). Business process modelling has increased the ability to understand business processes and to make rational decisions for organising activities in a traceable and understandable way [Cum07].

Two approaches exist for modelling the business processes. One approach is a top-down approach, and the other is bottom-up. In a top-down approach, expert proposes the model that how business processes should be executed. It starts from an overall process by considering it as a "black box", and then this "black box" is broken down into more details (like activities and tasks) until all details are specified. In contrast to a top-down approach, the bottom-up approach starts documenting the details at a lower level, i.e., how the functions are executed at an operational level. After getting this information, functions are combined to make activities. Activities connecting other activities build processes. In this way, the whole business process model is built.We started from lower level details, so this approach gives a detailed insight into processes and their executions.

Mostly in business process improvement, the bottom-up approach is used as it helps to identify deficiencies in actual executions. The top-down approach is used for business process re-engineering [Cle94].

Various elements and different stakeholders are involved in business processes, as discussed in Section 2.7. They have distinct demands and expectations from business process models. For example, executives want a holistic view of their enterprise, and process owners require not only a holistic view but details of business processes. These details involve the structure of processes, operations carried out in these processes and characteristics/attributes of involved objects. Similarly, the operational managers want further details of business processes and performance related information.

Representing all details of involved elements in one model will make the model very complex for comprehension. Therefore, different models are proposed in the literature to fulfil stakeholders' requirements in a business process lifecycle. Depending on the modelling purpose, business processes are represented at different levels of granularity and from different perspectives. In a perspective, particular details of processes are considered like organisational culture, organisational structure, and functional perspective (operational details) as discussed in [CKO92, LK06]. These perspectives enables the stakeholders to focus on certain relationships and elements related to a business process. Some research work in the business process modelling domain is discussed in Section 3.2.

3.2 Research in Business Process Modelling

Continuous technological developments and ever-increasing customer demands for efficiency and improvements in services keep business process modelling an important research area. The fact is that business process models are used for easy communication, and they provide insights about their processes with other management methods.

Several modelling methods, techniques, and hundreds of tools exist for process modelling. In [GK95], the authors stopped at 72 methods and 144 tools for their comparative study. Similarly, one PhD student reportedly stops at a count of 3000 process modelling techniques [Rec06]. The selection of a particular modelling technique is crucial for the success of a modelling goal.

The research work in business process modelling can be discussed with respect to changes in the business domain and accommodating these changes in business processes during its lifecycle. Different modelling languages are devised to address the aspects of processes in different phases of the business process lifecycle. One of the most important is to support business processes with information technology. Therefore, most of the business process modelling domain work is for Business-IT alignment. The steps carried out in Business-IT alignment are similar to the BP lifecycle phases as discussed in Section 2.6.

Different models are used in Business-IT alignment which fulfils different objectives of phases like communication, mapping business requirements to IT services, simulation, automation (workflow), controlling, analysis, and improvement. In Table 3.1, we show the steps and corresponding models used for business-IT alignment. Models of one phase are transformed into other models to accommodate the needs of other phases. The issue of the transformation of models is further discussed in Section 3.2.5.

In the planning phase, managers and experts discuss the operations of the enterprise which can be partially or fully automated. Models with graphical notations are often used for understanding and communication like Event-driven Process Chains (EPC) [Sch98b], Flow charts [IBM69], Business Process Modelling Notation (BPMN) [OMG11], and Use case diagrams [BRJ05]. Several variants of modelling languages are proposed for business-IT alignment, like Unified Modelling Language (UML) diagrams [BRJ05] or Petri nets [Pet62].

Simulation of business processes is carried out to validate and verify the business process design. Validation and enactment of business processes are discussed in Section 3.2.5 and Section 3.2.6, respectively. There is a lack of business process model for the evaluation, analysis, and recommendation phase of the lifecycle which is discussed in Chapter 4. We further discuss the research work in the business process modelling domain with challenges and researchers' contributions to address those challenges in the following sections.

Table 3.1: Business Process Models for Business-IT Alignment

Phase	**Activities**	**Stakeholders**	**Models**
Plan	Requirement elicitation	Managers, domain experts, IT manager	Flow chart, EPC, Use case, package
Design	Mapping requirements into technical services	Domain experts, IT team	DFD, ER diagram, UML Diagrams like class diagram
Implement	Coding, simulation, enactment, and deployment	IT team, managers	UML diagrams, BPMN, Petri nets
Execute	Execution, logging	IT team, employees	BPEL
Evaluate	Measurement and Monitoring	Process owners and Managers	Statistics
Analyse	Performance analysis, business analysis	Managers and process owners	Charts, key performance indicators
Recommend	Defining improvement objective	Managers, process owners, executives	BPMN, Flow chart

3.2.1 Devising Modelling Languages

New ideas (products) and technological developments increase the demands of users toward business process models. These developments also expose the inabilities of modelling languages and thus enforce researchers to incorporate the new concepts in modelling languages to fulfil their demands. Different new modelling languages are proposed and extended to satisfy users' requirements.

Business process models are extended to represent the involved business elements with more details like legislation, risks, or involved roles. Similarly, successful modelling techniques of other domains are also applied in business process modelling like Petri nets [Pet62] were applied in workflow management [vdA96]. Several other extensions of Petri nets are also proposed to apply them more effectively in the business process domain like Workflow nets [vdA98], Object Oriented Petri nets [MK05], and Attributed Petri nets [Eic04].

BPMN [OMG11] are also devised to provide graphical notations for communication between business and technical users. The BPMN core set of elements focuses on the control perspective [ODvdA+09], while an extended set of elements attempts to address other perspectives like organisation (roles using swim lanes) [Rec10].

3.2.2 Integration of Modelling Approaches

Most comparison papers on business process modelling techniques suggest that a single technique is insufficient and propagate the combination of modelling techniques [Dam07, CMH09]. The reasons behind such motivations are to use the strong characteristics of modelling languages in phases. In [Dam07], the author suggests combining the graphical (flow charts) and tabular techniques to increase the understanding and improve the communication between stakeholders in business process models. In [DRvdAS08], the authors map and merge different modelling constructs of one language to another language for integration of process models for system configurations. Similarly, in [Men99], author combines the object oriented and workflow modelling techniques for business process re-engineering.

However, integrating different models faces some problems like models at different levels of details (coarse and fine granularities) and perspectives are mixed [DRvdAS08]. Such integrations are the cause of misunderstanding and confusion in the minds of stakeholders. Despite these problems and challenges, integration of modelling approaches is still an interesting research topic and discussed with further detail in a few case studies like in [CMH09], where authors use flow charts([IBM69]) and integrated definition modelling (IDEF0 [sta93]) language to model the business processes of a banking institution.

3.2.3 Integrated Framework

Different views and models are built to fulfil the requirements of stakeholders. Mostly, these views or models are taken in fragmented parts and cannot collaborate or be efficiently used with one another [DDB05]. Like models that are developed for a particular phase would not be reused or easily converted for usage in another phase. Similarly, when views are created "as needed" basis in the absence of an integrated framework, then consistency challenges arise as certain assumptions, and dependencies are not explicit [Bro09]. These issues support the misconception that process modelling is an overhead and less optimally used in enterprises [DRvdAS08].

The problems encountered in integrating modelling approaches can be addressed by introducing an integrated framework of modelling. Motivations for an integrated modelling framework are discussed in [DDB05, BFN06, Bro09]. In [DDB05], authors suggest the need for ERP-style integration of business process model to provide a consistent and coherent picture of enterprise operations from multiple perspectives. In comparison with fragmented parts of a model, the integrated framework ensures the sharing of consistent and common concepts through a central repository [Bro09]. The different views of models can be developed using a generic modelling language which is extendible by adding attributes related to a particular perspective. In [Bro09], the author provides an architectural framework to integrate and synchronise different views of a system. When there is a need to decide which attributes should be included in a particular view, a matrix/scoring system is also proposed in [Bro09], where weights are assigned to attributes for inclusion in a specific perspective or view.

Different enterprise modelling frameworks are proposed, like CIM-OSA (Computer Integrated Manufacturing Open System Architecture) [KZ99] and ARIS (Architecture of Integrated Information Systems) [Sch98a]. Research is carried out to effectively apply such frameworks in different scenarios of a business process lifecycle. Different modelling languages are also used in frameworks like in [WPC07], authors use Petri nets in CIM-OSA framework for postal company processes. In some other frameworks, like TOGAF method is the main focus rather than modelling language as they use OMG Standard modelling languages.

3.2.4 Generic Modelling Language

Different modelling methods are also compared in literature [LYP02, BFN06] and then their strong characteristics are considered to build a generic modelling language to provide maximum benefits [LYP02]. Generic modelling approaches can also be helpful to reuse the concepts introduced in one phase to other phases while maintaining the same notations and semantics for a common and standardized way between users. In [LYP02], authors compare modelling approaches under six perspectives and then propagate to use their strong characteristics for devising a generic modelling method. Different views and perspectives can be built while using the same language.

Usage of a generic modelling language for different purposes also poses some issues as it would not fulfil/satisfy all stakeholder demands at a time. Besides the attributes extension, modelling notations are also very critical in business process modelling. Different notational approaches are required for different modelling purposes and audiences [Pha98]. For example, users feel it convenient to use Gantt chart diagrams to manage the schedule rather than Petri nets or any other modelling notation. This issue can be resolved by generating models from a central repository using conventional modelling notations. Nevertheless, it requires a mapping function from one modelling concept to another.

3.2.5 Validation and Verification of Business Process Models

Business process models are investigated for validation and verification before execution. Validation of business processes refers to whether business processes behave as expected, whereas verification is concerned with checking the model is free of logical errors [vdA08]. Different modelling languages are evaluated in this aspect by various researchers. EPC business models are investigated to check their structural correctness in [vdA99, MVvD+08]. Petri nets are also used for validation and verification as they provide formal semantics and graphical notations for understanding business model. Different researchers contributed with the formalisms of Petri nets to check errors in the context of business domain [BS07, vdA03]. Different other formalism issues like OR formalism in business process models are discussed in [MvDvdA07].

Similarly, the notion of soundness is introduced in workflow nets [vdA98] to check the correctness of models in the business process domain. Other methods are proposed to transform one modelling language into other modelling languages for verification, like EPC diagrams to Petri nets [Kin06] or in [vDvdAV05, vHOS05]. Similarly, in [KSG05], EPC diagrams are also transformed into UML Activity diagrams.

Business processes are also simulated before execution for validation and to check bottlenecks. Simulation of a business process provides a walk-through to the process where an analyst can see the behaviour of a business process [Wes07] and identify potential problems. However, validation and verification techniques (like simulation) of business processes verify the syntactical and semantical correctness of a business process. They do not guarantee that their execution will also be correct in reality, as discussed in the literature [vdARW+07, vdA05]. Various studies in the field of process mining [vdARW+07, vdA05] show that the execution of business processes differs in reality, from the way how it is designed or planned. The trend also holds in organisational projects where the actual way of work is detached from the standard processes [BFN06]. Similarly, in [ENMZ06], the authors argue for including different aspects like time and resources in business process simulations.

3.2.6 Enactment of Business Processes

Business process models are investigated for the enactment of resources and execution of a business process. Workflow management systems support the execution of business processes. For this phase of the business lifecycle, business process models are enhanced with technical information that facilitates the enactment of business processes [Wes07]. In different surveys of business process modelling [Alo16, IRRG09], model-driven process execution is rated as the number one challenge in the business process modelling domain. Different modelling languages are devised or extended for this purpose. Petri nets are also used for workflow management [vdA98], and different extensions of Petri nets exist like workflow nets [vdA98].

Modelling constructs of BPMN language are transformed into constructs for execution languages such as Business Process Execution Language (BPEL) [JE07]. In [MLZ05], the authors proposed a method to transform graph oriented models into execution languages (BPEL). Similarly, in [ODvdA+09], the authors claim to improve the transformation of BPMN notations into BPEL. In [KGK+11], 62 BPEL extensions were classified based on their conformity to standard and extension type (e.g., modelling tool, process engine).

3.2.7 Comparative Surveys of Modelling Languages

Several surveys [Alo16, IRRG09, VTM08, SHK+07, LK06, RM07, AS04] and comparisons [RRIG09, Dam07, LS07] are made to evaluate business process models in different phases of a business process lifecycle. These surveys discuss the strengths and weaknesses of modelling languages empirically [IRRG09] and analytically [RRIG09]. In analytical surveys, the Bunge-Wand-Weber model (BWW model [WW90, WW93b,

Table 3.2: Research in Business Process Modelling

Category	Strength	Challenges	References
New/Extend Models	Better modelling support Business-IT alignment	New domains and technologies Isolated views	Petri nets [vdA98, MK05, Eic04], BPMN [OMG11, Rec10]
Integration of models	Integrated views Strong characteristics usage	Combining different levels Consistency issues, updates	Integration attempts [Dam07, DRvdAS08, Men99], examples [CMH09]
Integrated Framework	coherent view of process Consistent models	Different modelling notation Costs	Integration framework literature [DDB05, BFN06, Bro09], examples [KZ99, Sch98a]
Generic modelling	Standard notation in enterprise Reuse of models	Lack of modelling construct abstract, general	Approaches [LYP02, BFN06, OMG11]
Validation & Verification	Syntactic & semantic correctness Business process simulation	Require formalism No guarantee for reality	Petri nets related [BS07, vdA03, vdA98, vDvdAV05], EPC based [vdA99, MVvD+08, vHOS05]

Table 3.3: Research in Business Process Modelling (Continued from Table 3.2)

Category	Strength	Challenges	References
Enactment	Model driven process execution Automatic allocation of resources	Dependent on modelling constructs Models into execution language	References [vdA98, JE07, MLZ05, ODvdA+09]
Legislation & Environment	Conformance to standards Understanding the context of BPs	Changes in legislations Require enrich representations	Legislations related [SGN07, SG10], context related [SN07, NE05]
SOA & Models	Business service orientation	Rapid changes in technologies	References [vdABvH+07, Jae06, Bel08, FJ07], languages [BGRM08, RW08, Ste09]
Comparative Surveys	Strengths & weaknesses of models Guidelines for model selection	Defining evaluation criteria Selection of evaluation technique	Comparisons [Dam07, RRIG09, LS07, Gia01, VTM08], surveys [AS04, VTM08, IRRG09, SHK+07, LK06, RM07, Alo16]

WW95a]) is used for comparison, where constructs of modelling languages are evaluated for the representation of concepts. In empirical surveys like [IRRG09], feedback from different stakeholders of business process models is incorporated, and different issues and research challenges are identified. Such surveys are helpful for providing further directions to research in business process modelling, deciding which modelling language suits the best for certain phases (scenarios), and what are their strengths and weaknesses.

In [LS07], the authors provide a comparative survey of different graphical and rule based modelling approaches. They define the criteria for comparative analysis like expressibility, flexibility, adaptability, and complexity. Moreover, they evaluate different modelling approaches against workflow patterns [vdAtHKB03] because workflow patterns are used for functional comparison of processes. Their focus is on the design and execution time issues. A comparison of modelling languages where a differentiation despite the control flow perspective will be made is still required.

Diagrammatic notations like flow charts are compared with tabular techniques like activity tables in [Dam07]. The authors use the simplicity, flexibility, visibility, user involvement, and software support characteristics as criteria for the evaluation. A review of different process modelling techniques, their purpose and limitations are discussed in [AS04, Alo16]. Similarly, several process modelling frameworks are surveyed in [BFN06], where their purposes and key characteristics are mentioned.

In [Gia01], authors evaluate different modelling languages by comparing their support from different perspectives during the business process lifecycle. Such evaluation of modelling languages provides a guideline in which situation or phases a particular modelling technique is best applicable. Similarly, in [VTM08], authors evaluate business process modelling languages for analysis and optimisation of processes and provide state of the art from this perspective.

3.2.8 Legislations & Environment

Enterprises have to follow the legislative rules and standards that are set in the market. Legislations like the Sarbanes-Oxley Act (2002) attracted many researchers to accommodate the legislative aspects in business process models. Other researchers focus business process models on providing their support/benefits to conform with these legislations. Business process models are enriched with annotations for better communication between domain experts and legislative officers, for example, control tags were introduced in [SGN07]. Similarly, a framework for aligning business processes with compliance is presented in [SG10], where process models are also discussed for compliance conformance.

Business process context is also modelled in business process models [SN07]. The context of a business process includes customer demands, market changes, environmental conditions, and other involved elements of business processes. Such approaches are helpful in building flexible business process models [NE05]. Flexible process modelling languages are devised to accept continuous changes in the business domain

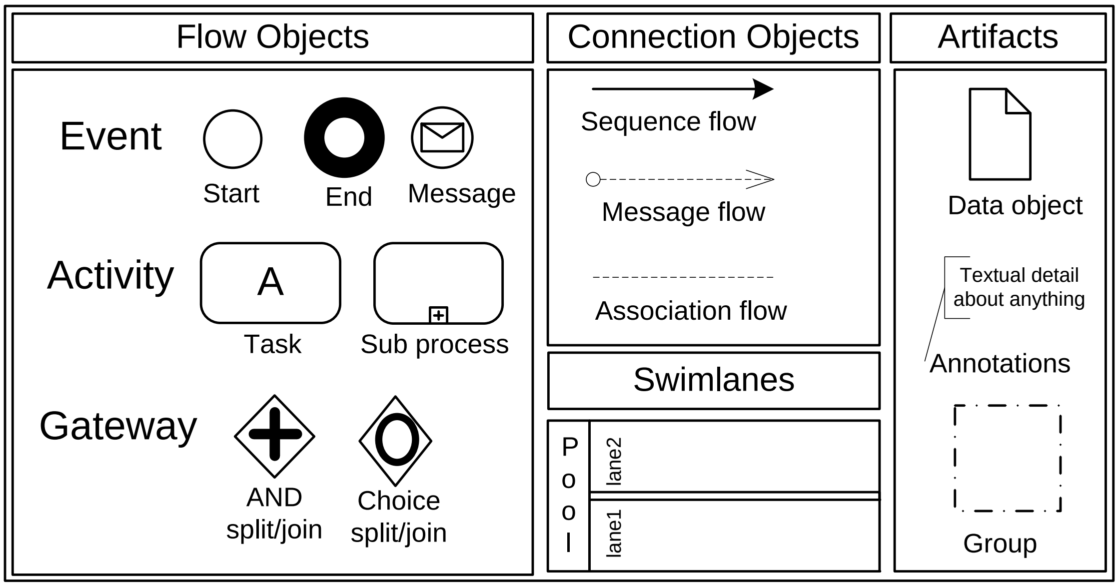


Figure 3.1: Main Categories of BPMN with Example Constructs

into systems. One aspect of such changes is to adopt them in information systems, which coined the term adaptive information systems.

3.2.9 Service Oriented Architecture and Modelling

Service Oriented Architecture (also referred to SOA) is an architectural approach which advocates a set of practices, disciplines, designs, and guidelines to use technologies to support business processes [Ses07]. Business functionalities are implemented in the form of services and different services collaborate to fulfil customer demands. Business process models are also investigated for SOA, for example, in [CG08], the authors propose an approach for designing business processes in a service oriented way. A SOA-based architecture framework is explained in [vdABvH+07], where different variants of business process modelling languages are discussed. Similarly, the relation between workflow modelling and business processes for service composition is explained in [Jae06]. Different modelling concepts in the service-oriented lifecycle are discussed in [Bel08].

A new modelling language is introduced in [BGRM08], which addresses challenges posed by SOA's nature like dynamic nature and distributed aspects. In [RW08], the authors attempt to bridge the business & IT gap in SOA domain by proposing a method to transform business process diagrams (BPMN) into UML service diagrams. Different frameworks like the ARIS framework [Sch98a] with representations like event-process chains (EPCs) are also investigated in [Ste09] to devise a new modelling language for service oriented business process management. A business oriented perspective of service oriented architecture is discussed in [FJ07].

3.2.10 Other Work in Business Process Modelling

Different other works exist to provide better modelling support in a business process lifecycle. Business process modelling is also investigated to generate context based models. In [CC07], authors build views of the business process model based on the context where it is used. They develop a domain specific aspect language for this purpose and discuss it in the context of software development.

Inclusion and elimination of certain features in business process models is also investigated. In [ENMZ06], the authors discuss a feature based modelling approach where characteristics like time and cost are included.

In [LKKS10a], a method is proposed to build the business process models from employees' task descriptions. A framework for selecting business process models in different phases is provided in [LT99], where different characteristics of modelling languages are discussed from different perspectives. We summarise the discussed research work in business process modelling in Table 3.2.

3.3 Business Process Model and Notation

Business Process Model and Notation (BPMN) [OMG11] is a modelling language ISO standard (ISO/IEC 19510:2013 [ISO13]) defined by the Object Management Group (OMG). These graphical notations are used for communication between business and technical users. Modelling constructs of BPMN language are transformed into constructs for execution languages such as the Business Process Execution Language (BPEL) [JE07].

In BPMN specifications, BPMN graphical notations are divided into four basic categories [OMG11]. In Figure 3.1, we show these categories and examples of their constructs. These categories are discussed as follows.

Flow objects consist of activities, involved decision nodes for their order (sequential, parallel, iterations), and events of processes.

Connecting objects, as the name implies, are used to connect activities and other elements using different arrows representing messages and associations between them. This core set of elements defines the control flow perspective of processes.

Different modelling elements are grouped through **Swimlanes**, which use pools and lanes [OMG11]. A pool is used to represent process participants, while lanes are used to partition these participants and their activities from one to another. A process participant can either be an organisational entity within an organisation or different organisations for collaboration in a process. Mostly, organisational perspective is provided by using Swimlanes constructs.

In BPMN, additional information about the process such as involved data object and guidelines for operations is provided by **artefacts**. These elements consist of data objects, annotations and group constructs. Several other modelling constructs

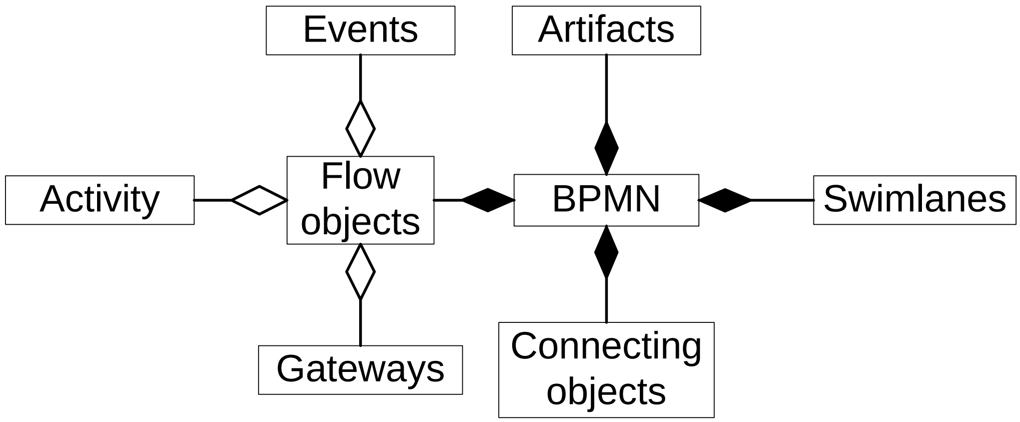


Figure 3.2: A Meta-model of Business Process Modelling Notation

are used in these categories for further specification of a business process. Besides these modelling constructs, different extensions are also possible in BPMN to provide further insights into processes in a BPMN model. An abstract meta-model of BPMN is shown in Figure 3.2.

We kept this meta-model intentionally simple and abstract rather than describing different classes and notations in each category. Further details about different kinds of notations can be found in [OMG11].

3.4 Phases and Modelling Languages

Several gaps occur in a business process lifecycle due to the lack of communication, especially during the transition from one phase to another phase. Therefore, different models are proposed in the literature to fulfil stakeholders' requirements in a business process lifecycle. We divide the business process lifecycle (presented in Section 2.6) into two parts, as shown in Figure 3.3. The part on the right side is before execution, and the part on the left side is after execution. Most of the process modelling languages are devised only for the right side. For example, in the planning phase, Event-driven process chain (EPC) models [Sch98b], Flowcharts [IBM69], and other models are used for communication. Similarly, for implementation into IT services, different models are proposed, e.g., for software engineering, different types of UML diagrams [BRJ05] are used.

In Figure 3.4, we show some examples of modelling languages with respect to their focus (business or IT) and phases of the business process lifecycle. These are represented on the vertical and horizontal axis. In Figure 3.4, we do not give precedence based on capabilities to any model within a focus and its phase.

Figure 3.4 shows that statistical techniques are used for evaluation and there is a lack of models for evaluation and improvement phases. We found that graphical models for evaluation and improvement phases are still an open issue and must be addressed.

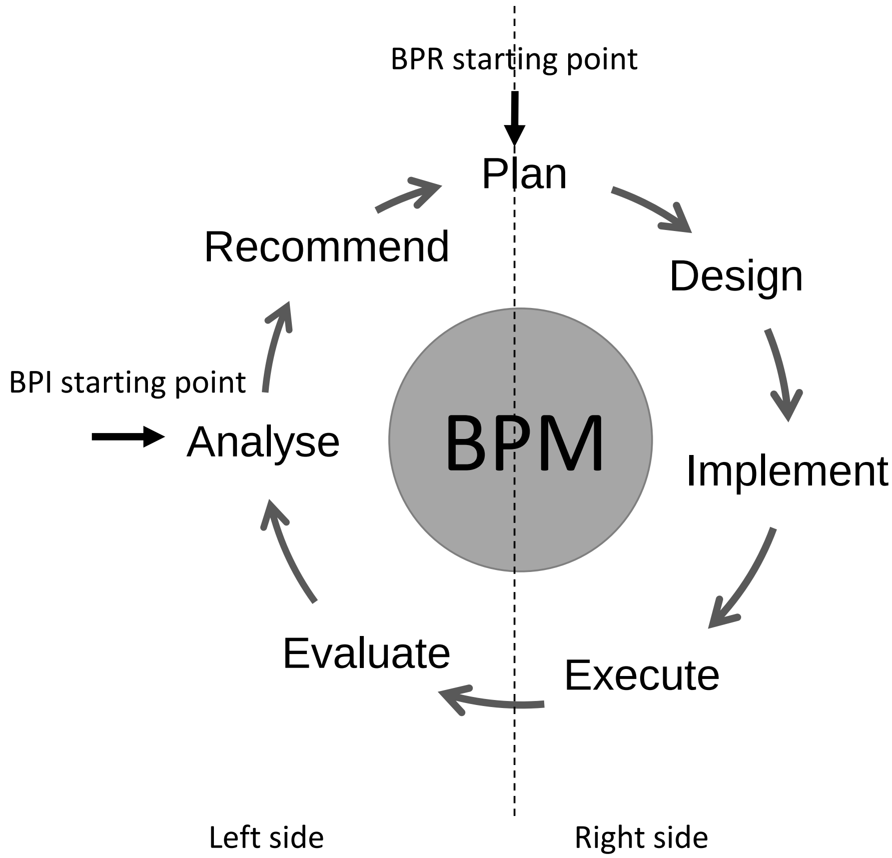


Figure 3.3: Business Process Lifecycle and Modelling Languages

This view is also strengthened by a study [Alo16], where authors review papers over 13 years. Author positions different process modelling tools and techniques only till the execution phase of the business process lifecycle. In our work, we also recommend that the anticipated analytical modelling language should focus more on a business domain than on information technology.

The gap will occur when existing models are used for evaluation and improvement as these models will not provide complete details. Therefore, there is a need to fulfil this gap and offer process models for overall business process improvement (evaluation and analysis). This representational gap in the post-execution context is further explained in Chapter 4.

3.5 Summary

In this chapter, we have discussed different modelling languages and research contributions. We have discussed how other modelling languages are used during the lifecycle of a business process. We also discussed BPMN in detail by modelling a scenario in BPMN and provided a meta-model of BPMN. This chapter answers the first two research questions presented in Section 1.2 (RQ 1.1: research in business process

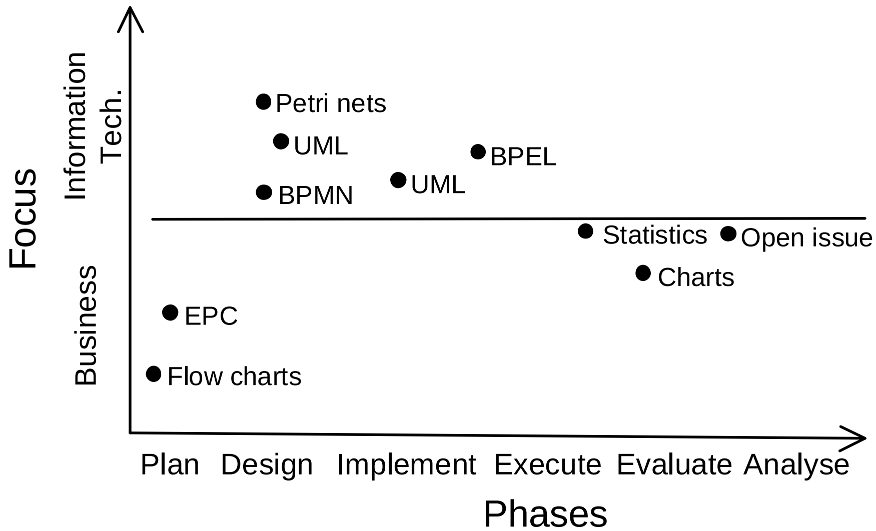


Figure 3.4: Phases of BP Lifecycle and Modelling Languages

modelling and RQ 1.2: business process models in business process lifecycle). We also positioned some modelling languages according to the business process lifecycle and their focus (business and technological perspective). We found that the existing process modelling languages are insufficient for evaluation and analysis. This topic is further discussed in the following chapter.

4. Post Execution Analysis

> This chapter shares material with the IEEE HICSS'2014 "Business Process Modelling Language for Performance Evaluation" [LKW+14], IHCI'2011 "Business Process Improvement Framework and Representational Support" [LKS11c], FIN Tech. Rep.'2011 "Business Process Modelling: Active Research Areas and Challenges" [LKS11d], IEEE SKIMA'2011 "Business Process Modelling for post-execution Analysis and Improvement" [LKS11a] and FIN Tech. Rep.'2010 "Post Execution Analysis of Business Processes: Taxonomy and Challenges" [LKS10].

Evaluation of business and its involved elements is essential to determine the fulfilment of enterprise goals. Performance results provide the basis to control and improve the processes. Different methods from diversified fields are used for this purpose, such as economics, statistics, and computer science. In computer science, the focus is to provide support in carrying out business operations (via information systems, automation), storage (recording the interaction, states of process and entities), computations (decision support systems, knowledge extraction), and reporting (like visualisation).

In this chapter, we focus on the evaluation of the business process, which involves computation and their corresponding representation for further analysis. We also differentiate between business intelligence and business process intelligence in Section 4.1. In Section 4.2, we explain the evaluation of business and its processes in different perspectives using dimensions. We also classify different attributes based on the analysis. Different organisational metrics and classes are discussed in Section 4.3. In Section 4.4, we provide an analytical framework for business process improvement, followed by Section 4.5, which emphasises the need for representational support for business process improvement. In Section 4.6, we discuss the challenges for business process modelling languages in the post-execution analysis context. The relation between performance evaluation, visualisation and business process models is discussed in Section 4.7, that provide the context for analytical modelling language. In Section 4.8, we discuss the related work in post-execution analysis context, followed by Section 4.9, which summarises this chapter at the end.

4.1 Evaluation of Business and Processes

Evaluation of businesses and their processes (referred as Controlling [FS16]) is a challenging research field like other management fields (e.g. planning, organising). Controlling is a continuous process where different metrics are made to evaluate the achievement of goals at different levels. Different methods and tools also exist to evaluate the performance after the execution, like balance scorecards [KN96] and key performance indicators [iso14b, Par15].

In order to evaluate the performance, data is required. Therefore, different concepts and techniques related to data collection, integration, reporting, and analysis of businesses are discussed in the area of Business Intelligence (BI) [VLM02, VLM02]. Different methods and tools cover these perspectives like data modelling, data warehouse [KSS12], and decision support system [TSD13]. Different data models in different domains are discussed in [SA09]. Data mining approaches are also devised to extract the knowledge from data. The application of the knowledge requires a deep understanding of processes.

These business intelligence approaches are further extended and applied on business process level, resulting in business process intelligence domain where process oriented warehouse and further systems were investigated [GCC+04, Mue04]. In [GCC+04], authors refer to business process intelligence as the application of business intelligence (BI) techniques to business processes. Business process intelligence spans over various fields like process mining (discovery, conformance), business process monitoring (activity monitoring), and process visualisation. We further discuss the evaluation of a business process in the following sections.

4.2 Evaluation based Classification

The processes are analysed in different perspectives and are evaluated with different dimensions depending on the requirements. Different quantitative and qualitative measurements are made in this phase. The performance is usually evaluated in the form of quantitative measurements, which help to indicate about quality. For example, First Pass Yield (FPY) is an interesting measure to give an indication about the quality of a process in production and is defined as a key performance indicator in ISO Standard 22400 [iso14b].

Perspective provides the means in which analysis has to be done. Like financial perspective provides direction to analyse the processes from sales and cost dimensions [KN96]. Besides the financial perspective, other perspectives like quality and time dimension are also important. The organisational perspective provides direction to analyse the performance from organisational dimensions, like departments,

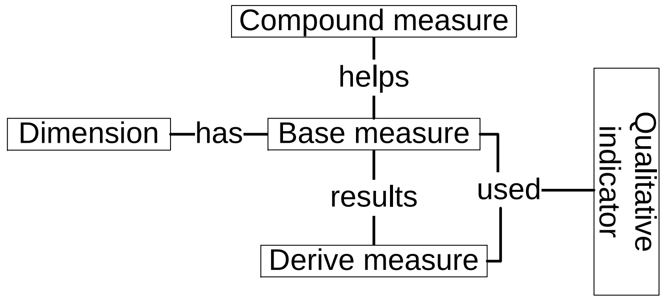


Figure 4.1: Evaluation Meta-model with Base and Derived Measures

units or from roles like team/group leader, department manager, or director. It may also need to analyse from geographical perspectives, like branch, city, area/state, country, and continent. Different other perspectives depending on the requirements, can come into consideration, like environmental perspective and customer perspective. Similarly, process perspective analyses processes for improvement purposes which may involve time, cost and organisational dimensions for analysis (identify deficiencies, improving efficiency, reducing wastes, lean aspects). Different examples of dimensions are discussed in [Pen05, IGG03, VLS16].

In evaluation, companies need to have an end-to-end picture of processes, like from the abstract level to the lower level details. These details are essential to evaluate the overall impact of changes in processes. Different stakeholders are involved in enterprises at different levels, as discussed in Section 2.7. These stakeholders evaluate the performance of processes.

Different methods are used to fulfil the requirements of each stakeholder. Executives are interested in an abstract level evaluation, like overall profit and losses. These abstract evaluations are accompanied by textual descriptions and graphical charts (like reports and statistical charts) [dRORRC19, ZBA21]. Different trends and projections are also estimated for the future at this level. Managers evaluate processes at a lower level with more details about activities and involved resources. They are interested in identifying the deficiencies and increasing the performance of processes.

Evaluation of business processes and business objects are carried out in different dimensions using base and derived measures. Base measures are the primary measurements from which other measurements are derived. For example, in the time dimension, the base measures are processing time and idle time. From base measures, different other measures like total time, minimum, maximum, and average time are derived. Compound measures are the measurements which are computed from different other measures like a number of requests fulfilled in a particular time. Based on different measurements, qualitative indicators are estimated like efficiency and quality, as shown in Figure 4.1.

Depending on the granularity and stakeholder requirements, different dimensions and their characteristics become crucial for analysis like time, cost, and quality. In

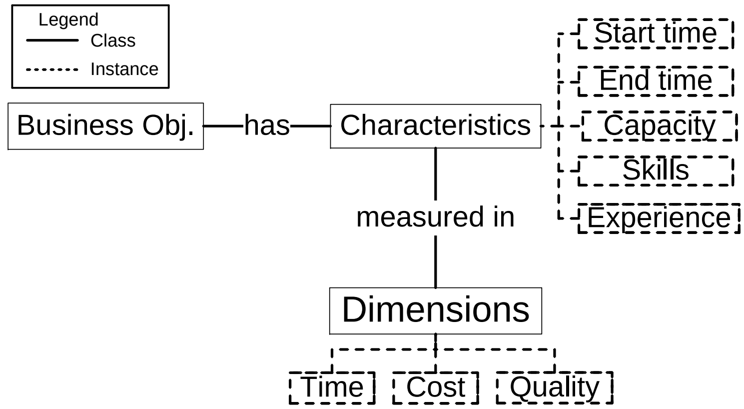


Figure 4.2: Business Object Characteristics and Dimensions

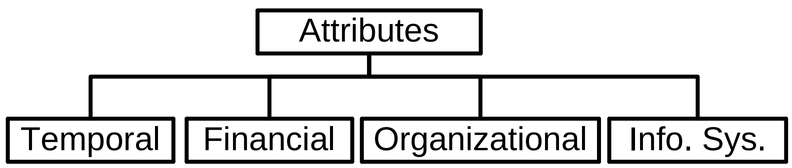


Figure 4.3: Classification of Attributes

order to achieve the real benefits of evaluation of all important dimensions, their attributes should be part of the evaluation and their representation. The stakeholders' requirements make the inclusion and filtration of certain data/information from the evaluation (and their perspectives). Based on the perspective requirements, other dimensions can be included or divided into hierarchies (like time in seconds, minutes, and hours) or classes based on threshold values (like high cost and low cost). The relationship between business objects, characteristics, and dimensions is shown in Figure 4.2.

The classification of business objects is already discussed in Chapter 2. Here we discuss the classification of attributes based on their participation in different analysis.

4.2.1 Classification of Attributes

Attributes of objects are classified on the basis of their participation in further analysis. Attributes of objects from one kind of analysis can be combined with other attributes and objects that provide the basis for new investigations or evaluations. In this way, a process of creative analysis evolves. Some analysis consider attributes of objects while others focus on the attributes of a process after an instance is executed. Some kinds of analysis are described below with examples of attributes analysed in analyses. In Figure 4.3, we show attributes' classification and the following sections discuss them in detail.

4.2.2 Temporal Analysis

Business processes are analysed from time perspective to measure the efficiency and performance of involved objects. Examples of attributes involved in such analyses are cycle time, change-over, set-up time, total manufacturing time, operational time of tasks/activities (time in execution), waiting time, customer negotiation time, and other temporal metrics for performance evaluation.

4.2.3 Financial Analysis

In this type of analysis, the monetary characteristics of objects are analysed and their participation in business processes. These are critical identifiers for business processes affecting overall cost and business. These attributes can be further classified based on their participation in business analysis like stock and flow. The stock refers to quantity (money and goods) of a company at a particular time while flow is the transactions of objects that occurred over time. Examples of attributes of business objects are money, quantities of products, purchase invoice, and receipts of payment (flow of money). Activity based costing is an example of such analysis.

4.2.4 Organisational Analysis

Different characteristics of organisational objects are included in the analysis to measure the efficiency and effectiveness of organisational resources (employees/machines) like to determine the usage/performance of resources (machines) in business processes. Such analyses are also used to see the interaction between different organisational resources (employees) like social groups as described in [vdARS05]. Such an analysis answers questions like how resources collaborate to carry out the task or which employees are involved in task execution. Different other metrics are also made in this analysis like overall equipment efficiency (OEE), mean time between failures, downtime, and uptime. From an employee's performance perspective, different other attributes are measured like employee turnover, performance, successful projects and their timeliness.

4.2.5 Role-based Analysis

Analysis based on a particular role to determine which business elements are of interest for a particular user. For example, for a customer, related business elements and attributes are invoice, ordered items, and order status. The other business elements like worker's performance, machine usage, and time of parts in a queue are not related to a customer; they are important for a production manager's role. The role-based classification will find all the involved objects related to a particular role like customer and system user.

4.2.6 Information System Analysis

In this analysis, different objects and attributes related to IT systems are analysed, like the status of various components, their performances, and other details. In such analysis, users are concerned with the information system because other systems fall into the organisational resource category. Therefore, program views/screens, executed functions, and elements/information accessed during execution are considered in this analysis. Such analysis helps to answer the question of how well IT systems are aligned with business operations? In which areas can this alignment be further improved?

4.3 Organisational Metrics and Classes

Data generated and captured during process execution (as discussed in Section 2.4) provide excellent means to ensure that strategic goals are being met consistently in an efficient and effective manner. For this purpose, goals are further defined as quantifiable measures and supported by different indicators. These indicators are used to evaluate the performance of business processes.

The analytical data can be used to identify which activities, organisational resources, and involved elements add more value to the enterprise [BP18, Kle10]. The classification of process elements based on performance depends on the metrics used in an enterprise. Enterprises can define their own metrics by defining target values, upper and lower threshold values (tolerances). For instance, if the result of a business object's performance is within the target value, then it can be classified as a green class, if its performance is close to threshold values, then classify it as yellow and if its performance is out of threshold values, then classify it as a red class. If target values and threshold values are not available, then overall average values can be used for this classification and threshold values can be defined based on statistics. These threshold values serve as criteria for different classes. Based on the classification, activities, organisation resources, and involved elements are correspondingly represented in process models and reports.

The performance evaluation is carried out in different dimensions like time, cost, and quality. Although, the relation between time, cost and quality is not as simple as discussed in [VKLR07, KL09], where increasing one factor has a direct effect on the other, like reducing the time to produce a product may increase the cost of the product. Similarly, decreasing time or reducing the costs may also affect the quality of a product. In the following, we discuss an analytical framework and discuss it in more detail.

4.4 Analytical Framework for Improvement

In enterprises, different silo systems exist which can be applications and their databases. In reality, the communication between silos is not seamless. Different other applications, interfaces and macros are used to fulfil this task. The situation is more challenging in bigger organisations at the manufacturing level, where process chains are lengthy and the majority of the processes are executed manually. These processes are supported by different customised applications on old systems. As a result, enterprises find it difficult to decide where to start and what changes should be implemented for improvement. Complexity in a business process is due to various factors like inter-dependencies between activities, stakeholders, involved elements, attributes, and applications. Research in business process improvement needs to address these complex issues and provide support to decide which action should be taken for business process improvement.

In order to provide the necessary support for business process improvement, a complete framework for analysis is required to be specified. This framework should address issues like data collection from silos, its integration, computation with business rules, and representation in business process models. We also need clear directions like defining steps for improvement and mechanisms to carry out the changes. An abstract picture of the overall framework is shown in Figure 4.4.

4.4.1 Data Collection and Integration

Computers are widely used in business as they range from hand-held devices to main servers to run businesses. Human interacts with business objects (physical materials), organisational resources, and computer applications to carry out enterprises' processes. Information systems play an essential role and record the interaction between humans, business objects, and applications during the execution of processes. These interactions are stored in databases, log files, and different messages. This data is helpful to improve overall businesses in case of either business process structure, organisational resource structure, or human-computer interaction (HCI).

Data about business process characteristics like involved business objects and their attributes can be collected from an information system's log files, database tables, company documents, and other resources.

Enterprise data warehouse systems extract the data from different legacy systems, applications and their corresponding databases. Afterwards, it is integrated with each other. Different data warehouse approaches are used for this purpose like a normalised data model approach [Inm92, Inm05], a non-normalise dimensional approach [KR13], and a hybrid approach [LO15]. The log files from different applications (e.g. MES) are also collected which registers different events (like business object "received", "processed", "successfully completed") in the system during the process execution. Data from log files of an information system or from a MES system messages are converted into a suitable format for analysis (this data is sometimes referred as *process trace data*).

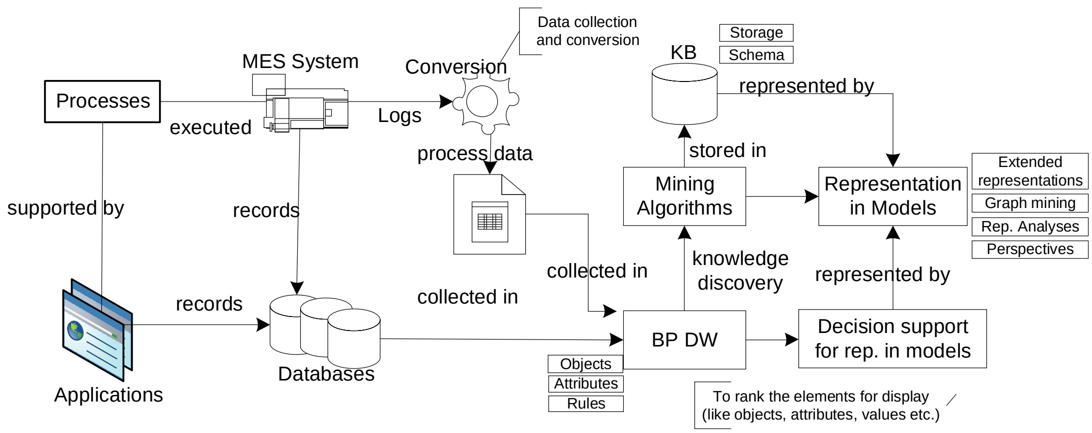


Figure 4.4: Framework for Business Process Improvement and Analysis

4.4.2 Computation and Knowledge Extraction

After data collection in an enterprise data warehouse, different computations are made for performance reasons. Different modelling techniques are used to gather customer requirements regarding analytics as well as their implementation in information systems. Dimensional modelling is one of the techniques where different dimensions and respective measures are modelled for communication and afterwards implementation in data warehouse. One popular notation for dimensional modelling is Adapt, as further discussed in [BF98]. Different dimensions and their related measures are computed in this stage.

Process trace data extracted from log files are also analysed. Several techniques (like process mining algorithms [RvdA06, vdA05, vdARS05] and business process intelligence [GCC+04]) are applied to process trace data to extract knowledge. Application usage mining [KR05] techniques analyse user's behaviour with applications and attempt to improve the interaction between applications, humans and their working. Similarly, other techniques can be applied to the data to evaluate the processes and extract knowledge like data mining, balanced scorecards and other process metrics.

A knowledge base is required for knowledge management. The main purpose is to store the knowledge from analysis techniques. There are several topics which needs to be further investigated like how will be the schema design, how would be the knowledge documented and represented, and the format for storage as well? At the end, it is also important to describe knowledge as a company's best practices or its usage in daily operations.

4.4.3 Visualisation / Graphical Representation

The extracted knowledge and information are visualized graphically for intuitive understanding. For this purpose, graphical representations are used as an effective communication tool and help stakeholders to make decisions. Such representations help a stakeholder for better understanding and communication.

In [Maz09], visualisation is defined as

"a cognitive activity, facilitated by external visual representations from which people build an internal mental representation of the world."

In this definition, external visual representation can be charts or graphical models built with the help of information technology. The world in the definition, means data, information, and concepts. Some authors also include the cognitive process and the process of building graphical models in a visualisation definition [Maz09]. In [Chi00], the author differentiates between different visualisation types like data, scientific, and information.

Different visualisation techniques are also employed to evaluate business processes and their elements. These techniques depend on the user requirement, including evaluation goal, level of detail, and dimension under analysis. The goal of the evaluation means what we want to measure. Depending on the goal of the evaluation, the data is prepared for visualisation, and different views are built. This data can be operational/raw data as in the case of data visualisation or abstract as information visualisation. In Figure 4.5, we show an example of an analytical Dashboard (consisting of different views) prepared in a visualisation tool (in this case, Tableau). In this case, process representations are abstract and do not provide details about process structure [dRORRC19, ZBA21]. Similarly, Figure 4.5 shows a detailed view of a particular process step. Figure 4.5 is taken from the public dashboard of Tableau [Sun14].

Based on the stakeholders' requirements, certain information is filtered (selecting circles in Figure 4.5) or provided with more context details (such as KPI or line charts in Figure 4.5). Therefore, a decision support system is required to rank the knowledge for representation with the context for stakeholders. The ranking is also very important to reduce user's cognitive load in graphical business process models while representing performance details and other knowledge.

A business process may consist of many processes and activities ranging up to hundreds depending on the granularity of detail. For process improvement, process managers are interested in details of these activities with extended representations, which may further increase the complexity of a business process model. Besides the decision support system as discussed earlier, tabletops and smart boards will be very useful for providing a complete picture of a business process as they are quite big in size. These devices are better as compared with computer screens which are not that big. Management of complex business process models and their representation in tabletops need further investigation for optimal usage. Similarly, tangible interfaces and tabletops can also be further investigated to help and train new employees with extended representation.

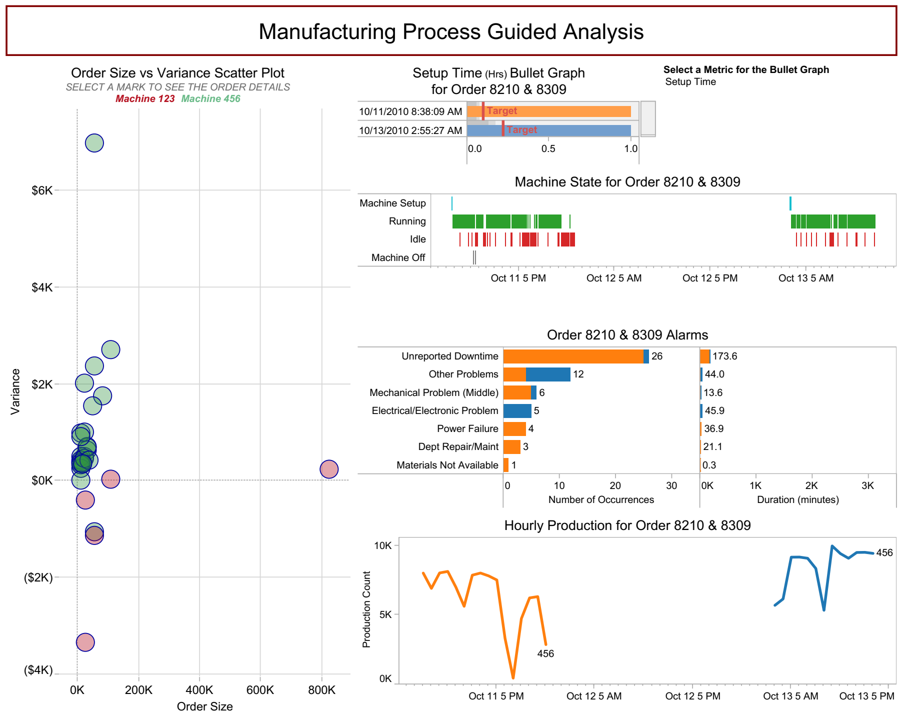


Figure 4.5: Data and Process Visualisation in Tableau

4.5 Post Execution Analysis and Representational Support

Evaluation of business processes is vital for analysis and improvement of an organisation. The post-executional analysis of business processes uses the results of the evaluation phase and analyse the performance of business processes in a broader context. In this phase, focus shifts toward process aspects and their performance rather than data perspective as in the evaluation phase. Post-execution analysis of a business process uses these evaluation results to provide recommendations for the whole process. These recommendations can be used to improve quantitative (like operating time, overall cost) and qualitative (like first pass yield, satisfaction of customers and employees) aspects of the process.

In this phase, the current (AS-IS) business process model can be built from execution logs (data perspective) to understand the current execution of business processes. In case of discrepancies between actual and target values or behaviour, the deficiencies in business processes are further investigated. Different analyses are carried out to find the root cause of problems identified in this phase. The post-execution analysis of business processes is a starting point for business process improvement techniques.

Currently, the knowledge in the post-execution analysis is represented at an abstract level using statistical charts and other representations as discussed in Section 4.4. In order to provide better support for business process improvement, knowledge representation should be along with the process structure, including further details within the business process models [dRORRC19, MDFL+20]. In this way, models provide better insights into processes and enable analysts to improve the process itself.

Mostly performance attributes are represented with involved business objects of a process. Sometimes these attributes are applicable to the overall process rather than a specific instance or business object. In this case, they are represented by the process itself. Similarly, business rules and conditions are represented where they are applied to provide the rationale for decisions. For post-execution analysis, descriptive models are required and all details are needed to be represented in models for analysis.

Graphical representation of extracted knowledge and process trace data also allow applying different methods like graph mining [LKKS10b]. Similarly, extended business process models help analysts to understand processes and identify deficiencies in business processes. We discuss the extended representation challenges in post-execution analysis in the following section.

Mainly, business process modelling is investigated for phases before its execution like analysis, design and implementation. For plan and design phases, different perspectives and level of detail is important to model business processes. For example, abstraction is required for planning the activities and certain details are not considered during modelling (like implementation details and execution). In comparison, the post-execution analysis phase requires detailed representation to find the deficiencies for optimisation and improvement. For post-execution phases, we need models which have more focus on the business domain and at the same time also support details from the information technology domain. Limited research is carried out to provide graphical modelling support for post-execution analysis.

After execution, business process analysis attempts to answer several questions like what is actually happening in the system? Which type of business objects are involved in execution? How are different processes executed? Where are different deficiencies and problems exist? What are the reasons for the problems? Whether business rules are completely followed or not?

4.6 Modelling Challenges in Post Execution Analysis

In the literature, several surveys [MDFL+20, Alo16, IRRG09, VTM08, AS04] and comparisons [RRIG09, Dam07, LS07] discuss the limitations of modelling languages and current challenges in the business process modelling domain. Their findings show that users' demands are not satisfied and require further research in business process modelling [IRRG09]. When business processes are modelled for current status analysis and improvement, then their requirements are more than the simple representation of processes for understanding [MDFL+20, AS04, Dam07]. These requirements demand the enrichment of business process models with details and require new constructs to represent reality with performance data. We discuss the representational challenges for the evaluation and improvement phase after process execution in the following subsections.

4.6.1 Environment of Business Processes

In a survey of modelling techniques [RRIG09], the authors found that only a few modelling techniques represent a business process environment using some constructs in their models. The absence of environmental factors from models makes analysis difficult for analysts to understand the execution of business processes and their performance. The performance can be affected due to external factors (e.g. time, weather, market's condition, and employee's skills, raw materials from suppliers) directly affecting business operations.

4.6.2 Elements and Attributes

Mostly business process models do not represent the elements and attributes involved in business process executions. The involved elements and attributes are implicitly assumed as available before execution. Because of this, the dependencies are implicit and do not provide details in the analysis after execution. Different articles discuss the importance of explicit representation of attributes in business process models, for instance [EVTG20, AS04, DDB05, Mac93, BFN06]. For example, in Petri nets, the presence of all involved elements is abstractly represented by a token (dot).

Similarly, the rules and other assumptions are not explicitly represented in models. The representation of involved elements (business objects) is important for a business analyst who wants to analyse the participation role played by these elements in business process execution. In [IHG01], authors found that activities extended with attributes provide a better capability for process analysis.

Incomplete representation of elements in process models is discussed in [RRIG09], where authors found it as the main hindrance to the specification of rules. For example, the representation of objects like gold/silver customers is still missing in the process models. Based on the characteristics of cases, different process structures/-paths are followed.

4.6.3 Representation of Successful and Failure Paths

Business process models do not fully represent the perspective of business processes and involved elements. For example, is not a trivial task to identify and represent weak structures in process models. The weak structure means that the path on which often process executions leads to failure or most of the time is consumed without significant contribution, e.g., repetitions. What are the alternative paths to avoid such structures for improvement and optimisation? The best practices for carrying out business operations must be represented in business process models.

4.6.4 Structural Challenges of Business Process Models

Restrictions of most modelling languages are not compliant with business processes that occur in reality. For example, few modelling languages apply structural restrictions on process models like workflow nets [vdA98] where more than one input place is not allowed because of the complexity in its formalism, validation, and verification. Similarly, explicit representation of other involved elements is also often avoided. Due to this, business process models do not represent the details of reality. In a real business process, more than one starting place can occur, requiring all business elements to be represented explicitly. This question requires further investigation about the representation of reality in business process models without modelling restrictions.

4.6.5 Simulation, Reality, and Representation

In the case of loops, specific paths are improbable to be executed in real life. Consider a process model where two activities (A and B) are executed in parallel. The result of the two activities is evaluated later. If quality is not fulfilled, then a loop path is created to repeat the activities to fulfil the quality standard. If only one activity causes the quality problem, then only that activity will be repeated. Since process models represent process at an abstract level, a process model suggests that both activities will be repeated in the case of repetition due to parallel control construct. Simulation logs of the model will also generate activity B as a repeated activity which is not repeated in reality. Apart from the problem of granularity level in process model, various conditions and objects are involved in business process execution due to which simulation of business process does not represent the reality. Representation of business processes in reality requires the extension of current modelling languages.

4.6.6 History Construct

Business process models lack representation of the history of business process instances [RRIG09], like through which particular process structure the instance has been executed. Different annotations and lists are used to represent such information with models. For example, in a loan mortgage application, the profile of a client (his past behaviour with the company and transactions) is vital to take decisions. Currently, such information is not explicitly presented in models. In [RRIG09], authors found it as the main hindrance for the integration and specification of rules in business process models. The specification of history construct in a model will help stakeholders to better understand the dependencies between activities and rules. The representation can also help the stakeholders to understand which processes lead to success and how often it happened.

4.6.7 Priority of Activities

In business processes, some activities are executed independently, i.e. in parallel. In most cases, users want to prioritise their executions for efficiency and use annotations for communication in models. Like longer activities should be started earlier (or later depending on the resource situation and importance). Therefore, other activities would not have to wait to complete the previous activity. The modelling languages do not provide any constructs. Due to this, separate lists or annotations are currently used for this purpose. The prioritised activities have to be represented in models for better understanding and planning for efficient utilisation of resources.

If the priority of activities is followed strictly in a process, then process discovery algorithms [vdAWM04] would consider such activities as sequential in structure. Therefore in the analysis, the independence of activities with one another would not be represented in models. Therefore, casual independence and priority of activities should also be represented in a business process model for ease of communication.

4.6.8 Importance and Representation in Models

The importance of earlier discussed challenges and their existing representation are summarised in Table 4.1. Three ranking levels are defined with symbols like "+", "O", and "–" which represent high, medium, and low, respectively. Two significant phases of business process management are used for this evaluation; one is before execution, and the other is after execution. This ranking is carried out after studying several surveys and comparisons in business process modelling literature which we discussed earlier. The x/y notation is used, where x represents the importance of an attribute, and y represents the level of modelling support by existing modelling language i.e., importance/representation. Therefore, the notation $+/-$ means that challenge is important in the phase, however, it is not represented using business process models. The notation O/O means that the challenge is at a medium level of importance and partially represented by models. It is important to mention that some modelling languages address the limitations which we mentioned earlier like extended notations of BPMN to represent the different messages and involved elements. However, other limitations are not addressed or if addressed, other models are used. This makes business process modelling an expensive task as models developed for one purpose are not reusable for another.

4.7 Context for Analytical Business Process Modelling Language (ABPML)

In Chapter 3, we have discussed business process modelling and its usage in different phases of a business process lifecycle. We also positioned the usage of different modelling languages during the phases of the business process lifecycle in Figure 3.4. In this Chapter 4, we discussed the performance evaluation of businesses and their visualisation for further analysis (business intelligence). We also discussed the process perspective for analysis, like business process intelligence. In the previous section, we discuss the challenges of modelling languages for post-execution analysis representation. Performance of processes and involved elements should be represented

Table 4.1: Challenges, their Importance, and Representation

Challenges	Importance & Representation	
	IT Sys. Dev.	Post Exec.
4.6.1 Environment of BPs	+/O	+/−
4.6.2 Attributes representation	O/O	+/−
4.6.3 Successful & Failure Paths	O/−	+/−
4.6.4 Structural Limitations	O/O	+/−
4.6.5 Simulation & Reality	+/O	+/O
4.6.6 History	+/O	+/−
4.6.7 Priority representation	O/−	O/−

with the process structure at a detailed level. By doing so, models provide further insights about processes and enable process managers to improve the processes.

In order to solve this problem, we propose an analytical business process modelling language in Chapter 5. This analytical modelling language takes the concepts from the business intelligence domain like evaluation (measure and metrics), and visualisation (cognitive aspects). In Figure 4.6, we position the proposed analytical business process modelling language (ABPML) with respect to earlier discussed domains.

4.8 Related Work

For the discussion of related work in this section, we distinguish between work referring to performance measurement (evaluation of businesses and their processes), framework (data collection, integration and reports), and process mining (process structure aspects). Due to numerous studies in these areas, this section provides a short overview.

A standard is defined by International Organization for Standardization (ISO) for measuring the performance in manufacturing operations management in [iso14a, iso14b]. In this standard, 34 KPIs are defined to evaluate the performance from different perspectives and dimensions. Similarly, different organisations have different KPIs for measuring performance in manufacturing. A survey of different metrics and practices for performance evaluation in the manufacturing domain is provided in [BP18]. Similarly, different MES systems also provide the KPIs in the manufacturing domain as standard reports, as discussed in [Kle10]. However, these KPIs provide only data perspective and do not provide details about process structure. In industry, individual dashboards [Mal05, Eck10] and reports are made to evaluate the performance of operations using different tools like Tableau, Power BI, and Splunk. Process structure and process model representation are missing in these representations.

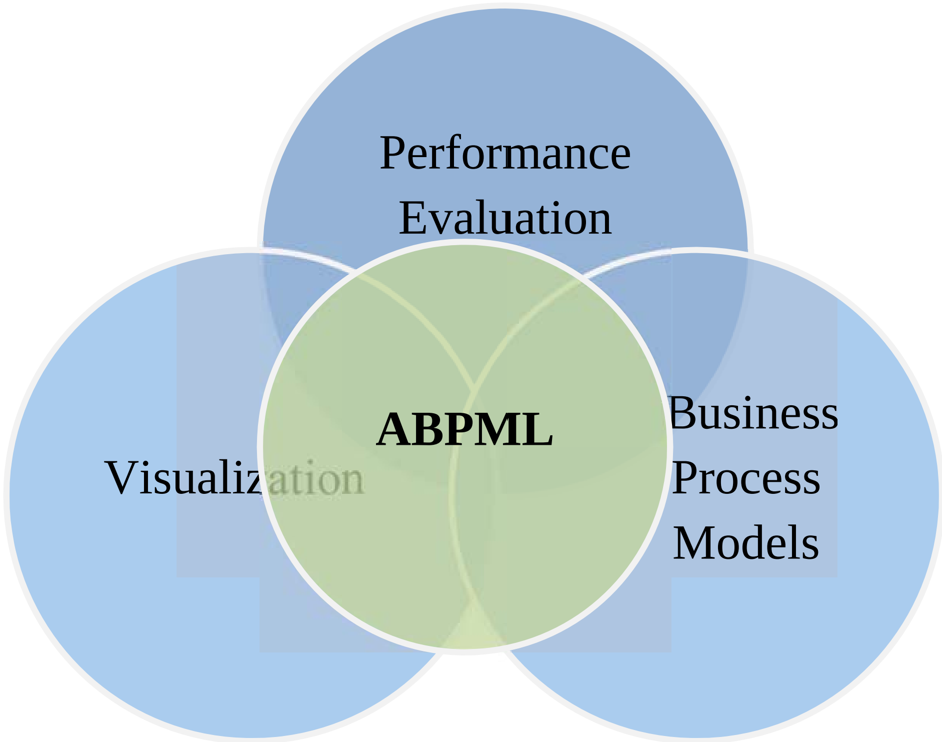


Figure 4.6: Positioning of ABPML

Different analytical techniques provide information about business process executions. Data mining technique focuses on the data perspective and tries to find interesting patterns to analyse and improve the performance in different aspects like quality, costs, and time. Process mining is another analytical technique. Process mining focuses on the process structure rather than the data perspective [vdAvDG+09]. In process mining, logs of information systems are used for analysis. Process mining technique aims to identify the quality of the process model and the adequacy of the execution environment [Cha05]. Similarly, the time and resource perspective is investigated in effort mining [ZBA21]. However, traditional charts are used to represent time perspective which is not sufficient for representation. Different techniques related to process mining [vdAW04] attempt to solve the issues related to data collection [KLK+10, IG08] from source systems and its conversion [vDvdA05, GvdA06]. In [zM08], the author proposes a data format for recording business events. This BPAF (Business Process Analytics Format) helps in correlating and aggregating business events from different systems to one location. In [MDFL+20], the authors discuss the research recommendations for process mining in the healthcare sector and demand for process modelling to represent different perspectives.

In [SCDS02], the authors demonstrate a tool built on the top of HP Process Manager software. This tool provides monitoring and analysis of business processes. They provide the architecture of business process intelligence tool by combining data warehouse approaches and process data warehouse. They also discuss different evaluation perspectives and provide the perspective of process, resource, and services. The tool and HP Process Manager suite have been further extended with process mining architecture in [GCC+04]. Different business process management suites have extended their portfolio with business process intelligence functionality [CdMM+09]. Therefore, covering aspects from planning, design, simulation, and post execution statistics. In comparison to our work, we have provided different perspectives and classifications. Moreover, other solutions restrict themselves till some KPIs representation using the traditional method. In our framework, representation is the key part and it is further explained with respect to modelling challenges.

Our proposed work has been extended in different directions. In [TdRORC16], the authors used our proposed performance aspects of business processes and take it as a basis to identify variability in process performance for the identification of potential improvement areas.

4.9 Summary

This chapter focused on post-execution evaluation and analysis of business processes. We classified the business objects based on their participation in different analysis. We also provided examples of organisational metrics based on the performance of business objects. We also provided the analytical framework for the analysis and improvement of processes. This framework discusses the collection of data till its visualisation. This chapter answers the first two research questions of the second part related to the evaluation of business processes and components involved in evaluation (RQ 2.1 and RQ 2.2). We discussed the representational gap for post-executional aspects and provided the challenges for its representation. These requirements and challenges help us to define the characteristics of the analytical modelling language. With this part, we answer the remaining two research questions of part two (RQ 2.3 and RQ 2.4). We also discuss the context of analytical business process modelling language, which we will discuss in detail in the following chapter.

5. Analytical Business Process Modelling Language (ABPML)

This chapter shares material with the IS-Conf'2018 "Streamlining Processes for digitalisation" [LKST18], IEEE HICSS'2014 "Business Process modelling Language for Performance Evaluation" [LKW+14], Journal paper "An Extension of BPMN Meta-model for Evaluation of Business Processes" [LKS11b], and IHCI'2011 "Business Process Improvement Framework and Representational Support" [LKS11c].

After the execution of business processes, records of business objects and their analytical data provide means to analyse processes in more detail. We have already discussed the challenges of the modelling language to present the analytical data in process models in Chapter 3 and Chapter 4. In this Chapter, we discuss the analysis of business process with process models and analytical data in two parts.

In the first part, we explain the characteristics of an analytical business process modelling language (ABPML) in Section 5.1. Based on these characteristics, we propose a method to use process models with analytical data using constructs and patterns for analysing activities in different dimensions as discussed in Section 5.2. In the second part, in Section 5.3, we extend an existing modelling language as an example of ABPML to better understand process execution and their performance. This helps for a detailed understanding of business processes to determine the deficiencies and potential improvement areas. In Section 5.4, we also provide the related work of modelling languages extended for analytical purposes followed by Section 5.5 which summarises this chapter.

5.1 Characteristics for Analytical Business Process Modelling Language

The efficiency and performance of business processes are measured using key performance indicators (KPIs). Similarly, business process models are used when the structure followed by business processes executions has to be analysed. However, what is the case when both are required for analysis? Then, we need key performance indicators (KPIs) and models simultaneously. We have mentioned the limitations of modelling languages in the previous chapter. In the following, we discuss the characteristics of an analytical modelling language. These characteristics will help to overcome the limitations of a modelling language for analysis. We assume that the detailed data about business process executions and their involved elements are already available from information systems.

5.1.1 Granularity of Detail

Different stakeholders view business process models at different levels of granularity (abstract or in detail). Executives are interested in an overall picture of business processes, therefore, they require a suitable abstraction of business process models, whereas operational managers look for specific details of processes and the activities of their responsibility. The same situation holds for the analytical data perspective. Therefore, an analytical modelling language should provide constructs to represent processes and quantitative analysis at a different granularity of details. In the case of structural limitations as discussed earlier in Section 4.6.4, analytical modelling language may apply limitations at an abstract level. However, these restrictions must be relaxed at an operational level to provide further details through models.

5.1.2 Context Based Representation

Different stakeholders are involved in business processes, each wants to view the processes from his perspective like monitoring, control, and organisational analysis. Context adaptive views or models must be built based on user demands rather than models which are built in earlier phases. Such views or models can be further extended to provide better insights into processes.

Model adaptation based on its usage by stakeholders can also be considered to provide maximum flexibility to end users. For example, the profile of the end-user can be maintained which stores his personal preferences (likeness and expectations) and based on such configuration, models are represented (like providing specific details and extension of attributes). Such functions are standard in visualisation tools (like Tableau [1]), where information is filtered and presented in a specific order for end-users (using favourites).

[1] https://www.tableau.com/

Table 5.1: Characteristics of ABPML and Challenges (Section 4.6) Addressed

Characteristics \ Challenges	Env.	Att.	Path	Str.	Sim.	Hist.	Prio
Granularity	O	O	–	+	O	–	–
Context based rep.	+	+	O	–	–	–	+
Data integration	–	+	O	–	O	+	+
Formalism	O	O	–	+	+	O	–
Generic representation	O	O	–	+	+	O	O

5.1.3 Integration of Analytical Data and Objects with Model

Attributes and involved elements should be part of the models for analysis because of the reasons discussed in Section 4.6.2. Explicit representation of elements with attribute values will help to understand the structural deficiencies and reasons for failure. For example, in the case of a product manufacturing process, the iterative structure with attributes and values explains why a certain part of the process must be repeated and which activity should be carried out again. Such representation also shows why a particular resource is consumed more than regular consumption. Similarly, involved conditions and rules should also be explicitly specified in models. These explicit representations will provide the rationale for the decisions made in business process executions. Such extended models can also be used to provide training to new users. In this way, the new user can analyse past executions and understand the decisions made by experienced users. Extension of attributes in a model would help to understand such situations intuitively about the reasons of failure. Similarly, the extension of attributes will increase the intuitive understanding of business processes.

5.1.4 Formalism of Analytical Modelling Language

An Analytical modelling language should define business processes precisely and provide the semantics to be followed. In the process models, important representational elements should be provided, even though the formalism becomes complex or hard to define. Because enriching the representation of models will make their formalism complex, as the representation of models and their formalism is further discussed in [RM07]. The formalism of a modelling language can automatically integrate the analytical data with the business process models.

5.1.5 Generic Representation of Business Processes

Different models are used during business process lifecycle phases, which involve different constructs and details. These models have different focuses, like data and dimension models. During analysis, when different models consulted back and forth then ambiguities (confusion) may arise because models are at different levels of abstraction. Post-execution phase of business process analysis requires an integrated view of business processes and their elements. Therefore, the analytical modelling language should be integrated and generic in representation. In this way, organisational elements would have one consistent view of business processes. This also enables analysts to understand the dependencies among processes. The generic representation of business processes will enable to extend the models with different attributes in order to provide different views, like extending the model with time attributes will help in performance analysis.

5.1.6 Characteristics and Challenges

The characteristics of an analytical modelling language mentioned earlier will help to address the challenges discussed in Section 4.6. The expected contribution of characteristics and challenges is summarised in Table 5.1. The contribution of characteristics towards the characteristics is defined in three levels where the symbol "+" means "supported", "O" means "partially supported", and "–" means "not supported".

5.2 Proposed Modelling Constructs and Patterns

In design science, a language specification includes constructs, models, methods, and instantiation components. Therefore, we address these components for the specification of our proposed analytical modelling language. Constructs provide the vocabulary and symbols which are used to represent a problem or a solution [HMPR04] or just representing a situation. Constructs are used to represent the tangible or intangible elements of a process. They are used to represent activities, process participants (resources, places), events (communication between elements), gateways (decisions), and other involved objects (materials, orders). Therefore, they are fundamental building blocks of a graphical model. Semantic defines the meaning of symbols and their relationship. These elements are discussed in the following sections.

Patterns are used to share knowledge and solve problems [KKKS11]. Therefore, in our context, we define patterns as a combination of constructs to analyse the process and its elements in a particular perspective for improvement. These constructs are the basis of our proposed analytical modelling language.

Each pattern intends to analyse performance with a particular focus involving specific dimensions and their attributes. Here, we provide four patterns for visualisation of business process performance (with respect to business process modelling language). These four patterns are the most important and frequent in business process analysis.

We considered the characteristics of Section 5.1 and provided a modelling language which that visualises process performance with its structure. To accommodate different requirements, we combine constructs to build models for analysis from different perspectives and call them as patterns. Different allowed combinations are explained

Patterns	Purpose	Constructs
Time Dimension	analyse the performance of resources and activities with respect to time	Swimlanes, activities
Cost Dimension	analyse the performance from the cost perspective like material and resources	Swimlanes, activities, colours
Path Pattern	To understand the activities which will be fruitful	Edges, activities, colours
Colours Pattern	To represent which activities are distinct in a process	Activities, swimlanes, connecting objects
History Pattern	To understand which activities are frequently executed in process	Edges, thickness, activities
Information Pattern	To provide further information along business process models	Gateway with rules, contents

Table 5.2: Pattern and Characteristics

here which also define the method of constructing the models in the analytical process modelling language. Depending on the user's requirements, models are built at different levels of granularity to facilitate the understanding of processes.

Based on the metrics and classes defined by an enterprise as discussed in Section 4.3, activities, organisation resources, and involved elements can be represented using our proposed patterns. We recommend that only a few classes should be defined for the less cognitive load of process models on end-users. Different cognitive studies show that information is read or visualised in a particular order [LHBE10, Laj]. Therefore, the crucial dimensions and their metrics should be represented accordingly. We further explain these constructs and their semantics with the help of our proposed patterns.

5.2.1 Time Dimension Pattern

The time dimension is an essential factor in business process analysis. In this pattern, we focus on representation of process element's performance from time aspect. A few classes and characteristics in this dimension are classified in Section 4.1 like idle time and operating time. Gantt charts like representations are easier for understanding of stakeholders; however, other representations can also be used. It is interesting to know for process analysis which activities are time intensive or take much time in execution.

Process elements can be aligned and categorised based on their performance in the time dimension during process execution. Different classes (as discussed in Section 4.3) can be used for this alignment and categorization, like aligning activities based on idle time or processing time. Such alignment can identify the deficiencies in predecessor activities to improve the efficiency of the successor activity. The other aspect of time dimension pattern can also be reflected in other patterns as in the case of path and history pattern which we will discuss in the following section.

5.2.2 Cost Dimension Pattern

Cost is also a vital factor in business process analysis. This pattern observes the performance of process elements from cost and other related aspects involving material and other resources. Different classes can be used to distinguish process elements like high cost, medium and low cost, as discussed in Section 4.3). Similarly, process elements can also be grouped or aligned based on the cost incurred by them. The cost-intensive activities are one of the starting points for investigation in process analysis.

Aligning or grouping cost intensive activities may help to identify the deficiencies in the process model and their executions quickly. Similarly, representing process elements with their cost can also improve a user's analytical capability of processes.

5.2.3 Path Pattern (Time-Cost Dimension)

The time-cost pattern is helpful in deciding which activities should be further investigated. The activities together create a path of process execution which may not be that efficient or beneficial for an organisation. In the case of different possible paths, a path can be defined as a best practice which contributes to the organisational goals with limited expenses (in terms of time and costs). This path can be distinguished from other paths using different techniques (like size and colour). Similarly, difficult paths (incurring costs and problems) can also be distinguished from the other paths. The time and cost dimensions in this pattern are just an example of some dimensions influencing the path pattern; it can also be different from other dimensions as well like the organisational dimension and quality dimension which define the success of business process executions.

5.2.4 Colours Pattern

Colours have a significant cognitive effect on perception and analysis. The red colour activities are noticed quickly by users. The classes defined in Section 4.3 can be used as a basis together with different colours to distinguish the performance of process elements in a process execution. Different colours indicate the effect of the business objects, like green for optimal cost, yellow for high cost, and red for a very high cost. Similarly, these classes can be represented in other dimensions as well as time and quality. Although the relation between time, cost and quality are not as simple as discussed in [VKLR07].

Different modelling elements can be coloured based on the subject they represent and their related performance. In the following section, we will discuss this pattern in different modelling elements where we extend a modelling language.

5.2.5 History Pattern

History pattern represents which process elements are interesting from a statistical point of view in process execution. For example, elements are often executed and which path is taken in most of the process executions. This pattern can be represented in modelling languages using specific constructs (like shape and size) or represented as additional information. This additional information or text is further discussed in the following pattern.

5.2.6 Information Pattern

Information pattern provides different performance-related data as text on a process model. When we use this pattern, process states, conditions and rules about process control, and different statistical measures can be added to a process model.

The proposed patterns, their elements, and meanings are summarised in Table 5.2. In these patterns, different other attributes of the dimensions can be added and correspondingly represented using our proposed modelling language and its cognitive aspects (like colour, shape, and size). The above mentioned patterns are further explained with the help of a case study in Chapter 6.

Each pattern analyses processes in a particular perspective with a specific dimension(s). Our current pattern catalogue is not meant to be complete, as different patterns can be created based on the requirements of analysis and the creativity of a user. An enterprise can make a pattern catalogue for performance evaluation and analysis. However, here in this thesis, we have provided an overview of different problems, solutions and possible actions. Inclusion of all possible patterns is not intended in this work. In the following section, we further explain these proposed patterns by instantiating them in a modelling language.

5.3 Extension of BPMN as an ABPML

Extended notations are used to represent different aspects of a process via a modelling language. In this section, we use BPMN as an example modelling language to instantiate ABPML for analytical purposes. We also state the reasons why we have chosen BPMN over other modelling languages for our discussion and extension as an analytical modelling language. We propose the following extensions in BPMN for business process analysis and improvement. These are further explained with the help of a case study in Chapter 6.

We use the basic constructs of Business Process Model and Notation (BPMN) as discussed in Section 3.3. We have selected BPMN as a modelling language for extension, because it is rigorously defined and has been widely accepted as a standard (defined by OMG) for modelling and communicating business processes. Another reason for selecting BPMN is that in the scope of its definition the support for XML is already considered [OMG11]. Some attempts are already made to transform

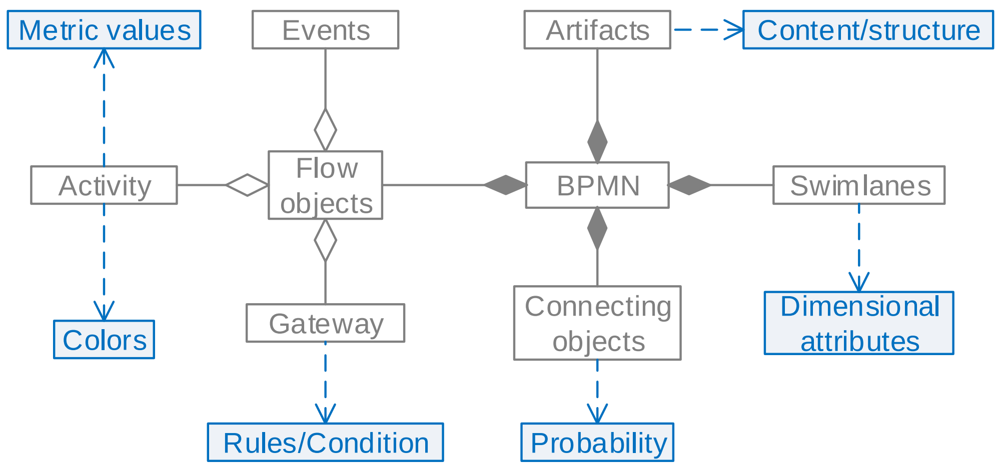


Figure 5.1: Extended Meta-model of BPMN for Performance Evaluation

BPEL into BPMN(cf. [ODvdA+09]). However, sometimes it becomes hard to model the extracted data as things would not be executed in the way that they can be modelled.

BPMN provides the guidelines to extend the language to represent domain specific concepts. In BPMN specification, extension by addition mechanism ensures the BPMN core elements validity. Moreover, BPMN is implemented in various modelling tools and is rich in representation. Similarly, different extensions are also proposed to suit different business needs. Therefore, the adoption of our proposed modelling language will not be a challenge in the industry. Additionally, BPMN is more expressive and serves well for communication purposes as compared with other modelling languages.

Different modelling constructs are required to represent involved business objects such as inputs, rules, and performance-related information. The existing BPMN notations and meta-model do not incorporate the performance details of business processes. BPMN has certain limitations; for example, when Swimlanes (Pools and lanes) are used to represent organisational entities, they just represent organisational roles. They do not provide any information about their performance, skills, workload, or working time. Similarly, data objects involved with activities are represented very abstractly as no information about their structure and their contents (values) is shown in a BPMN model. Some other limitations of BPMN model are also discussed in [Rec10]. Therefore, the BPMN meta-model can be extended to include the performance details of business processes and business objects.

We have discussed the meta-model of BPMN in Figure 3.2. We extend this meta-model for evaluation purposes of business processes. The extended meta-model is shown in Figure 5.1. The patterns and constructs introduced in previous Section 5.2 can use the elements of BPMN language for performance representation in a process

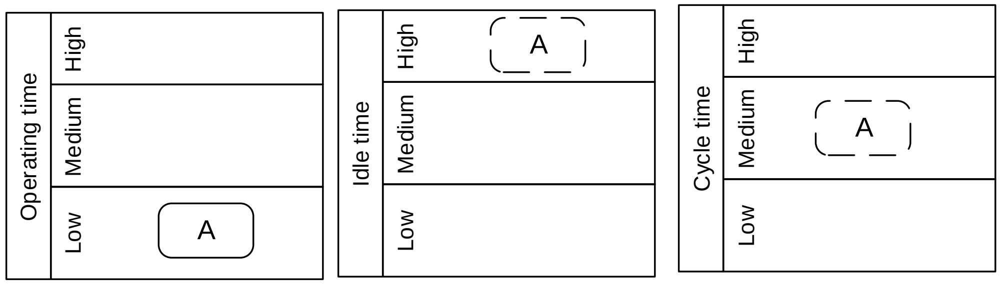


Figure 5.2: Process Model in the Time Dimension and its Attributes

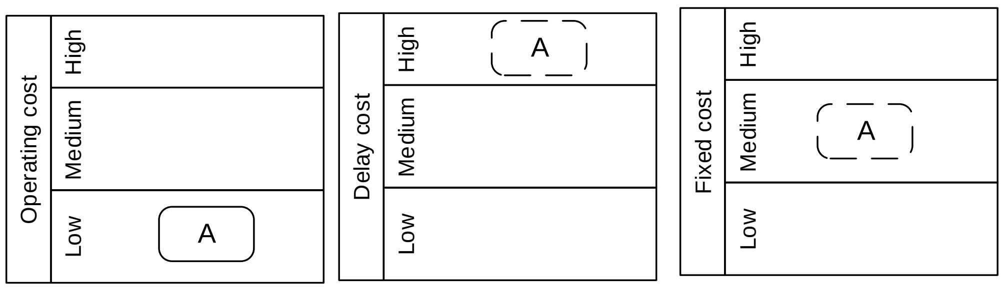


Figure 5.3: Process Model in Cost Dimension and its Attributes

model. In the following sections, we discuss elements of the BPMN meta-model and the patterns in the context of BPMN modelling constructs in more detail.

5.3.1 Swimlanes as Dimension and Attributes

Primarily in literature [OMG11], Swimlanes (pool and lane) are used to represent process participants (organisational elements) and their interaction during a business process. We propose to use Swimlanes not only to see participant interaction but also the performance of organisational resources and activities. Based on collected data, the first activities and involved elements are classified in a particular dimension as discussed in Section 4.3. These classes can act as swimlanes for representation in ABPML (representing activities or business objects in these swimlanes). This way, activities can also be aligned using Swimlanes based on their classification in a particular dimension and attributes. Aligning activities based on their classes also complements the cognitive patterns (like Z-pattern and F-pattern) where information is read in a particular order [LHBE10, Bra].

For example, consider Figure 5.2, where different attributes are shown from the time perspective. The left hand side of Figure 5.2 shows "operating time" as an attribute. Different activities are classified based on this attribute and then represented in the lanes. For the sake of simplicity, we have shown only one activity "A". This representation shows that "A" activity consumes the operating time, which falls in the low class. If we consider the other attribute from time perspective which is "idle

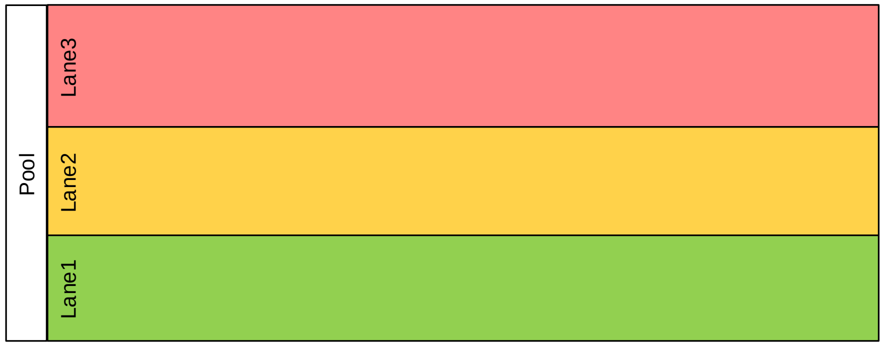


Figure 5.4: Swimlanes in Colour

time", then activity "A" may appear as classified in high idle time, as shown in the middle of Figure 5.2. Similarly, if observed from other attributes, it may show the activity in another class (as represented on the right side of Figure 5.2). For process improvement, the idle time of the activity can be reduced by allocating resources or better scheduling.

Similarly, in Figure 5.3, performance is represented from the cost perspective where activities are aligned in different classes based on different attributes like operating costs, delay costs, and fixed costs. Similarly, different activities can also be represented from other perspectives and dimensions for business process analysis.

When we represent performance details using Swimlanes in a BPMN model, we can determine which activities are consuming time and taking high costs. Afterwards, these activities can be further investigated to identify their deficiencies for improvement. In this way, the representation with performance elements helps to identify the deficiencies in the process and improve them.

5.3.2 Elements in Colours

Depending on the organisational metrics and classes as discussed in Section 4.3, colours can be assigned to elements of a process modelling language. The assignment of colours to different elements highlights the critical features for analysis. A few examples of different business process modelling elements in colours are discussed in the following.

Similar to the previous section, where activities are aligned in swimlanes based on the performance in a certain perspective, in this pattern, swimlanes can also be coloured as shown in Figure 5.4. Different activities can also be coloured based on their performance to highlight as represented in Figure 5.5.

During analysis, different colours can also represent the instance executional history, like which path the instance has taken and at which particular stage a specific decision is taken. Similarly, based on the history of a process model, connecting objects

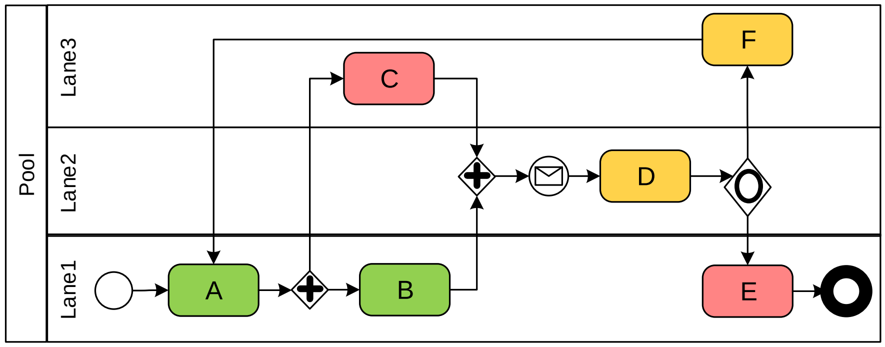


Figure 5.5: Activities in Colour

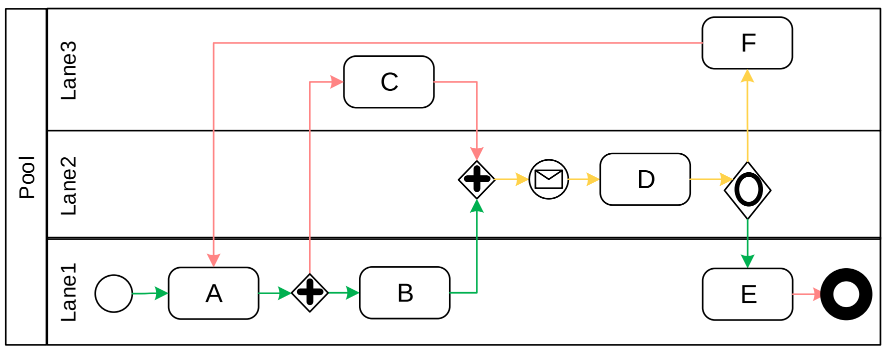


Figure 5.6: Connecting Objects in Colour

or process paths can also be coloured to represent optimal execution or best practices. This colouration can also be used to show the bad or costly path as shown in Figure 5.6. This path colouration is important for the analysis in those processes where different path choices are possible for execution. Different colours can indicate the effect of business objects like green for the optimal cost, blue for the optimal time, and red for non-optimal paths. Although, the relation between cost and time is not as simple as further discussed in [VKLR07]. This example compliments the colour pattern of ABPML in the BPMN modelling language.

5.3.3 Connecting Objects with Statistics

Data about the performance can also be represented on the connecting objects (connecting process elements). The connecting objects can be differentiated using the size and colours. A thick edge represents that most cases take this particular path during execution compared to a thin edge edge path which represents the opposite. Another way is to represent different statistics over these connecting objects, like how often a specific path is taken (in the past, complementing the history construct). Depending on the characteristics of business objects certain assumptions can be made and predications can also be represented over these connecting objects (representing the probabilities of a certain path in process execution). Similarly, successful paths

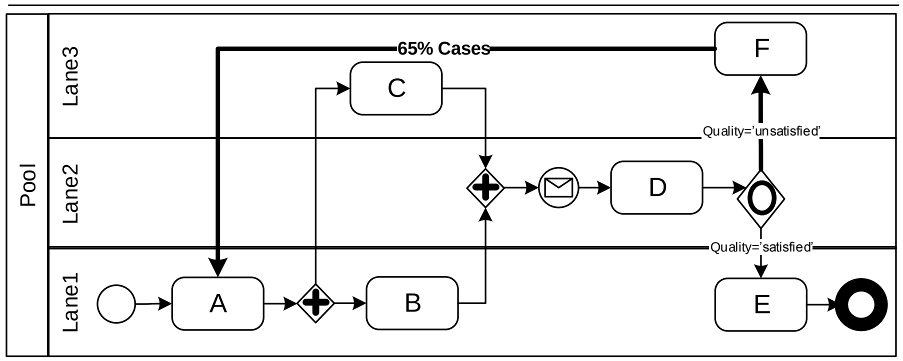


Figure 5.7: History Construct with Statistics

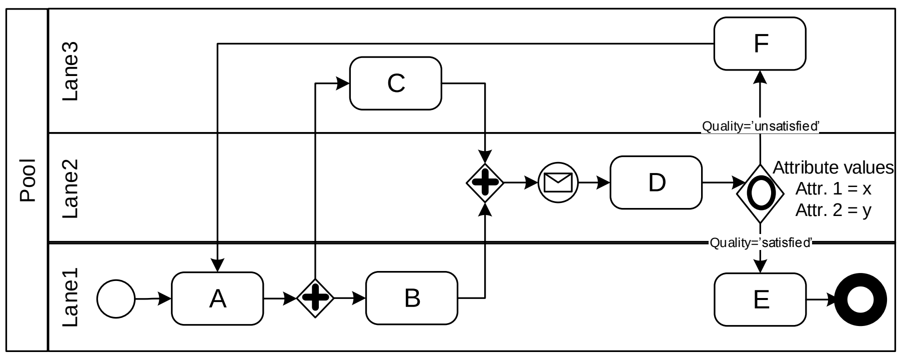


Figure 5.8: Gateways with Rules or Conditions

(or best practices) can be determined by evaluating the performance of processes and their involved elements. The successful paths can be represented by colouring the edges. The frequency of execution on a particular path can be represented by changing the thickness of edges (connecting objects). These representations correspond to the history pattern of the proposed modelling language.

5.3.4 Gateways with Rules

Different decisions are made in process executions. These decisions are implicitly represented in program logic or explicitly stated in the documentation. In process execution, the explicit representation will help users to understand the rationale behind these decisions. In BPMN, different control flow elements are used. BPMN artefacts or text boxes can describe the condition near the control elements. Similarly, certain exceptions and business rules can also be mentioned on those control flows, like executing a gold customer requires a rule to be treated differently.

5.3.5 Artefacts with Contents

In BPMN, certain artefacts (like annotations and data objects) are specified to provide additional information about the process. These artefacts can be used along

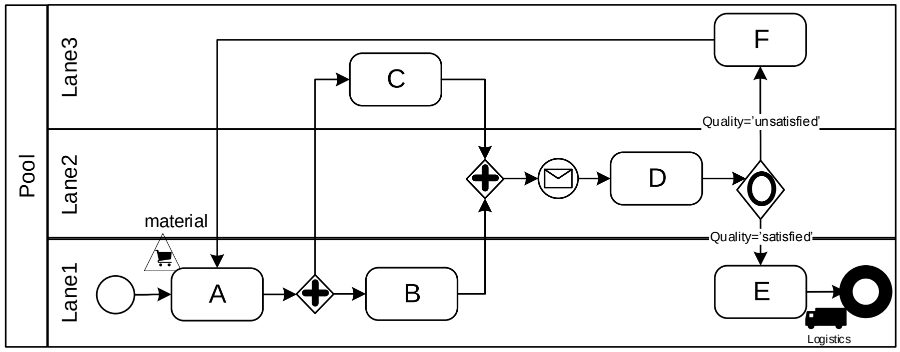


Figure 5.9: Objects in Process Model

with other elements of BPMN to provide performance details (metrics) as well as about the context of the process like material required and specific conditions (limitations).

5.4 Related Work

Our work is compared and contrasted with methods and modelling languages used for post-executional representation. However, most of the research in the business process modelling domain is related to the information system design and analysis, like its development [BRJ05, Alo16], workflow management [vdA98], simulation of business processes [KLO08], or alignment of IT services with business processes [vdA05], or further configuration of information systems [DRvdAS08].

Limited research focuses on the performance perspective of business processes using modelling language [ETDRORRC21, Alo16]. There are some approaches to analysing business processes after execution. However, in those approaches same models are used, which are conceptualised for information system development like some process mining [vdARW+07] tools use Petri nets [vdA98]. Therefore, the solution provided by those tools serves only on ad-hoc basis, which is not appropriate for analysis and improvement.

Several approaches (like [Men99, CMH09]) attempt to integrate different modelling approaches for the analysis phase of system development. However, the integration of modelling approaches poses new challenges as discussed in [DDB05]. In [DDB05, BFN06, Bro09], the authors discuss the importance of an integrated framework for modelling and enrichment of models but only from the perspective of information system development phases or project management.

A survey on business process analysis for optimisation and improvement is provided in [VTM08]. In that survey, the authors categorise different approaches to notational, formal and semi-formal categorizing. Their survey indicates the lack of business process modelling languages for post-executional phases. However, they do not provide any extensions or examples of modelling languages which we have provided in this thesis. The concept of excluding activities at the abstract level and including them at the detailed level is also discussed in [DRvdAS08, BO08], whereas in [Bro09], it is discussed at the attribute level. Different views of models are generated based on the environment of execution (roles) as discussed in [CC07]; however, it is discussed from the software process perspective, irrespective of business processes. This concept needs to be further investigated from business process aspects. In [VDP+20], the authors propose a modelling language to represent knowledge at different abstraction levels. However, their main focus on the creation of execution code rather than representing processes for understanding at different levels.

In [CST04], the authors proposed an approach for business process modelling based on the different roles involved in a business process. In their approach, the focus was on the UML extensions in order to describe the relationship between business objects in a specific context (in this case role) and their re-usage in the business domain. In [Nic02], the authors used four kinds of business objects (people, places, things and events) for business object modelling purposes. Furthermore, the authors also presented the collaboration patterns for clear communication of business requirements about the product. Object modelling for designing systems also represents the relation of interaction between different objects, as discussed in [DvdAtH05].

Many papers discuss the context and environment of business processes with respect to the adaptation of changes in information systems [SN07, NE05]. Such approaches should be further extended to build business process models for analysis. Environment and context elements should be explicitly represented in detailed process models. BPMN also provides the concept for activities (containing sub-activities) [BO08]. However, they do not discuss the attributes to be attached to a model as explicitly. Similarly, in [EVTG20], manufacturing processes are represented in detail using BPMN language construct. The authors even introduced a new construct to represent business situation like fulfilment of a box. However, it is the only construct introduced in the paper. Their studies show the lack of constructs in BPMN to represent the environment and demand for further research and practical implementations.

Our first attempt to extend process models with more information was discussed in [LKR08]. In that approach, we extended the process model to represent the successful and unsuccessful path of the process with a smiley. Another approach to provide further details about a business object in process models was discussed in [LKR09]. In that paper, we discussed different Petri net types and discussed the possibility of extending them for the representation of business objects involved during business process execution. Another attempt was with the graph mining approach [LKKS10b], where graph-based representation was discussed to extract the knowledge and possibly aid analysis with process structure representation. However, these approaches are good at formalism aspect, however, not intuitive and business users friendly.

BPMN is the de facto standard for modelling business processes. However, it provides only generic constructs for the representation of business processes [ZBGD19]. In the current BPMN 2.0 specification [OMG11, p. 22], data, information modelling, and business rules are out of scope. Therefore, BPMN is extended in various directions for domain-specific and different perspectives representation, such as corporate communications [PO19], ubiquitous environment [FSER17], industry 4.0 [AAGK19, RBdC21], events from smart sensors [LWC+21], and security threats [KCPM21]). In [BE14, ZBGD19], the authors provide a systematic literature review on the state of art of BPMN extensions. They classify BPMN extensions based on their objective, target domain and representation format.

In [Bus10, SBK10], the authors extend the BPMN process model with time by representing with different BPMN elements like in activities, connecting objects and in pools. However, the authors have focused on providing further information rather than performance analysis of business processes. In this work, we have provided different patterns to better understanding and represent a business process for performance evaluation. In [VHZ21], the authors represented the cost of manual and IT assisted systems in an industrial use case with the help of colours on the connecting objects (arrows). However, no other modelling constructs were provided in their work. Similarly, there are also some other attempts to extend BPMN models in different dimensions like knowledge in [SBK10, BHTG17] or for modelling process goals and their measures in [KL07].

Our proposed framework and representational support (BPMN extensions) have been used as a further extension to a framework [AN16]. The authors applied the framework and BPMN extension in a bank loan process. They found that the framework and business process model representation help to make correct and timely decisions for business process improvement. However, in [AN16], the authors do not present any framework or representational elements in comparison to our work [LKS11c].

In [BD11], the authors propose a meta-model level extension of BPMN for non-functional properties of business processes like performability. However, they do not provide any patterns, modelling constructs or any representations. They used the existing BPMN annotations or documents to represent performance-related information. That work [BD11] was further extended in the form of a framework [DPBG16] for simulation purposes to annotate input and output data. In [IDPD21], the authors extend their work with BPMN by providing the extension for requirement engineering. They used our proposed colour pattern to show different classes of events and activities.

Similar research to [BD11] was carried out in [TRJ14], where a quality evaluation framework was presented, and different quality aspects were defined at the meta-model level. However, the authors did not provide any constructs or representation with BPMN. Similarly, in [WG19], KPI based approach is presented for business process improvement by extending the meta-model of BPMN. In that study, the authors used Scrum agile development process as a case study and classified the key performance indicators on this basis. However, no process representation in BPMN and their KPIs were provided. In [HZD+19], the authors discuss the performance from time, cost, reliability, and quality aspects and show their values with annotations (a textual table with the activities). All these work discuss our work and extend the work in this domain; however, no other patterns and constructs were added. In [dRD+19], the authors introduced the graphical notation for process performance representation, where the authors add another layer to process models to represent the performance information. The authors used only one icon (short rulers - a measuring scale) and used it in a different context which has limitations regarding expressiveness in constrast to our proposed constructs which are more expressive.

In [vdA09], the author proposes business process maps inspired by geographical maps and navigation systems. The author discusses different features of navigation systems (like zooming, colour and layout) and bring them into the context of the process model with events logs (aggregation, abstraction, and further customizations). However, the author focuses on generating process models from event logs and then predicting the arrival time of some instances. Similarly, in [vdA16], the author provides the additional features of business process maps like map quality and guidance instructions. The author also mentions that different information can be represented on those maps like mash-ups. However, the performance aspects of a business process and involved representation were not discussed in detail as in the case of this thesis.

Different business process management suites also provide cockpits to represent performance metrics in graphical forms like histograms, radial graphs, and several other techniques. However, these representations are abstract representations without providing information about the structure. Similarly, process mining tools (like Celonis [2], ProM [vdAvDG+09], EVS [IGHP05] also exhibit performance metrics through different graph based representations. In HPPM (HP Process Manager) [GCC+04], they provide performance representation via traditional visualisation methods and graph-based representations are used to represent the process model.

In ARIS PPM tool, frequent paths are represented by the weight of connecting arrows. However, performance metrics are represented using traditional statistical approaches. These approaches (KPI visualisation techniques) lack the support of business process modelling language to provide a process perspective for improvement. Moreover, these approaches provide the facilities in one perspective (like modelling), however, these tool lack from another perspective (performance evaluation), and vice versa. In our work, we demonstrate the performance of processes with business process modelling language.

In Signavio [3] BPMN Tool, it is possible to associate costs with activities and represent them as additional text [Kam21]. This approach is similar to our information objects

[2] https://www.celonis.com/
[3] https://www.signavio.com

pattern, however, other patterns are missing like aligning in swimlanes. Similarly, Signavio modelling tool does not represent or support other patterns.

5.5 Summary

In this chapter, we address the third part of our research questions (presented in Section 1.2). We present the characteristics of an analytical modelling language to address the challenges in the post-execution analysis context. We design analytical business process modelling language (ABPML) by performing a thorough analysis of existing modelling language (Chapter 3), business process performance analysis requirements (Chapter 4), and different analytical tools (like Tableau, Celonis, ProM [vdAvDG+09, IGHP05]). We provide constructs and patterns of an analytical modelling language to analyse business processes in a post-execution analysis context. These are generic enough to use as a basis to extend other modelling languages. We demonstrate the instantiation of an analytical modelling language by extending BPMN.

The detailed related work (including systematic literature reviews) demonstrates that this field is still active and new extensions are proposed and evaluated. In the following chapter, we evaluate the proposed analytical modelling language and its benefits with the help of a case study.

6. Empirical Evaluation of Modelling Language

> This chapter shares material with the paper presented in KMIS 2022 "Empirical Evaluation of BPMN Extension Language" [LST22].

Evaluation is the essential part of a modelling language and its extension, as it provides the opportunity to understand how the proposed modelling language constructs solve the problem. The evaluation also helps to determine the required expectations of users and the model audience. It also serves to improve the constructs (modelling language or its extension). Design science research proposes the empirical or analytical evaluation of a new artefact/construct.

Different approaches can be used to evaluate a modelling language. This thesis evaluates the proposed extension of modelling language using two approaches.

The first approach is empirical in which we compare and evaluate proposed extensions of modelling language from different evaluation criteria with the help of a case study. Furthermore, in an empirical study, we also assess the understandability aspects of the proposed extension, i.e. how well it is perceived and understood by the users. In the empirical approach, semi-structured interviews can be conducted with users to get their opinion; however, we preferred the questionnaire-based method to get the audience's view at a larger scale. Semi-structured informal interviews were part of the work during concept making phase of the modelling language.

The second one is the analytical evaluation which addresses how well it fulfils the representational and interpretational needs of users from a technical perspective. In this approach, we will focus on ontological concepts.

From the empirical evaluation approach, we focus on user's analytical queries which can be answered using our modelling language, like how activities should be organized to improve the understanding and ability to make decisions.

These two approaches can be analysed together to evaluate how the results of one approach complement to the other and vice versa. Such evaluations help to understand how users perceive it and to improve the proposed modelling language and its extension. We will discuss them as concluding of our thesis in the following chapters.

In the following Section 6.1, we discuss the empirical evaluation criteria and case study. The case study results are presented in two groups in Section 6.2. These results are discussed in detail in Section 6.3. Finally, the limitations of empirical evaluations are discussed in Section 6.4 followed by Section 6.5 which discusses the related work regarding the evaluation of proposed extension and modelling languages. In the end, we summarize this chapter in Section 6.6.

6.1 Case Study

Empirical methods are suitable for quantitative analysis as they get end-users' results according to specific criteria under consideration. Examples of such criteria are the usage of language in different problems, comprehension, understandability of models developed in the language, ability to learn the language, and follow the model to take actions based on the knowledge provided from the model [GW03, NK06]. Empirical methods provide early feedback from potential users with the help of surveys and case studies. The initial feedback helps to adapt and improve the modelling language. However, analytical evaluations can be conducted as soon as the language specification is available. For example, in the case of ABPML, we conducted informal surveys and interviews with business analysts and modellers, in which they responded positively.

An empirical study can also show the qualitative aspects of the language by conducting controlled experiments or surveys. In such evaluations, feedback from the participants is collected over the presented content. In this case study, we follow certain aspects of the Quality Framework as defined in ISO/IEC 25010:2011 [ISO11] (last reviewed and confirmed in 2017, based on older version ISO/IEC 9126 [ISO01]), such as functional suitability (functional appropriateness), usability (learnability) and maintainability (analyzability). We take them as evaluation criteria and ask participants for feedback from these perspectives. Although such empirical evaluations provide valuable insights, however, they are time-consuming.

6.1.1 Questionnaire Design

In our work, we designed a case study of a manufacturing company. In the manufacturing company, a real-world simple production process is considered and presented in the form of a questionnaire to the participants. We selected the manufacturing area for our example case study as many fields are related to physical product development like clothing, sports goods, pharmaceuticals, and the automotive industry. However, such processes and their evaluations can be made in services areas like business processes in the area of insurance (insurance claim processes), car rental companies, and even the public sector (government offices) as well.

The questionnaire is presented to the users (business analysts, managers, and process experts) in the form of a web link. The questionnaire is presented in the Appendix Section of the thesis (Section A.1). The questionnaire design is divided into four parts. These parts are explained as follows.

In the first part of the questionnaire, general information of participants is collected like age, gender, education, organization, and position in an organization. The goal of this information collection is to get an overview of the participants for the survey.

The second part of the questionnaire focuses on the professional experience of the participants. We collect the details regarding their professional experience and years of experience. We further collect details regarding their experience like at which level they are involved, how often they do evaluations, the number of processes involved in their assessment and techniques used for performance evaluation.

The third part of our questionnaire is the central part introducing a simple organizational process. This part describes the production scenario of a soccer shirt in an organization using the BPMN business process model (as shown in Appendix Questionnaire General). The process we introduce here is very simple and contain only six activities and four different roles in the organization. Moreover, we kept the business process intentionally simple as we wanted to ask questions from participants without making it complex to understand.

Here, the focus is to compare two methods for analysis and improvement of a business process. The first method uses traditional graphical charts whereas the second method is a short demonstration of our proposed extensions ABPML (extended BPMN representation) as presented in Section 5.2 and Appendix Section A.1. In this Section, we ask five main questions each focusing on a particular pattern and its comparison to the traditional approach.

To get feedback from the participants, we applied a four-level Likert scale ranging from very dissatisfied to very satisfied [Lik32]. This means that if participants like a particular method or representation, they can give feedback about their satisfaction. To ensure some feedback from participants, we intentionally left the neutral perspective (from the 5-level Likert scale) as we wanted to get really their opinion. Although the 4-level Likert scale has some disadvantages [JKCP15], however, it fits the purpose in our empirical evaluation. The output of this part of the questionnaire is to get the user's feedback regarding the efficiency of proposed extensions compared to the traditional approach.

The fourth part of the questionnaire focuses on participant's feedback on proposed modelling patterns based on different criteria like understandability, support in decision-making, application in other areas and organizational hierarchy level. For this purpose, we ask again five questions as of our proposed patterns, further containing sub-questions from four mentioned criteria in order to evaluate them from these perspectives (evaluation criteria).

6.1.2 Conduction of Case Study

In the empirical study, 38 participants from different organizations and domains have participated. We conducted the empirical study in two separate groups by presenting the same questionnaire. The first group is from one particular organization (manufacturing company, referred as Case Study 1). Although we asked more than 30 participants in the first group to fill out the questionnaire, only 14 participants provided their feedback. The same questionnaire was asked to the second group (referred as Case Study 2), which was very generic as it was intended for professionals from different companies, academic staff, and students. In this group, 24 participants have filled out the questionnaire. In this group, five students participated as well. In [HRW00, SAW08], authors have shown that students are proper substitute for professionals in empirical studies as they will be future professionals. We will present and discuss the results accordingly to the above mentioned groups.

In the next section, we will discuss the method which is used to analyse the collected feedback from the participants of mentioned case studies (groups).

6.1.3 Analysis Method

Statistics are divided into descriptive and inferential statistics. In descriptive statistics, different statistical calculations like mean, median, mode, range, and standard deviations are used to analyse the data. In inferential statistics, various tests are used to test the hypothesis and support the conclusions about a population from which a sample is presumed to have been drawn. In this chapter, we use both techniques to analyse the responses (data) and discuss them in detail in following Section 6.2.

In the previous Section 6.1.1, we mention the use of the 4-Level Likert scale in order to receive feedback from the participant. This feedback is categorical data and needs to be converted into numerical data. The classification of categorical data is sometimes necessary for statistical techniques [AF96, p. 32]. Here, we convert the 4-level Likert scale from very dissatisfied to very satisfied as 1 to 4 magnitude values respectively. Similarly, the strongly disagree and strongly agree categorical scores are mapped into 1 to 4 numerical values respectively.

In this work, our hypothesis is whether enrich models are better for analysis and improvement or not. We want to evaluate the expressiveness of methods and to know whether our proposed extensions are better perceived by the experts as compared to traditional methods or not. Furthermore, we want to see how users like to analyse processes from time and cost perspective. We also want to evaluate whether rules or conditions are useful in processes or do they increase complexity for users. The goal of the evaluation is to identify the gap between analytical methods at the process level. If the gap exists, this means that users maybe unhappy or rate sufficient for both methods, and better representations are required.

For this purpose, we have constructed a hypothesis and their corresponding null hypothesis for five patterns (e.g. time, cost, time-cost-colour, rule and history perspective) that we have introduced in Chapter 5. The null hypothesis states the data is normally distributed and there is no significant difference between these two approaches. An alternate hypothesis is the opposite of the null hypothesis, it means there is a significant difference between these two approaches. These approaches are referred as traditional approach and proposed approach (ABPML).

6.1.4 Wilcoxon Signed-Rank Test

In order to analyse responses and test our hypothesis, we used Wilcoxon signed-rank test from inferential statistics. Wilcoxon rank-sum test and Wilcoxon signed-rank method were developed by Frank Wilcoxon in 1945, as discussed in [Wil45]. These non-parametric tests do not assume anything about the underlying distribution (expecting data is not normally distributed). Wilcoxon test is used if the number of participants in the experiment is low [Geh65, HWC13], as it is the case in our case study. Since we do not have a large set of responses, we use statistical inference to infer the characteristics of different analysts based on the responses we have received in this case study. There are various examples in research where it is used to compare two approaches [RGL07], medicines (pharmaceutical studies [KE19]), or even behavioural analysis like comparing the perception of two eyes in different experiments [RGL07].

We want to analyse the scores of participants in two methods. For this purpose, we will make null and alternative hypotheses related to our work. Then, based on the participant's feedback, we will test our hypothesis.

$$H_0^q : \mu \leq \delta$$

with the alternative hypothesis

$$H_1^q : \mu > \delta \ ,$$

where δ describes the *median* in a survey question q.

We will use the Wilcoxon signed-rank test as it is used to compare two sets of scores that came from the same participants. This method is more powerful than the sign test as it makes use of the magnitudes of the differences rather than just their signs.

The Formula of Wilcoxon signed-rank method is as follows

$$W = \sum_{i=1}^{N_r} [sgn[x_{2,i} - x_{1,i}) \cdot R_i] \tag{6.1}$$

In this method, first for each item in a sample of n items, we calculate the differences between them (like subtracting scores of one method from the other). If the difference in scores is zero, then we omit them. We count non-negative values and take it as n-

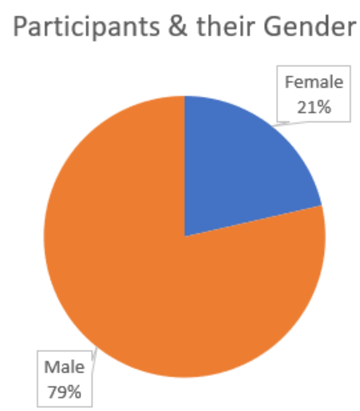


Figure 6.1: Case Study 1: Gender Distribution of Participants

as a new sample size. Then, we rank the differences according to their values only, that is, without considering their positive or negative signs. The smallest absolute difference score gets the rank of 1, and the largest gets the rank of n. Suppose, two or more difference scores are equal, then each is assigned with the average rank of the ranks they would have to be assigned individually had ties in the data not occurred. Next, we reassign the signs (positive and negative) to each of the n Ranks Rj, and then sum the ranks of the positive and negative differences. The Wilcoxon test statistic is W+ and W-. Finally, the test statistic is chosen, which is the minimum of the sums of positive and negative ranks.

After that, we compare the test statistic to a critical value (from the Wilcoxon signed-ranks Table [1] where the confidence interval is 95%, i.e. Alpha 0.05). If the test static (lowest in sum ranks) is less than or equal to the critical value, then we reject the null hypothesis. That also means there is a significant difference in the medians. Similarly, we can also reject the null hypothesis if the p-value is less than 0.05.

For the computation of Wilcoxon signed-rank, we used Microsoft Excel. We will discuss its score further in the following Section 6.2 with respect to its corresponding patterns and feedback from the participants. For the descriptive statistical part, we used Microsoft Excel to represent statistical charts.

6.2 Results

We carried out the case study in two different sets; the first one is expert centric, whereas the second one is more general, collecting feedback from experts and general users. Therefore, we present the results of two case studies separately to distinguish them from each other. First of all, we present general information about the participants like their demographical information. After this, we present the result of two

[1] https://www.real-statistics.com/statistics-tables/wilcoxon-signed-ranks-table/

Table 6.1: Case Study 1: Descriptive and Inferential Statistics of Two Methods

Patterns & Values	W+	W-	W (n)	p-value	H0	H1	Average Rating Trad.	Average Rating ABPML
Time	4.5	73.5	13 (12)	0.0068	0	1	2.42	3.5
Cost	36	9	5 (9)	0.11	1	0	3	2.5
Time-Cost (Colour)	3.5	74.5	13 (12)	0.005	0	1	2.29	3.43
Rule	4	62	10 (11)	0.01	0	1	2.21	3.14
History	18	18	3 (8)	1	1	0	2,71	2,71

main parts of the questionnaire. The first one is the comparison conducted between the traditional approach and our proposed extension. The second part is the questionnaire results that evaluates the proposed extensions from different perspectives.

6.2.1 Case Study in a Company

In the first case study, most of the participants who filled the questionnaire were male participants (79%), as shown in Figure 6.1. This can probably be explained by the fact that most of the employees working at different manufacturing organizations are male (e.g. women represented only 29.5% in the manufacturing sector in 2019 according to US Statistics Bureau [Cen19], 27% in 2015 [CP15]). These participants were involved at various levels like process experts, production planners, team leaders, and other managerial positions. The further results of this part and the second part of the questionnaire are discussed in Section A.2.1, where we present their professional experience regarding evaluation.

In the third part of the questionnaire, we want to compare the two methods (traditional method and ABMPL) and test our hypothesis as mentioned in Section 6.1.3.

6.2.2 Time Perspective Comparison

From the time perspective, we wanted to test the following hypothesis.

H0: There is no significant difference between these two approaches (traditional and ABPML) from the time perspective.

H1: There is a significant difference between these two approaches from the time perspective.

As it can be seen from Table 6.1, we have a critical value of 13. Now, we compare our test statistic and critical values; since the test statistic 4.5 is less than the critical

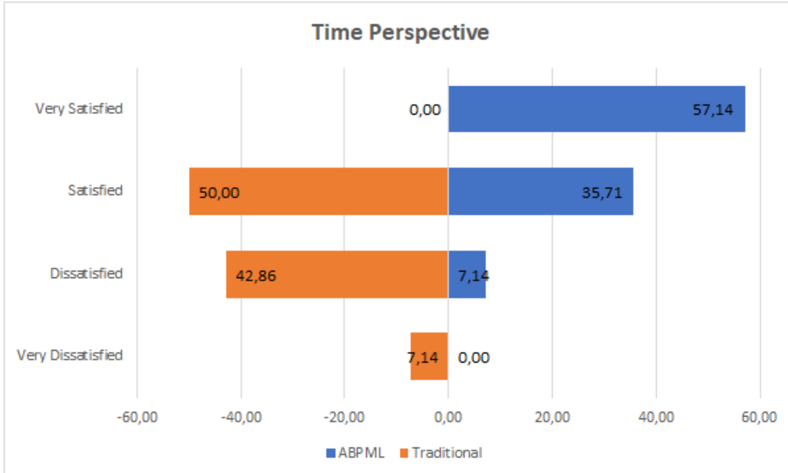


Figure 6.2: Case Study 1: Time Perspective Comparison

value of 13, therefore we reject the null hypothesis. This is also supported by the p-value as it is less than 0.05. Based on the feedback from the participants, there is a significant difference between these two approaches, as concluded by Wilcoxon signed-rank test as mentioned in Table 6.1.

From the descriptive statistics perspective, an average rating of ABPML is 3.5, which is above than satisfied level. In contrast, the traditional method got an average score of 2.42. This is also confirmed by the feedback of participants, where more than 57% of participants said that they are very satisfied with the time pattern proposed in the ABPML method compared to the traditional approach, where no one responded with very satisfied feedback. In our study, more than 92% of participants are satisfied with the ABPML method as compared to the traditional method, which gives 50% of participant with satisfaction feedback. This preference for ABPML over the traditional approach can also be seen in the results shown in Figure 6.2.

6.2.3 Cost Perspective Comparison

H0: There is no significant difference between these two approaches (traditional and ABPML) from the cost perspective.

H1: There is a significant difference between these two approaches from the cost perspective.

From the cost perspective, participants responded with mixed feedback on these methods. The feedback is also shown in Table 6.1. Based on Wilcoxon signed-rank method, there is no significant difference between these two approaches. However, based on the descriptive statistics, it can be seen that most of the participants showed satisfactory behaviour towards the traditional approach. The results show that the average score of the traditional method is more than the ABPML. The traditional method is favoured by more than 71% of participants compared to the ABPML

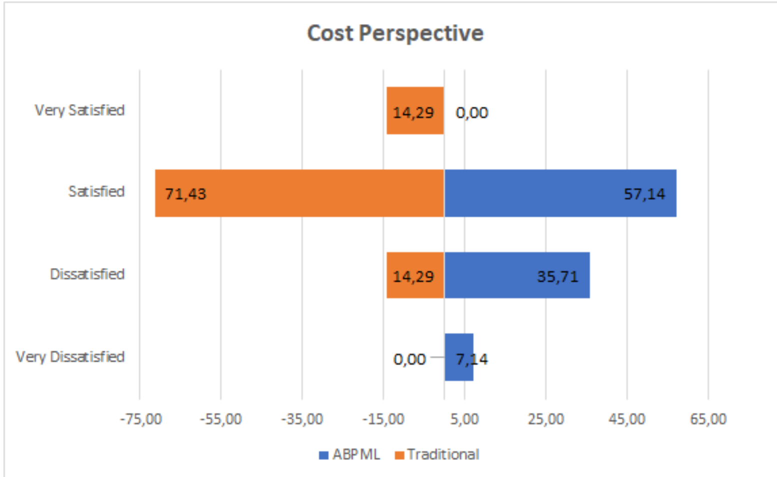


Figure 6.3: Case Study 1: Cost Perspective Comparison

method by only 57% of participants. The results are also shown in Figure 6.3. We will discuss these results further in Section 6.3 of this chapter.

6.2.4 Time-Cost Perspective Comparison

H0: There is no significant difference between these two approaches (traditional and ABPML) from the time and cost perspective.

H1: There is a significant difference between these two approaches from the time and cost perspective.

In this pattern, we combine different KPIs and represent them in colours. The feedback from the participants and their corresponding Wilcoxon signed-rank test is shown in Table 6.1. Since our test statistics is less than the critical value, therefore, we can reject the null hypothesis; that is, there is a significant difference between these two approaches. It is also supported by p value that is less than 0.05.

The hypothesis (H1) is also confirmed by the descriptive statistics as represented in Figure 6.4. More than 90% of users showed satisfaction with ABPML representation compared to the traditional representation of separating time and cost KPIs, which is only 42%. The dissatisfaction to the traditional approach is also more than 50% in comparison to the ABPML dissatisfaction which is merely 7%. The average rating of the ABPML is 3.43 in comparison with the traditional approach which got 2.29 average score by the participants.

6.2.5 Rule Perspective Comparison

H0: There is no significant difference between these two approaches (traditional and ABPML) from the rule representation perspective

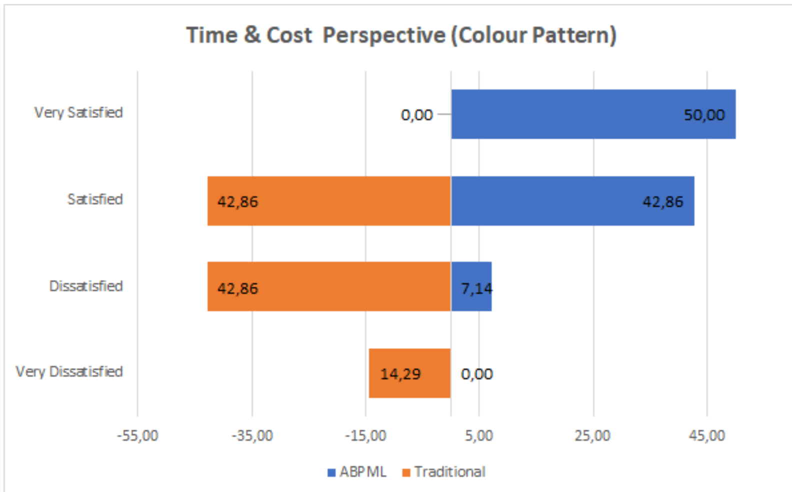


Figure 6.4: Case Study 1: Time-Cost Perspective Comparison

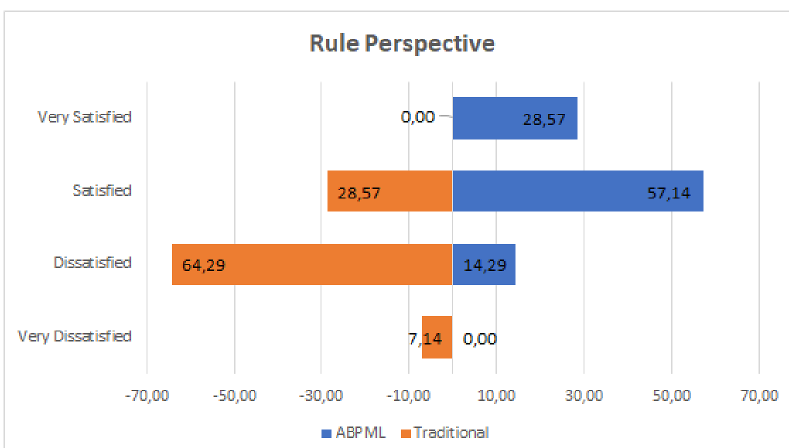


Figure 6.5: Case Study 1: Rule Perspective Comparison

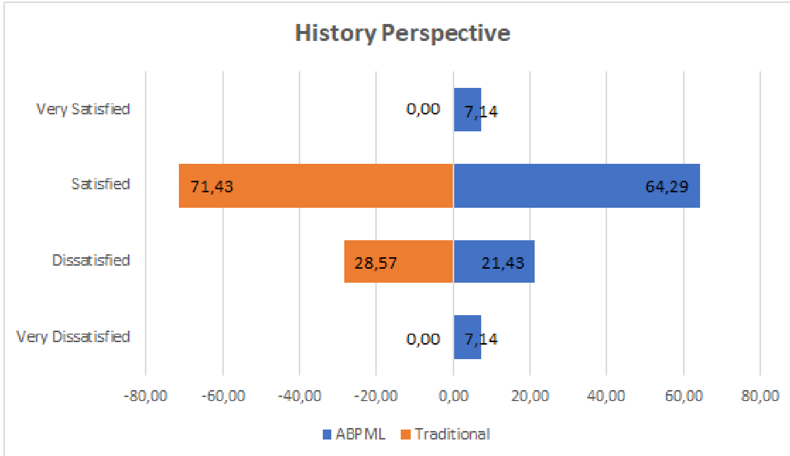


Figure 6.6: Case Study 1: History Perspective Comparison

H1: There is a significant difference between these two approaches from the rule representation perspective

From the rule perspective, the participants' feedback and their corresponding Wilcoxon signed-rank test is shown in Table 6.1. Since our test statistic is less than the critical value, therefore, we reject the null hypothesis. This is also supported by the p-value. Figure 6.5 shows the feedback from a quantitative viewpoint. From Figure 6.5, it is clear that more than 85% of participants showed satisfaction with the explicit representation of rules along models (as in ABPML). Only 28% of participants were satisfied with the traditional method (textual representation in text). However, most of the participants (64%) said that they were dissatisfied with the traditional methods and 14% of participants showed dissatisfaction with the proposed method of ABPML representation.

Based on this feedback, we can conclude that there is a significant difference between these two approaches.

6.2.6 History Perspective Comparison

H0: There is no significant difference between these two approaches (traditional and ABPML) from the representation of history perspective

H1: There is a significant difference between these two approaches from the representation of history perspective

Representing history in ABPML also got mixed responses like cost perspective, where participants showed almost the same feedback. The Wilcoxon signed-rank method and its result for history pattern is shown in Table 6.1.

The positive and negative signed-ranks got identical scores, and our test statistic is not less than the critical value; therefore, we accept the null hypothesis. From the descriptive statistic viewpoint, the average score of the two methods is also the

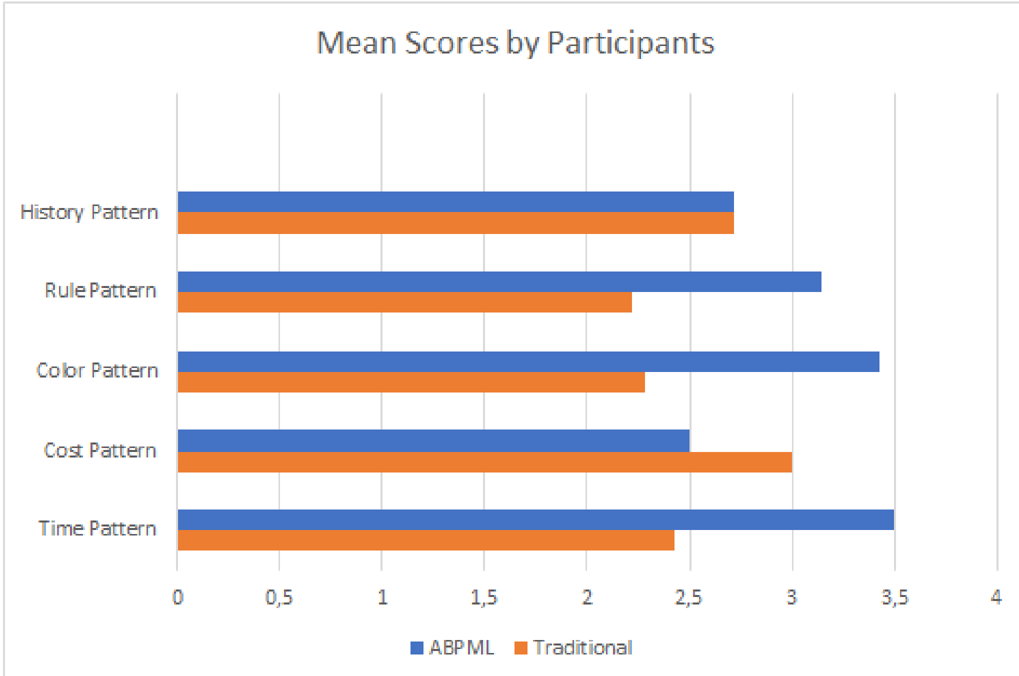


Figure 6.7: Case Study 1: Mean Scores of Two Methods w.r.t. Patterns

same. For the history representation, both the traditional and proposed approach got similar feedback, like the traditional approach had 71% with satisfaction, whereas ABPML had 64%. Similarly, the dissatisfaction rate was also quite close to one another as 28% for the traditional method and 21% for ABPML. These results are shown in Figure 6.6.

The overall summary of patterns with Wilcoxon scores and their hypothesis is already summarized in Table 6.1. The mean score of each pattern with respect to traditional and proposed approaches is shown in Figure 6.7. The coding of values with their categorical score was defined in Section 6.1.3, where we mentioned score four as very satisfied and one as very dissatisfied.

6.2.7 Feedback over Patterns

The fourth part of the questionnaire is about evaluating patterns from the participants' viewpoint. We evaluate the patterns based on four criteria like understandability, support for decision-making(for correct and timely decisions), ability to apply in different domains or areas, and support at different managerial levels (like aggregating values on different levels).

The time pattern is rated very high in all mentioned criteria compared to all other patterns. All participants agreed that it is easy to understand. Similarly, more than 90% of participants agreed that its help in decision-making and flexibility to apply in different domains. On its usage at different levels, participants were divided as 65%

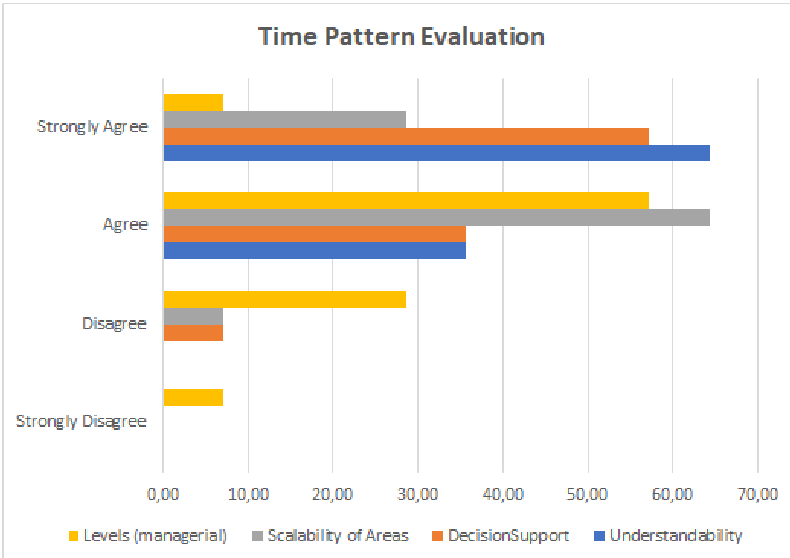


Figure 6.8: Case Study 1: Feedback over Time Pattern

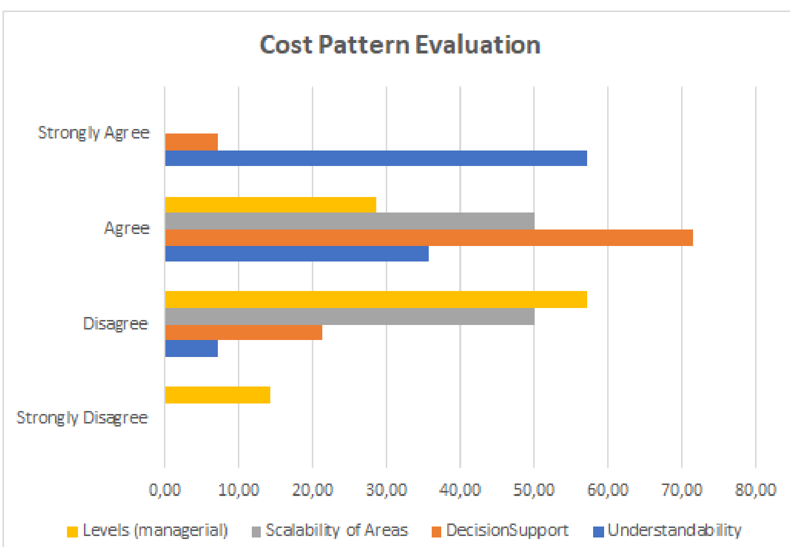


Figure 6.9: Case Study 1: Feedback over Cost Pattern

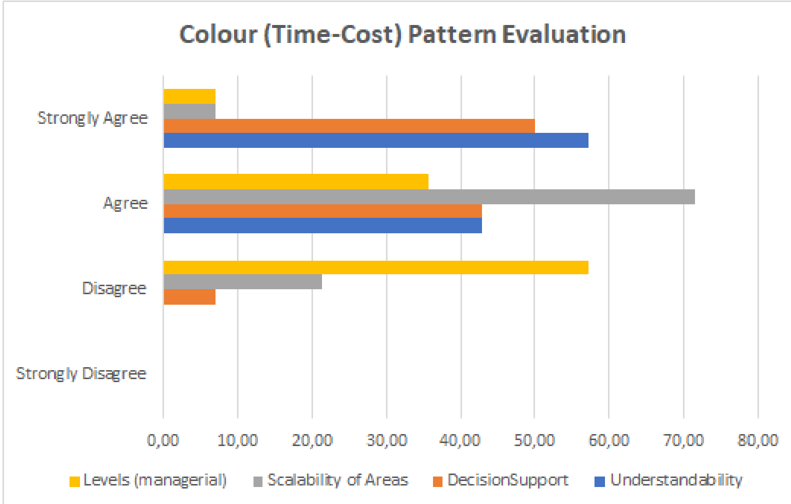


Figure 6.10: Case Study 1: Feedback over Time-Cost Pattern

of participants agreed that it can be used at different managerial levels; however, at the same time, 35% disagreed with that perspective. These feedbacks are represented in the following Figure 6.8.

The cost pattern also got more than 90% of agreement on the understandability perspective, as shown in Figure 6.9. Regarding the decision-making support, 78% of participants were satisfied with that perspective. However, more than 50% of participants disagreed with its ability to apply in different areas and disagreed with its usage at different managerial levels (precisely 71% of participants). We will discuss their feedback and reasons later in Section 6.3 of this chapter.

The time-cost pattern with colour representation is also appreciated by the participants as all participants agreed on its understandability perspective (57% with strongly agreed feedback) as shown in Figure 6.10. More than 90% of participants agreed on its ability for decision-making (50% with strongly agreed feedback). In addition, 78% of participants agreed upon its ability to apply in different domains. However, 57% of participants disagreed on its ability to apply at different managerial levels.

Figure 6.11 shows that the rule perspective also received similar feedback as the time-cost pattern where all participants agreed the perspective of understandability. Similarly, more than 90% agreed on its ability for decision-making, however, only 42% strongly agreed. The feedback of 71% of participants favoured its applicability in different areas, whereas 28% of participants disagreed. More than 60% of participants disagreed with its applicability at different managerial levels as underlying rules and regulations will be complex in representation.

From the understandability point of view, all participants agreed on the history pattern as it is easy to understand. More than 78% of participants favoured its support in decision-making, whereas 21% disagreed in this perspective. We received

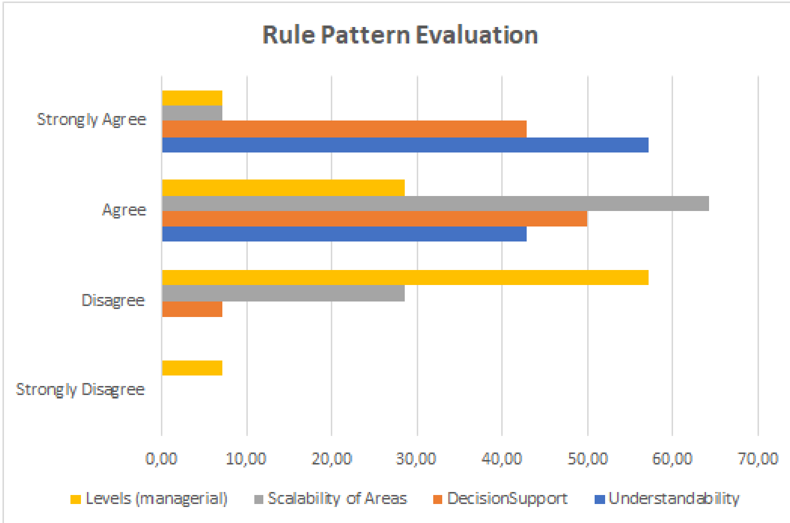


Figure 6.11: Case Study 1: Feedback over Rule Pattern

mixed responses in other criteria as well. 57% of participants agreed while the same percentage were disagreed on its applicability in different domains at managerial levels. Their distribution of responses is shown in Figure 6.12

6.2.8 General Case Study

This group involved participants from different organizations and different domains. In this section, we refer to it as the second group (Case Study 2). In this group, we reach out to the participants through professional and social networks. The results regarding this group's demographical information are presented in Section A.2.2. We received mixed responses due to the nature of the group in our case study, which we will discuss in the following section.

We assessed our results based on two aspects. The first is to compare the traditional and extended BPMN (ABPML) approaches. The second is to evaluate proposed patterns on different criteria.

From the time perspective, the trend of satisfaction can be observed by the general group of participants in both approaches (i.e. proposed and traditional approach). We can easily differentiate the representational satisfaction (including satisfied and very satisfied ratings) by the participants in both approaches as 83.3% for ABPML and 58.33% for the traditional approach, as represented in Figure 6.13. From the inferential statistical perspective, we reject the null hypothesis and accept the alternative hypothesis for this pattern as there is a significant difference based on the Wilcoxon signed-rank method. The statistical scores are shown in the following Table 6.2.

For the proposed patterns in cost perspective, it is similar to the first group responses, where participants observed no significant difference in distribution. However, from

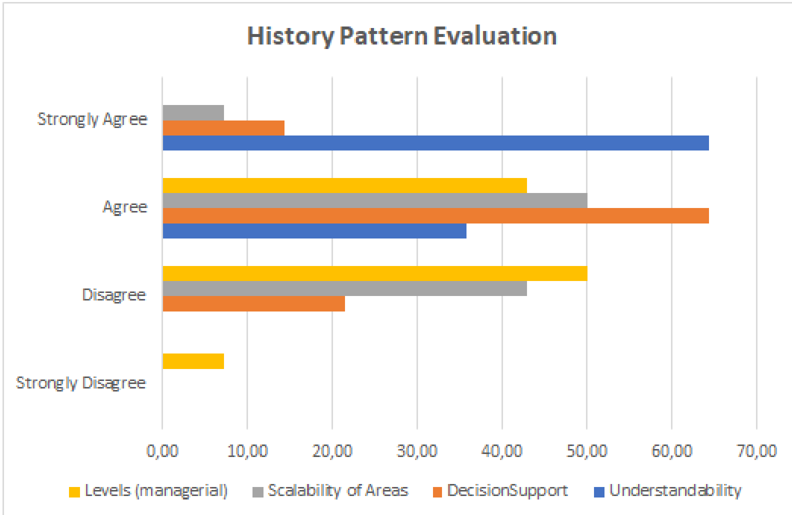


Figure 6.12: Case Study 1: Feedback over History Pattern

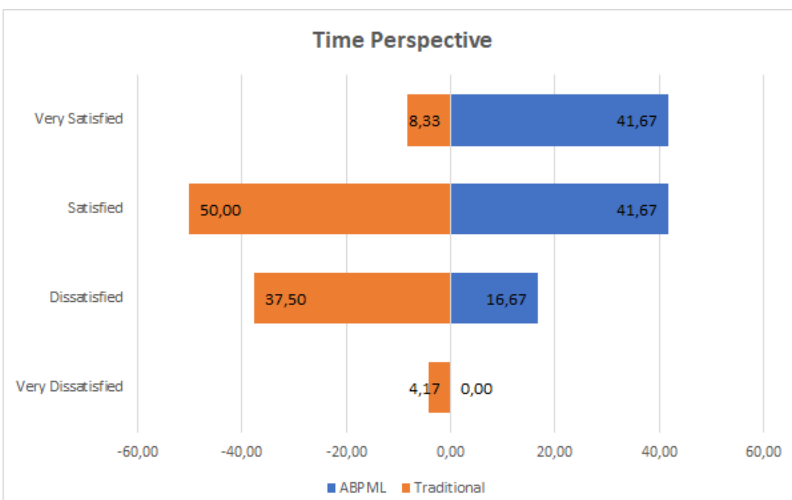


Figure 6.13: Case Study 2: Time Perspective Comparison

Table 6.2: Case Study 2: Descriptive and Inferential Statistics of Two Methods

Patterns & Values	**W+**	**W-**	**W (n)**	**p-value**	**H0**	**H1**	**Average Rating Trad.**	**Average Rating ABPML**
Time	61.5	214,5	73 (23)	0.02	0	1	2.62	3.25
Cost	88.5	64.5	35 (17)	0.57	1	0	2.83	2.71
Time-Cost (Colour)	26	145	40 (18)	0.01	0	1	2.63	3.29
Rule	34.5	136.5	40 (18)	0.03	0	1	2.54	3.04
History	67.5	52.5	25 (15)	0.67	1	0	3.04	2.96

the scores, it can be seen in Figure 6.14 that they slightly prefer the traditional approach compared to our proposed methods. From the cost pattern, 79% of the participants found the traditional methods satisfactory whereas 62% of participants found our proposed extension are also satisfactory. From the Wilcoxon signed-rank method, the p-value is more than 0.05; therefore, we accept the null hypothesis and conclude that there is no significant difference between these two approaches, as suggested by the inferential statistics score presented in Table 6.2.

The colour pattern is the pattern that received the most positive response from the participants in the general group. This pattern received more than 87% satisfactory rating, as shown in Figure 6.15. From the inferential statistics perspective, the p-value is 0.01, which is less than 0.05; therefore, we reject the null hypothesis and conclude there is a significant difference between these two approaches. The average rating for our proposed colour pattern was 3.29 by the participants.

In the case of rule pattern, there is a significant difference between these two approaches, as observed by the participant's feedback. It is also represented by Wilcoxon signed-rank method in Table 6.2. The difference is also represented in the descriptive statistics as the mean score of ABPML is around 3.04 in comparison to 2.54. Roughly 80% of participants showed their satisfaction with the proposed rule pattern in contrast to 58% of participants with the traditional methods, as shown in Figure 6.16.

The history pattern got a mixed response from the participants as it can be seen in Figure 6.17. In the Wilcoxon signed-rank, there were nine responses where the difference between the feedback was zero making our population size of 15 where the difference between these two methods exists. In the case of the history pattern, our test statistics is less than the critical value; therefore, we accept the null hypothesis

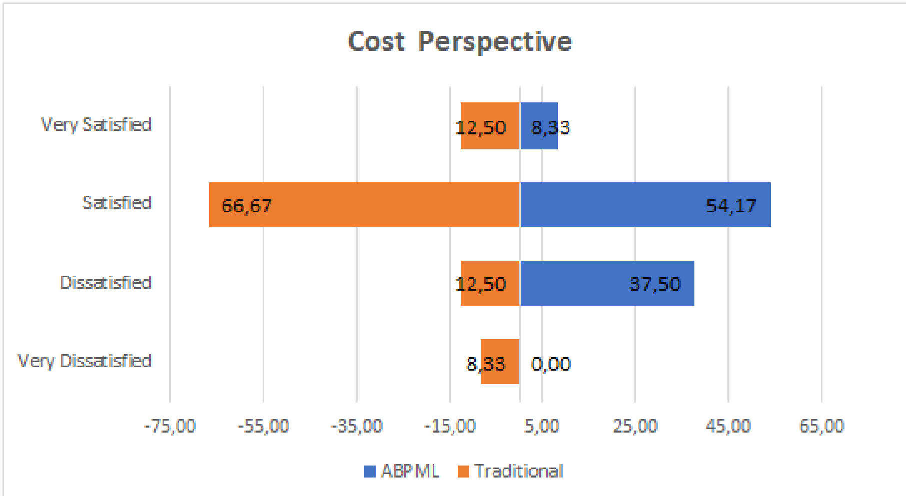


Figure 6.14: Case Study 2: Cost Perspective Comparison

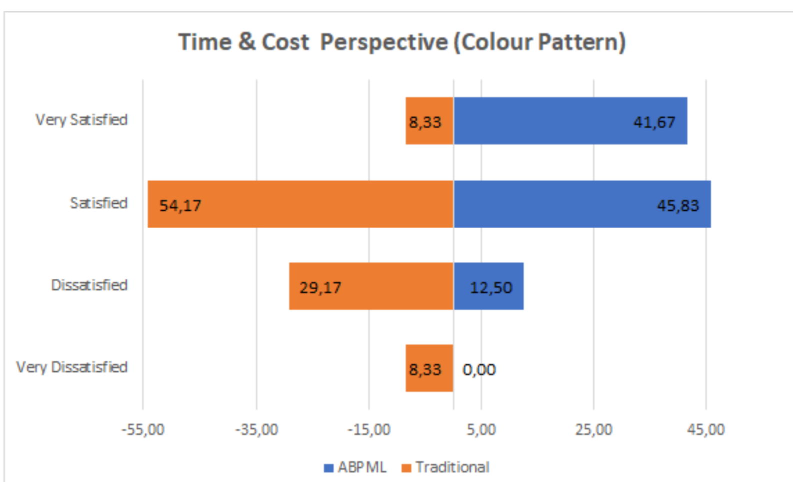


Figure 6.15: Case Study 2: Time-Cost Perspective Comparison

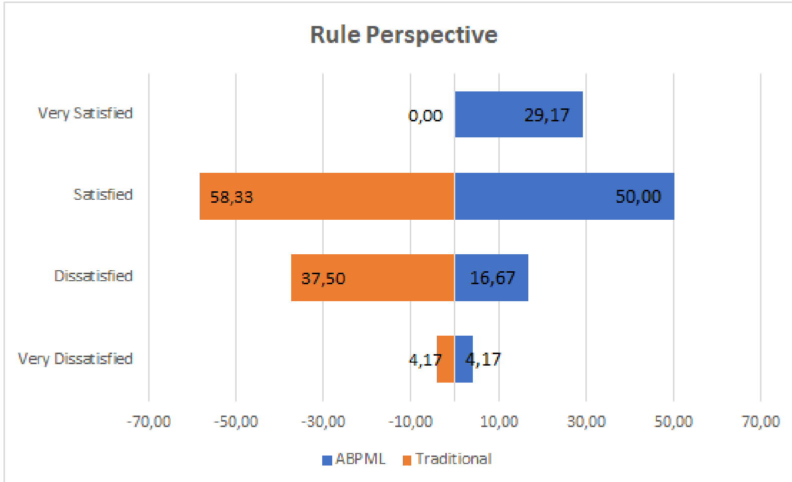


Figure 6.16: Case Study 2: Rule Perspective Comparison

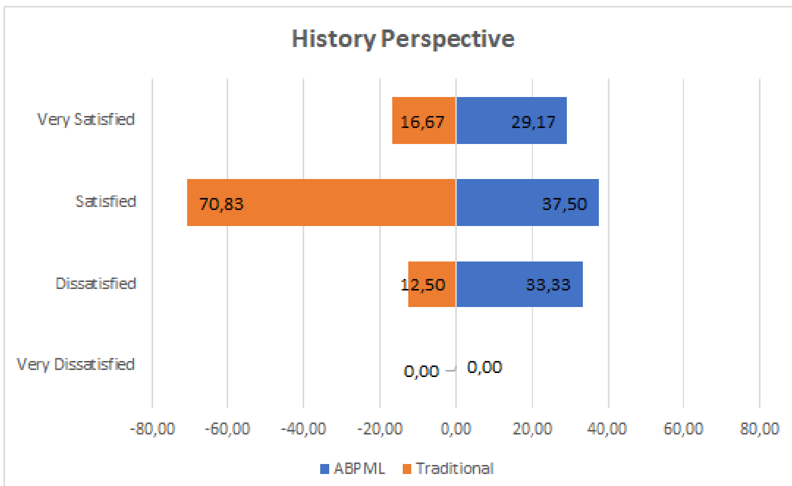


Figure 6.17: Case Study 2: History Perspective Comparison

and conclude that there is no significant difference between these two approaches. This is also represented by their average scores as it is 3.04 for the traditional method and 2.96 average for the proposed history pattern of ABPML.

Figure 6.18 shows the mean score of all patterns and their traditional methods.

6.3 Discussion

The case study was carried out in two separate groups. In the first group, participants belonged to a particular company and had experience with different evaluation techniques and production environments. This can also be seen in the demographical results, where most of the participants (70%) with more than five years of experience. Whereas in the second study, the experience was more distributed among partici-

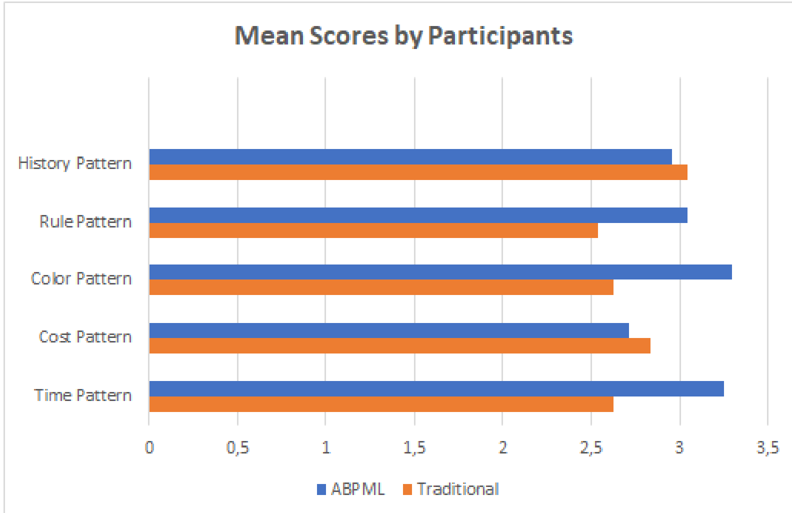


Figure 6.18: Case Study 2: Mean Scores of Two Methods w.r.t. Patterns

pants. The responses given by the first group are more evident in their agreement and disagreement as compared to the general group, as shown in their results.

We have received feedback from different participants not only about the method but also about the questionnaire. Some of the feedback was related to questions and the terms, such as their definitions and the method used.

In the second part, we asked about professional experience regarding evaluation at different levels. The evaluation criteria were not clear to some of the participants, both at the process and managerial levels. The employees at the managerial level have a different perspective regarding performance evaluation compared to process level evaluations. This aspect is not explicitly mentioned in our example.

The term manager is a broad term comprised of departmental manager (disciplinary or organizational), project manager, and plant manager. In our study, we focused on processes; therefore, our proposed method is more beneficial and understandable to the roles at a process level. Some examples will be helpful to understand the usage and benefits of patterns from other perspectives like managerial.

There was also a suggestion to ask specific questions at the end of the questionnaire, as it will already provide some understanding about evaluation after the example production scenario.

The time pattern received the most positive feedback compared to other patterns, as it can be seen from the Wilcoxon scores, mean value as well as the percentage of participants who showed their satisfaction. Aligning activities in time dimension based on their KPIs make the analysis easier, especially in understanding the relationship with other activities. Other methods like Pareto charts and Gantt charts can also be used for this purpose. However, these representations do not show the relation of activities with one another. This provides us with the first justification of the limitation of existing methods and representational benefits of our proposed extension for analysis and improvement of a business process.

Regarding cost pattern, no statistically significant difference could be observed by the feedback of participants, as shown in the results. The cost pattern receives the highest dissatisfaction scores of our proposed patterns. Since the response data “points towards” the positive influence of the traditional method, it means that participants are comparatively satisfied with traditional analysis methods from a cost perspective. This raises the question of whether there is no impact on the proposed pattern at all or if there can be another way to explain the missing impact. To this end, a detailed look at the scenario example and feedback from a few participants provide a plausible explanation: Cost is always related to some values with activities. In our questionnaire, it is related to some categories like low, high, and medium. It was not mentioned about the definition of categories and their thresholds. Whereas in a traditional method, it can be clearly quantified and one can analyse each activity accordingly.

Similarly, one feedback was that production process activities are too broad in their abstraction. These activities can be further specified and then their corresponding cost can be assigned. Once they are at the detail level with cost, then the proposed cost pattern can show a better advantage over the traditional method. Abstraction and specification of activities can also be related to the evaluation of patterns themselves, where it is least rated that the pattern can be applied on different managerial levels. Therefore, a further demonstration of cost and hierarchy levels is required.

After the time pattern, most positive feedback is received to the colour pattern. Colour is an important element in visualizations, as represented in different cock-pit or dashboard charts. Aligning activities in one perspective (roles, time) and representing colours for other dimensions (like cost) is positively rated. Activities can be highlighted with different colours to get attention based on their performance. This is also interesting from an analytical perspective as it is considered one of the limitations of BPMN. Technological development (from a hardware and software perspective) encourages using colours as a standard in business process models (rather than merely black-white representations).

In our case study process model, legends were missing because few participants explicitly mentioned this point in their feedback. However, legends can improve the readability and understanding of the process (and corresponding proposed patterns). In the case of colours, the legend is a must need and should be explicitly provided.

An interesting perspective that needs to be considered is the number of symbols, elements, colours and meanings. However, it should not create an extra cognitive load on a user as it will affect their perception and understanding. Using standard colours and their corresponding usage is a good way, as in the case of our proposed pattern. We used standard colours in our questionnaire like red, green, and yellow to represent our patterns and their categories. The result of Figure 6.4 and Figure 6.15

Table 6.3: Case Study 1: Evaluation of Patterns under Quality Criteria

Patterns	**Understandability**	**Decision Support**	**Scalability**	**Levels**
Time Pattern	3.64	3.5	3.21	2.64
Cost Pattern	3.5	2.86	2.5	2.14
Colour Pattern	3.57	3.43	2.86	2.5
Rules Pattern	3.57	3.36	2.79	2.36
History Pattern	3.64	2.93	2.64	2.36

shows that most of the participants found the colour pattern very important as it is intuitive, as discussed in Section 5.2.

When we describe rules and conditions in a traditional way, most of the participants are not satisfied. On the other hand, the explicit description of rules in process models for analysis and improvement is appreciated by participants, as discussed in Section 6.2. We provide additional information on model edges, which is a better way to explain the reason why a particular path is taken. However, if models are at an abstract level, then the description of underlying rules and conditions could be challenging.

The history pattern received mixed feedback from the participants, and no significant difference was observed between these two methods. One possible reason for no significant difference is the same as of cost pattern; that is, the process model is too easy and small so that no benefits can be foreseen as communicated by the end-user in feedback. On the other hand, the increased number of activities and complexity can help to present the limitation of traditional methods or the benefits of new proposed patterns. Similarly, a legend can explain the relationship between the thickness of connectors and the frequency of their activities if there are different thickness of arrows that exists in the process.

In Table 6.3 and Table 6.4, we summarize the mean score of patterns evaluation from group 1 and group 2. These are correspondingly represented in Radar charts in Figure 6.19 and Figure 6.20.

It can be seen that all patterns are suitable for understanding the point of view. Time, colour, and rule patterns are also good for providing decision support. However, time and colour patterns are rated high in application in different areas. In contrast, all patterns have less mean score to be applied at different managerial levels. The reason is again the same as we discussed in the case of cost and history pattern; that process is too simple in the case study.

For some of the participants in group 2, the problem was not very clear, and they could not follow the questionnaire completely. A basic background in the field is required as the problem and method are not as intuitive as they can be perceived by

Table 6.4: Case Study 2: Evaluation of Patterns under Quality Criteria

Patterns	**Understandability**	**Decision Support**	**Scalability**	**Levels**
Time Pattern	3.25	3.04	3.17	2.67
Cost Pattern	3.0	2.67	2.75	2.58
Colour Pattern	3.54	3.46	3.42	3.04
Rules Pattern	3.17	3.12	3.08	2.86
History Pattern	3.17	2.92	2.88	2.83

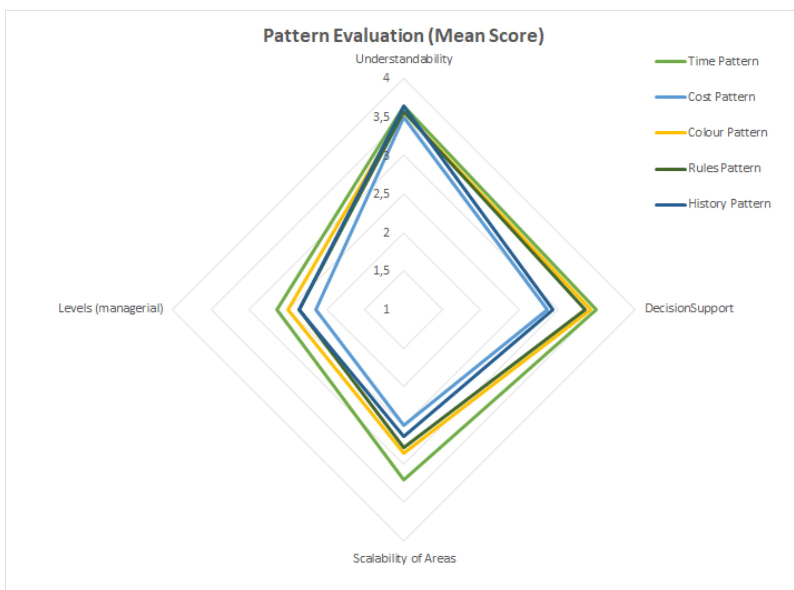


Figure 6.19: Case Study 1: Mean Scores of Patterns Evaluation

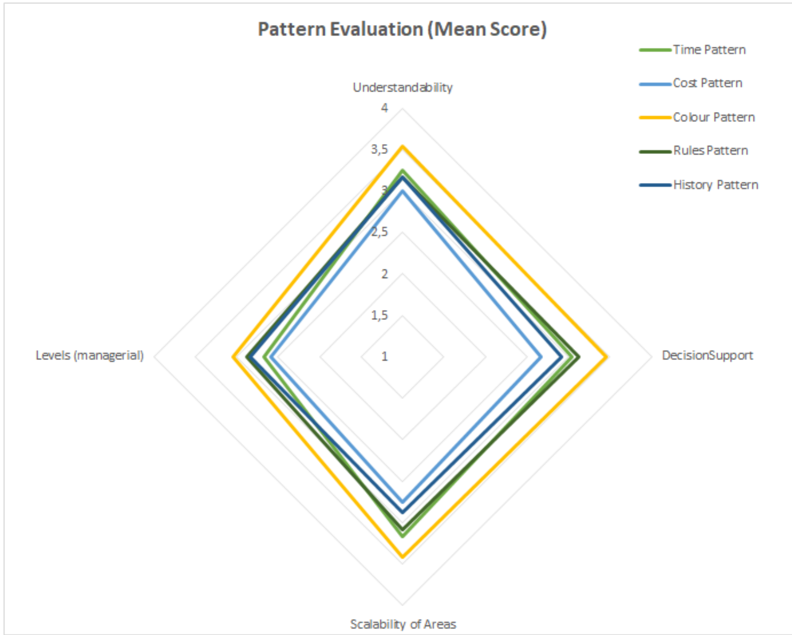


Figure 6.20: Case Study 2: Mean Scores of Patterns Evaluation

everyone. The participants could not be able to understand the benefits of extended models without context and background information.

Since most of the patterns are rated well (like time, colour pattern, rule), therefore, it will be adapted as a standard in modelling business process for analysis and improvement with a performance perspective at a certain point.

Before the empirical evaluation, we assumed that traditional methods are insufficient, especially from a time and cost perspective. However, empirical results did not statistically confirm the developed hypothesis. Instead, the results show that most of the participants favoured the traditional method in cost dimension analysis and history perspective. Similarly, we thought our proposed model extension is very helpful for analysis and improvement; however, the experts see the need of data preparation work and tool support as necessary step for its realization. From the second group, further education or training is also needed (need for change management phases).

6.4 Limitations of Empirical Evaluation

Our empirical evaluation and its case studies face certain limitations. The example process introduced in the case study was small and simple without involving many activities and different levels. Due to this, the benefits of the proposed modelling language were not apparent in cost and history patterns. A detailed process with more activities and aggregation levels can help to evaluate the proposed modelling language better. In [VDP+20], the authors proposed a new modelling language to address the challenges of multiple levels in production processes and their execution.

The case study was conducted only in one organization with a general production scenario. It should have been carried out with the company data and their production processes. Furthermore, such evaluation should be carried out in different organizations with their processes and performance data. Similarly, the general case study can be conducted on a broader scale like in academic institutes, students participating in business process modelling or operation research institutes.

Due to the length of the questionnaire, we have not introduced all possible patterns and their extensions for evaluation, such as the use of colours in the path (activities), information objects (materials) pattern and other patterns. However, these patterns and their combinations can be prepared and carried out for evaluation in other studies.

6.5 Related Work

The proposed modelling language was evaluated empirically in a Bank by the authors of [AN16]. In the study [AN16], users were asked to provide feedback over modelling notation to evaluate business processes and identify deficiencies. However, the authors used a very basic descriptive statistic method to discuss the results of their study. The results showed that the proposed extensions are suitable for performance analysis and identifying deficiencies. In that study, not all patterns were evaluated, and no new contribution was made other than evaluation in the banking scenario.

Different semi-structured interviews were carried out with BPMN users, and their results were reported in [GI+05, RIRG06]. In a follow-up study [Rec08], 590 BPMN users were asked, and their results indicated that users feel the lack of BPMN constructs for their usage. Similar findings were later confirmed and discussed in [IRRG09] where the author discusses the strengths and weaknesses of modelling languages from the empirical point of view. In order to address these BPMN limitations, even in BPMN 2.0, different BPMN extensions are made to represent different perspectives, as discussed in [AK15]. The later empirical evaluations also confirmed that these gaps still exist even in BPMN 2.0 standard specifications, as discussed in [AK15]. However, these empirical evaluations do not focus on evaluating the modelling constructs from the performance evaluation context we have provided in this work.

In some BPMN evaluations, a generic quality framework ([NK06]) is used for modelling language evaluation as it contains qualitative and quantitative methods. The framework is sufficiently generic and can be easily extended further. The framework identifies five characteristics of modelling languages which include domain appropriateness, participant language knowledge appropriateness, knowledge externalization appropriateness, comperhensibility appropriateness, and technical actor interpretation appropriateness. In this work, we have taken some aspects from the generic framework as part of an empirical evaluation. We also followed the quality aspects of ISO/IEC 25010:2011 [ISO11] for quality evaluation.

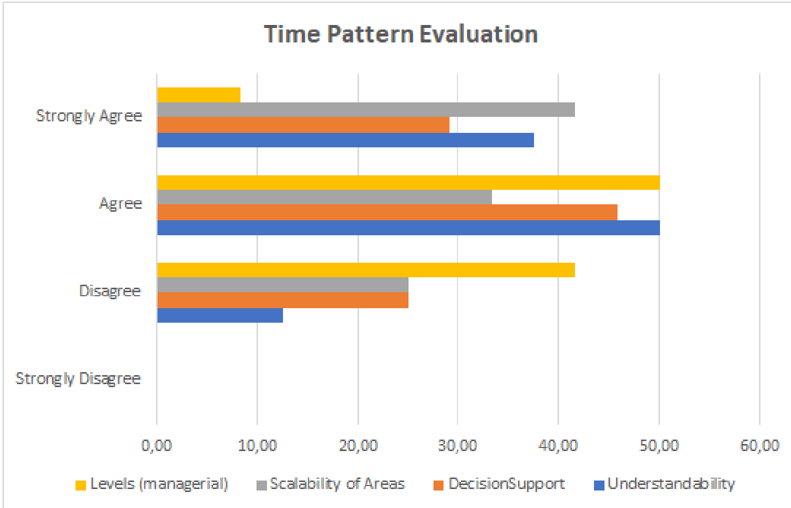


Figure 6.21: Case Study 2: Feedback over Time Pattern

In some BPMN extensions, our extended BPMN meta-model and proposed modelling extensions were used as a basis as discussed in Section 5.4. In [LZB18], the authors extended the BPMN meta model and proposed a modelling construct to discuss the outsourcing of business processes. They used our proposed patterns to represent the performance (like cost) and made a prototypical implementation of constructs in three tools just to represent different aspects. In [PVE+18], manufacturing processes are modelled using BPMN extension for human physical risks. The implementation was done in MS Visio template to show the BPMN extensions and evaluated in two companies. However, these extensions were evaluating human risks only at the activity level; therefore, they extended BPMN models only with activities.

6.6 Summary

In order to evaluate the practical suitability of the ABPML language, we conducted an empirical study. We used a manufacturing process for the empirical study and represented it from different perspectives. We discussed and analysed it from time, cost, and performance perspectives. We have gathered the opinion of experts from industry and academic fields, someone who is actually working on this business process evaluation level. We compared the traditional methods with the proposed extensions in two case studies (in a company and generic group). We have discussed the results from a descriptive and inferential statistics perspective. The results show that the proposed patterns are rated very well, like time, cost and rules patterns. However, cost and history patterns did not receive significant positive feedback. The results imply that it will be adapted as a standard for extracting knowledge/documenting as a performance evaluation for analysis and improvement at a certain point. A detailed case study can show the potential benefits of proposed patterns from a cost and history perspective.

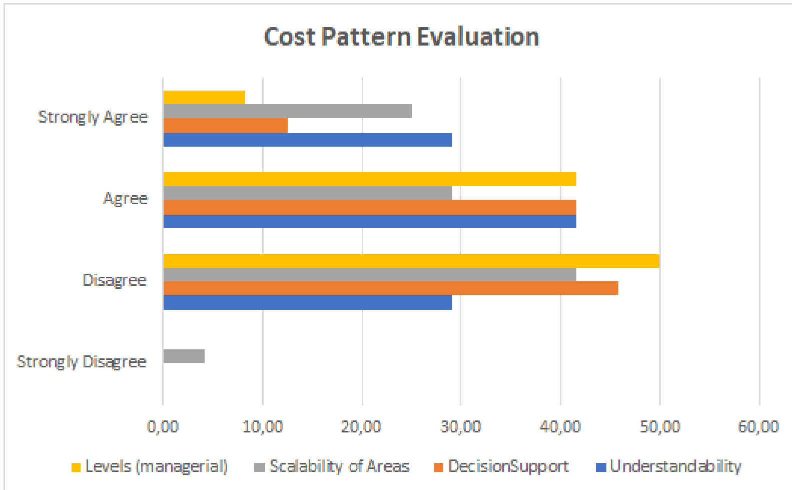


Figure 6.22: Case Study 2: Feedback over Cost Pattern

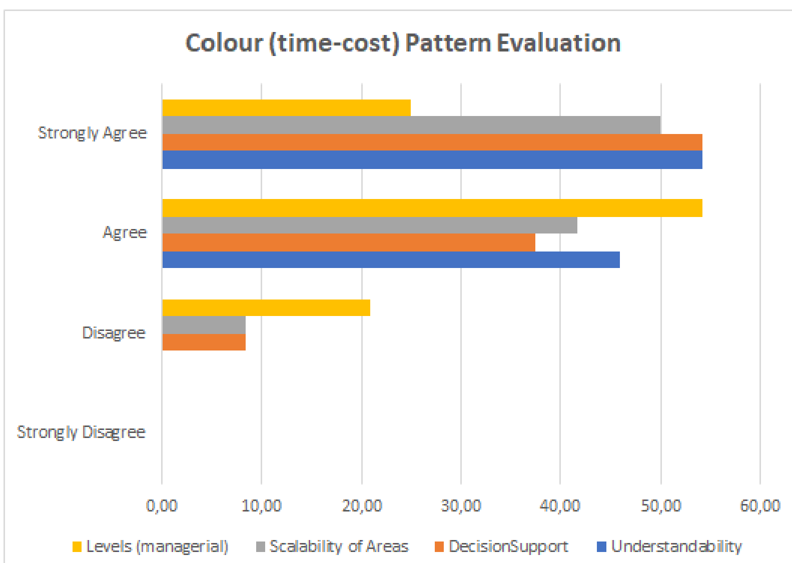


Figure 6.23: Case Study 2: Feedback over Time-Cost Pattern

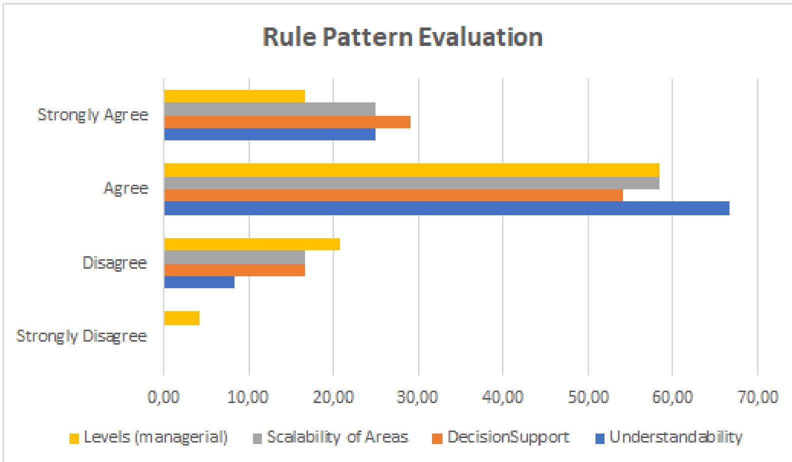


Figure 6.24: Case Study 2: Feedback over Rule Pattern

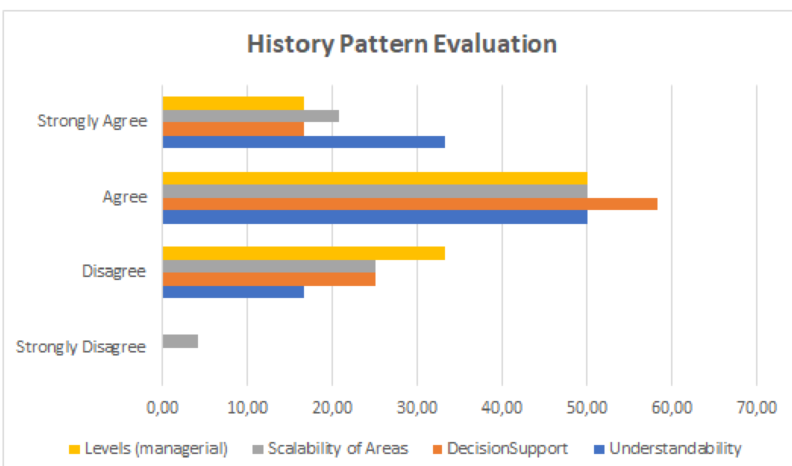


Figure 6.25: Case Study 2: Feedback over History Pattern

Empirical evaluation results can be further explored or analysed with analytical evaluation. For this purpose, in the following chapter, we evaluate the proposed extension from the analytical perspective.

7. Analytical Evaluation of Modelling Language

This chapter shares material with the paper presented in KMIS 2022 "Empirical Evaluation of BPMN Extension Language" [LST22], and FIN Tech. Rep.'2010 "Post-Execution Analysis of Business Processes: Taxonomy and Challenges" [LKS10].

Analytical evaluations focus on the conceptual basis of a modelling language, such as ontology. Ontologies are context-dependent projections (models) of reality. A representational model can also be evaluated by the ontological aspects. In [OHS02], the authors discuss that ontologically based evaluations are well suited for evaluating modelling constructs in representing concrete problem domains. Various modelling languages and their extensions have been evaluated on ontological basis [BBBR10].

In [WW93a], the authors propose a model called Bunge-Wand-Weber Model (BWW model) to evaluate the models based on their completeness and clarity.

In this chapter, we evaluate proposed modelling constructs of ABPML on an analytical basis. We do not want to evaluate the BPMN itself, as BPMN is already evaluated using the BWW model in [AK15, RIRG06, KJHP15, GI+05].

The importance of discussing BPMN limitations is to compare the results of earlier studies with the new proposed extensions. This will help us to determine how well the new proposed extensions cover the existing BPMN limitations. We also investigate which modelling limitations of BPMN can be solved using our proposed work. We also want to evaluate how our proposed constructs are evaluated in the BWW model context.

In Section 7.1, we introduce the basic concepts of the BWW model and explain the method. In Section 7.2, we discuss the limitations of BPMN and evaluate the representation power of our proposed extension with the BWW model followed by Section 7.3, where we evaluate from an interpretation perspective. In Section 7.4, we mention the analytical queries which can be answered using our proposed modelling language. The benefits of our proposed modelling language are discussed in Section 7.5. The related work of analytical evaluation is discussed in Section 7.6, followed by Section 7.7, which summarizes this chapter.

7.1 Bunge-Wand-Weber Model

Mario Bunge was inspired by system theory and provided a comprehensive system ontology (things in the world) [Bun77, Bun79]. Whereas Weber refers to an ontology that deals with theories concerning the nature of things in general in contrast to theories of particular things [WL97]. The BWW-model itself [WW93a, WW95b, WZ96] is an adaptation of Bunge ontology and applied for modelling information systems [WW93a]. It also serves as a representational model to analyse and evaluate conceptual modelling languages.

BWW model mentions elements that are present in the real world. These real world should be represented in modelling languages to project the world in a model. This is the reason to choose the BWW model to evaluate the proposed modelling constructs and find its limitations/gaps.

7.1.1 BWW Model: Basic Concepts

In the following paragraphs, we define some of the essential concepts of the BWW model.

Things: Things are essential in the BWW model representing elements/entities of the real world. They possess different characteristics in different states. They also belong to different kinds or certain classes, depending on several common attributes (termed as properties). Examples of things are a resource, organizational unit, and processed object. The definition of coupled Things is if one thing acts on another and it affects the History of other things.

State of Things: Things can be in different states as defined by their properties. These properties get change due to different factors or events in the environment. Therefore, the state of things can be different like lawful state-space defines States that comply with state law. Similarly, conceivable state space is defined as a set of all States a Thing can presume in its lifecycle.

A stable state is defined as a state in which a Thing or a System will remain the same until and unless a force is applied by a thing. In contrast, the Unstable State is a State that will be changed into another State by the Transformation in the System. The transformation itself is a mapping from one State to another State.

Event: Event is defined as the change in the State of Thing, whereas conceivable event space is a set of all events that occur to a Thing. Events represent the behavioural aspect of business processes. Events can occur during different stages of a business process, like at the beginning of a process, between the execution of activities, or at the end of a process.

History: History is defined as the sequence of states of things that takes place over time (in chronological order).

A system is a set of coupled Things, whereas a System Environment is a Thing outside the System interacting with the System.

System Structure is a set of couplings that exists among Things. A subsystem is a System whose composition and structure are a subset of the composition and structure of another System. Level Structure is an alignment of the subsystems.

BWW model demands an explicit representation of business objects, states of business objects, and state transition laws that allow monitoring of states' history. Therefore, in this research, we used the BWW model as an evaluation framework to evaluate the post-execution analysis part of business processes and their modelling capabilities in a structured way.

7.1.2 Bunge-Wand-Weber Model Method

In ontological evaluation using BWW-model, two mappings are carried out. The first one is representation mapping, whereas the second is interpretation mapping. In scientific literature, it is also referred to *Ontological Completeness* and *Ontological Clarity*, respectively (c.f. [WW93a]).

In the first mapping, the representation power of the modelling language is evaluated. For this purpose, mapping from the BWW-model (or real-world) is carried out on modelling language. This mapping helps to detect the redundant and missing constructs that do not represent the reality in a model (construct deficit). The representational mapping is shown in Figure 7.1.

The second mapping is the reverse of the first mapping, i.e. from modelling language to the real world (BWW-model). This mapping helps to identify the constructs that are in excess (do not contribute to representing the reality), and constructs that represent different kinds of concepts (construct overload). It also provides which constructs are precise in modelling. These ontological discrepancies affect the clarity and understanding of modelling languages.

The discrepancies are shown in [WW93a] and represented in Figure 7.1. We summarized them below.

Construct Deficit is the case when an ontological concept is not represented by any modelling construct. This is usually a problematic situation as the real world can not be projected into a model.

Construct Redundancy is the case when several (overlapping) modelling constructs represent the same ontological concept of the real world. This discrepancy is not necessarily problematic as long as the overlapping modelling constructs represent

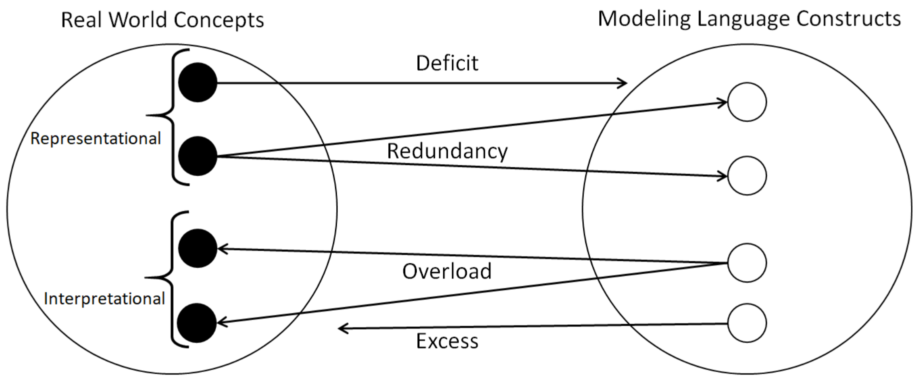


Figure 7.1: Bunge-Wand-Weber: Evaluation Criteria of Modelling Languages

disjunctive subtypes of the ontological concept. In [WL97], the author shows the importance of subtypes and different modelling constructs in representing information systems. However, a construct deficit may occur if the subtypes do not together cover the ontological concept completely.

Construct Overload is the case when a modelling construct corresponds to several ontological concepts of the real-world. This is usually a problematic situation as it creates problems in understanding. It is not clear which real world concept is represented by the modelling construct.

Construct Excess is the case when a modelling construct does not represent any ontological concept of the real world. Such discrepancies occur during technical limitations or representation of the proposed software or information system.

We use these four discrepancies in our work to evaluate our proposed modelling language constructs.

7.2 Construct Deficit: Evaluation based on BWW-Model

We have discussed in Section 4.6 the limitations of modelling languages in the post execution analysis context. In this section, we aim to discuss the limitations of BPMN from an analytical perspective as reported by different researchers in the literature. Based on these limitations, we will evaluate our proposed extension of BPMN in the context of analytical evaluations.

Construct deficit is the case when modelling constructs are not available to represent the needs of a user in a modelling language. Business process performance metrics are not represented in the case of modelling languages in general and BPMN in particular. This deficiency ofo construct is depicted in Figure 7.2. Therefore, it is required to extend modelling languages with performance details for better analytical support.

For simplicity and understandability, we discuss the limitations of BPMN in literature and our proposed extensions (ABPML) in corresponding sections as defined

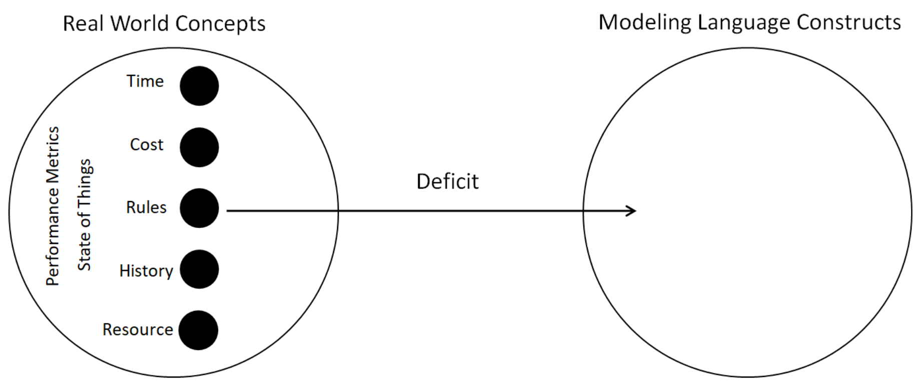


Figure 7.2: Construct Deficit: Performance Representation in Business Process Modelling Languages

in Section 5.2. The BPMN limitations help to compare and evaluate our proposed extension based on the BWW model.

- Dimensional Constructs (Time, Cost)
- Environment Context (Information)
- Rules Pattern
- Colours Pattern (Time, Cost, Path)
- History Pattern

7.2.1 Dimensional Constructs

In different semiotic evaluations of BPMN by different researchers [NK06, WS05, RRK07], it is demonstrated that BPMN lacks domain-specific representation. For example, in [WS05], the authors show that the BPMN language does not accommodate business-specific expressions, although the primary purpose is to model business processes [AK15].

Time and cost are both essential aspects in business process execution and then later for analysis and improvement. BPMN has few limitations; for example, Swimlanes (Pools and lanes) represent organizational roles or entities. Different details regarding performance, skills, workload, working time, or cost perspectives are not provided or visualized.

In BPMN representation, only time-based events are represented, which means that certain activities are executed when a time-based event occurs. However, it does not represent how much time and cost are consumed during process execution. In BPMN, specific triggers or time-based events are represented. However, it does not provide information about their performance after execution, duration, and frequency. Therefore, the states of certain business objects have to be maintained and documented during their execution (missing context-related information).

In particular, the proposed patterns of ABPML and BPMN extensions, try to overcome these deficiencies by representing time and cost dimension using pools and swim lanes. In surveys [RIRG06, GI+05], the authors showed that the BPMN groups and other connectors are not properly used. This is due to the reason that they come as a construct of the model and not part of the process itself [AK15]. Our grouping constructs bring them meaning for understanding and a specific goal.

7.2.2 Environment Context

The representation of context is significant as based on the state of certain things, different routes/paths (conditions get valid) are executed, and it has to be shown correspondingly. For example, in the case of parallelism or the same activities (where the same action is performed), depending on the resources available and queue, a different route can be taken where less load is experienced (load-balancing). Similarly, if the target values are not achieved in a process, then different actions are carried out depending on the conditions and available resources. Such execution depend on the context, like allocating more resources, fixing the deviations or repairing the machine to achieve the target values.

Another example is in the case of deviation management, based on the actual performance (or measurement values), specific interpretations and decisions can be made with respect to context, and certain parts are executed with or sometimes without the involvement of humans or particular resources.

Context is defined in [Dey00] as the relevant objects, information or services needed to fulfil a task at hand (activity, user's task, and decision). In [HS15, EVTG20], the authors recommend that business processes must consider non-static context events which affect the process. However, it was not discussed how to model it in BPMN.

These business objects related to context provide good information on how business processes are executed in an organization and what role business objects plays in the process. These kinds of representation can support and ease the work for understanding and analysis of business processes and their efficiencies.

In [RRF08, RRF11], authors claim that modelling languages have to be more flexible to model context. The flexibility of modelling languages should lead to a decreasing time-to-market for products, as discussed in [RRF11]. Similarly in [EVTG20, Pen17], the authors claim that different modelling constructs are required to represent involved business objects such as inputs, rules, and performance-related information. The existing BPMN notations and meta-model do not incorporate the performance details of business processes.

In [RRK07], the authors mentioned a lack of constructs to represent different attributes of business processes and it was also confirmed by other evaluations ([AK15]).

In [AK15], the authors found that systems structured around things are not represented adequately. Due to this, it is not easy to get information about the dependencies of a modelled system. This information is necessary for a complete picture of a business process.

Different contextual information can be provided by adding conditions or extra constructs (elements) to represent the context. For example, the raw material can be presented in a process model as shown in Figure 5.9 (with a shopping cart) or further activities with specific symbols presented in [LKR08].

7.2.3 Business Rules

In [RIRG06], the authors mention that states of things can not be modelled using BPMN. Due to this, relevant business rules can not be captured or represented ([AK15]. The limitation of BPMN was also confirmed in another study as discussed in [Rec08], where users find workarounds (textual descriptions as separate notes) or ad-hoc representation outside of the BPMN model. These limitations demonstrate the construct deficit in BPMN models. In BPMN 2.0, activity types try to address it on an elementary level. However, it is still difficult for users for their comprehension [AK15].

In our work, we explicitly represent the rules/conditions at decision points and their values on the connecting objects. The condition can be used to refine events and relations with activities like edges between them from different perspectives like time, cost, and rules. This helps to understand rules and their execution to improve the understanding of business processes.

7.2.4 Colours Pattern and Path Constructs

In [Moo09], the author proposed diagram notation principles which were later used to evaluate BPMN by [AK15]. Authors found that visual expressiveness is also very limited in BPMN like Colour, Size, and Shape. Colour is the most effective characteristic in the cognitive field and uses different contexts. In process modelling in general, only black and white colours are primarily used. One of the reasons is the historical development of modelling languages in the twentieth century. However, due to the development in coloured display devices and printers, it should not be restricted to one colour only. Our proposed colour representation can be used to represent a state of things from a time and cost perspective in order to overcome the analytical perspectives.

The colour and size of the connecting objects can be used to demonstrate different concepts of real world like successful, unsuccessful states, paths, and frequency.

Control flow and environment data are not represented in BPMN. This is due to the lack of support, for instance, specific details for a task or subprocess [AK15]. A multiple instance marker, colours or information pattern can overcome this challenge. Similarly, data objects involved with activities are represented very abstractly as no information about their structure and contents (values) is shown in a BPMN model.

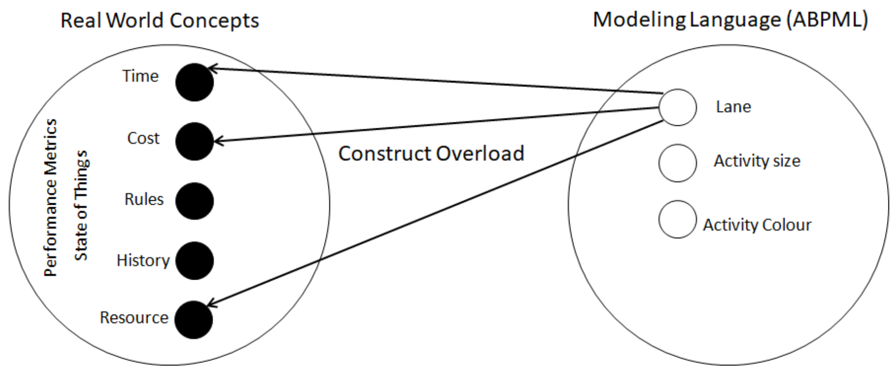


Figure 7.3: Construct Overload: Constructs Representing different Concepts

7.2.5 History

Modelling languages lacks the constructs to represent the State of a thing, which is also referred as History as discussed in [Pen17, RIRG06]. In [RRIG09], BPMN's lack of history construct is discussed further in detail. In our proposed extension, we try to address this problem and represent it by the paths which provide information on how often a particular task/activity is executed. Similarly, following this principle, the activities border can also be increased to show different concepts related to the activity history (e.g. time particular resources exist).

7.3 Construct Overload and Redundancy

Construct Overload occurs when the same modelling construct is used to represent different concepts of real-world (for different purposes and meanings). This is the most likely case in the BWW model evaluation of modelling languages. Since we try to fulfil construct deficit using some modelling constructs, therefore, our proposed modelling language faces this challenge.

In our proposed extension, construct overload occurs for pool and lanes modelling constructs as we use it to represent time, cost, and organization resource perspectives. The construct overload is depicted in Figure 7.3. In the case of lane and pool construct of BPMN, the construct overload challenge is also discussed in previous studies like [RIRG06]. In that study, the authors reported ambiguities in their usage in practice. They also found that these modelling constructs represent a different real-world entities which are completely different. Due to the construct overload in BPMN, it has a negative effect on comprehensibility, as concluded in earlier studies [WS05, RRK07]. The construct overload remains in BPMN 2.0 as well as later studies also confirmed it [AK15].

We have shown the modelling constructs which have construct overload in Figure 7.3. For the simplicity of the figure, we have shown only the mapping of lane construct to corresponding real-world concepts. Similarly, colours as a modelling construct of

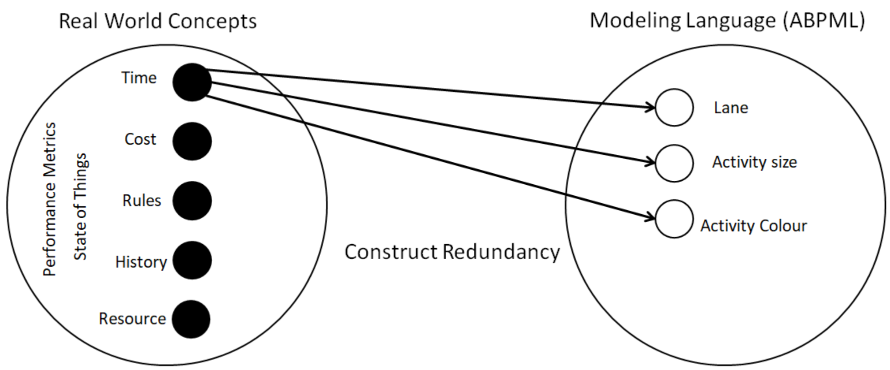


Figure 7.4: Construct Redundancy: Concepts Represented by different Modelling Constructs

our proposed modelling language can be used to represent time and cost dimensions. The same is true with the size of elements, as size can represent different concepts.

In order to address the construct overload problem, different notations can be further added/attached while representing particular perspectives. For example, in the case of lanes or pools, we can use a clock or hour symbol for representing the time perspective, currency symbol to represent the cost perspective and an actor/human symbol for the organisational role perspective. Another way is to create a box highlighting the particular perspective (like time or cost perspectives).

When we combine colours and sizes with different artefacts such as events, activities, lanes and pools, then we create new constructs. These constructs can be used with a legend to tell the meanings as well. This can help to avoid misinterpretations by users. Another way to distinguish from normal usage is to use our proposed modelling language only in a particular phase like post execution analysis and improvement to bring the construct overload problem within a particular context.

Providing different means to represent the reality also creates the challenge of construct redundancy. The time, cost and other performance metrics can also be represented by the usage of colours, size, lanes, and other modelling constructs. This construct redundancy is represented in Figure 7.4. Depending on the problem in hand, specific constructs are used to improve the representation, like highlighting particular elements using colours, or aligning activities in particular dimensions using lanes, as well as making it more visible using size.

Figure 7.5 summarizes our proposed extension contribution toward the representational mapping and challenges regarding the interpretation.

7.4 Analytical Queries

Different analytical queries can be answered using extended business process models. Although other techniques can answer analytical queries, however, these techniques

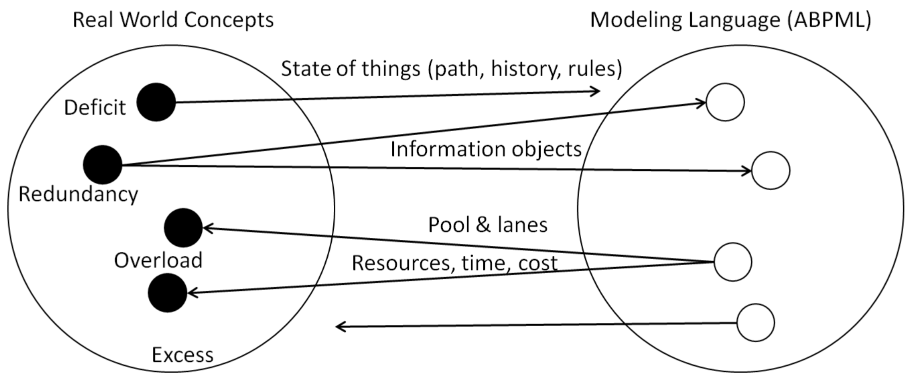


Figure 7.5: Representational Gap in Modelling Languages

do not explicitly represent elements in process models, and thus do not provide an intuitive understanding. In the following, we discuss these queries in the post-execution context. We have a different focus than the phases before execution. We emphasize that with the help of extended process models, we can improve business processes more effectively.

- What are the dependencies between processes and elements?
- Which decisions exist in business processes? What is the justification or reasoning for these decisions? What are the properties of business objects that influence the decisions?
- Which business cases (paths) lead to successful execution from a business viewpoint?
- Which parts influence the efficiency of a process?
- Which resources are allocated to the business processes yet are seldom executed?
- What are the explanations behind their seldom utilization and for which cases (and types)?
- Which business objects are engaged in task execution?
- What are the data requirements (attributes) for executions?

Few of the questions mentioned above do not demand a query language. These questions can be responded with a simple analysis of the extended business process models, including the resources involved. However, different techniques like query language are required to answer of some other questions. In [LKKS10b], we investigated the graph mining based techniques to answer the questions related to business processes.

7.5 Benefits

A vital question arises when a new modelling approach or technique is proposed: which benefits can be accomplished with the new method? Analytical modelling language focuses on business domain and process structure instead of technological or other aspects. Therefore, limitations related to the business domain are addressed here. The following section describes the potential benefits of the analytical modelling language.

Various cognitive studies show that users read and perceive information in a particular order. Therefore, the order in which information is presented is an important factor. Aligning activities in a particular order as presented in our proposed pattern and extended modelling language help the users to quickly identify the deficiencies in a process. Therefore, the elements essential in a dimension are presented in a prominent position.

Currently, most modelling languages provide functionalities in one direction, however, they do not support other functionalities. For example, few modelling languages allow us to represent the involved resources (elements), but they do not provide any formalism specification for simulation purposes or other features for analysis. In our proposed analytical modelling language, we attempt to provide both functionalities.

7.5.1 Intuitive Understanding

In the case of iterations, it is not always obvious from the business process model why an instance has to be repeated many times. Extension of attributes in a model would help to understand such scenarios intuitively about the reasons of failure. Similarly, the extension of attributes will increase the intuitive understanding of business processes.

Colours is important factor to enhance the intuitiveness of models. Therefore, it is commonly used in visualizations. In our proposed patterns and its case study, colour has received the highest positive feedback in business process models.

7.5.2 Rationale for Decisions

Implicit assumptions involved in a business process must be represented explicitly for better analysis and improvement. In the case of Petri nets, required conditions and elements are represented very abstractly, like the presence of tokens at places. Explicit representations of involved rules, elements, and attributes will improve the understanding of business process executions. Extended business process models will assist in understanding the dependencies between elements of business processes, like which elements or details are necessary for the execution of business processes. The analytical business process modelling will present the rationale for the decisions made in business process executions.

7.5.3 Training of Employees

Extended business process models can also be used for knowledge management. For example, new employees can be trained using business process models. They can walk through different business process scenarios and see how experienced employees address different situations. For this purpose, detailed representations or descriptions will help to model the reality, including the involved attributes and their corresponding values.

7.5.4 Models/Directions for Improvement

The detailed description of business processes in models can help to discover the deficiencies in execution. The particular areas can be further investigated for improvement or re-engineering purposes. With a better understanding of problems, we can also give directions to rectify the causes of problems and improve them. The steps for improve is the prescriptive analysis, as discussed earlier.

7.5.5 Just-in-Time Analysis

A history construct in business process models offers the capability to state the elements of business processes at a particular stage of operation. This feature is vital at later stages because the efficiency of elements can be affected by other elements or processes. For example, in comparing two instances, at a particular stage, the cost of one instance is very low because of efficient processing and the path it took during execution. However, at later stages, other elements/processes may affect the efficiency of the instance, and the overall cost of the two instances remains the same. In this case, the reasons for efficient execution will not be noticed. The other parts of the process overcome the improvement in one part of the phase. The representation of such scenarios is essential for business process improvement.

7.5.6 Understanding the Context

Representation of involved business objects and its settings (like market including associated laws) of a business process will allow to analyse the environment in which business processes are executed and thus improve the understanding of business processes.

Besides the environment of a business process, representation of other factors is also important for analysis and understanding of business processes. Explicit representation of elements with attributes will help to understand the structural deficiencies. For example, in the case of delivery of goods, the loop structure with attributes explains the reasons for failure in delivery and why it has to be repeated again.

7.5.7 Context-based representation

Once we are able to represent the executions of business processes (and their environment) completely in a business process model, then we can use extended models to understand the structural deficiencies of business processes. This is due to the reason that in abstract representation, the structural defects are not clearly represented; therefore, they can not be easily identified. Although, some of the benefits can be answered by other querying methods, here in analytical modelling language, the focus is the intuitive understanding of business processes through models.

7.6 Related Work

In order to evaluate different quality aspects of models, a semiotic quality framework is used in [AK15], which is based on semiotic concepts as discussed in [RRK07]. In [RRK07], the authors propose a generic framework that combines different frameworks like ontological, semiotic, and workflow patterns for modelling language evaluation as well as BPMN. Their framework was later used for various other evaluations of BPMN and explored the limitations of BPMN as discussed in later studies like in [AK15].

Some BPMN evaluations are pattern-based (like workflow patterns [vdAtHKB03, WvdAD+05, RTHVDAM06, OAWtH15]) where control flow perspective and data flow perspective are used as a reference to evaluate the capabilities of the modelling language and find its limitations ([RRK07]). Although some of the studies discussed in this chapter were published in the past (like 0from BPMN 1.0), however, they are still valid; as indicated in Chapter 3, the core notation and representation of business processes for analysis are relatively unchanged in both versions (BPMN 1.0 and BPMN 2.0) over the years. In [GHA10] and [AK15], the authors evaluated BPMN 2.0 based on graphical notations (as discussed in [Moo09]) and from the cognitive aspect. Their studies also confirm the lack of constructs to represent the different aspects. In [ZL21], the authors conducted a systematic literature analysis and found limited tool support for the visual expressiveness of notations. In [RIRG06], the authors found a high degree of ontological completeness in BPMN; however, states of things can not be modelled with BPMN.

In [OHS02], the authors evaluate UML modelling language based on BWW-model. They present the result of systematic and iterative comparisons between 47 ontological concepts in the BWW-model and 216 modelling constructs in the UML, that is, concrete meta-classes in the UML-meta model, of which 67 were found to be significantly relevant for representing concrete problem domains.

Various BWW model-based evaluations are presented in the literature like [GI+05, RIRG06] and [RRIG09]. In [AK15], the authors introduce and evaluate the BPMN 2.0. they also discuss the current work in its evaluation.

In [AK15], authors inter-link two (BPMN-ArchiMate) models to fulfil the construct deficit (provide compliance related information in process models) to represent conceivable, lawful state and event spaces of the BWW model. In this work, we extend

BPMN with different notations for the performance evaluation to fulfil the construct deficits (concepts of real-system not represented) of a modelling language.

In [Pen16, Pen17], the authors found many limitations of BPMN especially in the context of process compliance with policies. Their studies also discuss the lack of BPMN representation for state law, history and events. In this work, we address such challenges and provide model completeness for process performance analysis by introducing new constructs.

7.7 Summary

The BWW model is used to analyse the meaning of modelling constructs for information system development and to evaluate how well these constructs provide value for development. Using the BWW model to evaluate modelling constructs from a performance perspective is the first effort in the literature. We want to represent the representation gap of BPMN. We want to show how this representational gap is overcome by our proposed patterns (extension example of BPMN using ABPML). Different BWW-based evaluations are discussed to present the limitations of BPMN.

An exciting area of research is performance representation. How can we use Bunge Wand Weber Method to evaluate the modelling language which serves the purpose to represent the performance? Future work is to discuss and assess Bunge Wand Weber method itself for performance evaluation.

Further work is needed to validate and refine the proposals modelling language, both analytically (using other ontologies and mathematical formalisms), and empirically.

8. Conclusion and Future Research

This chapter concludes our thesis and provides an outlook for future research in this domain. First, we summarize our thesis in Section 8.1, followed by Section 8.2, which provides the outlook for future research in this domain.

8.1 Conclusion

This thesis motivates for intuitive analytical modelling language in post-execution analysis of business processes. In this thesis, we provided the context of business processes, starting from vision to industrial automation. Characteristics of business processes are also discussed to understand the context for business process analysis and improvement. First, we discussed the research work in the area of business process modelling domain. Later, we focused on the evaluation of business processes in a post execution context. We provided a classification of elements for evaluation purposes and an analytical framework to improve the business process. We further focused on a representational part of the analytical framework.

We identified the challenges and open issues in modelling business processes, especially in the post-execution phase. We manifested that the modelling languages devised for information system design are insufficient for post-execution analysis phases and their representation. Several limitations of modelling languages are identified and discussed in detail with examples.

As part of our research, we aimed to minimize the gap between modelling language and post-execution analysis in order to improve business processes. For that purpose, we developed a design science artefact (extension of the modelling language) to solve the problem of performance analysis of a business process. This was achieved by presenting characteristics of the analytical modelling language and modelling patterns in the post execution analysis context. The proposed patterns were elaborated further by extending the modelling constructs of an existing modelling language (in this case, BPMN).

We used two evaluation methods (empirical and analytical) to evaluate the instantiated extension of BPMN. The empirical evaluation was carried out in an organization with the help of a case study. The case study results demonstrate that certain patterns significantly outperformed traditional methods. From the analytical perspective, we evaluated the proposed modelling extension using the BWW (Bunge-Wand-Weber) model, which also shows the advantages of the proposed modelling language.

8.2 Future Research

The work presented in this thesis serves as a foundation for future research on post execution analysis using business process models to improve business processes. We will briefly discuss some potential research areas below.

Analytical Framework for Improvement: We presented an analytical framework to evaluate business processes for improvement. In this thesis, we focused our research on the representational part of the framework; however, future research can be done with the help of a case study on different components of the framework.

Modelling Challenges and Characteristics: In this thesis, we presented different challenges of modelling languages with an emphasis on post execution analysis of business processes. As a consequence, we also defined different characteristics of analytical modelling languages. Future research should explore the limitations of modelling languages in post executional analysis context, as well as extend the characteristics of analytical modelling languages proposed in this work.

Patterns and Modelling Languages for Performance Analysis: In this research, we proposed six generic patterns for the evaluation of business processes. We used time and cost as the main aspects for this purpose and extended their combination as the colour pattern. However, the colour pattern can be problematic for colour-blinded users. Future research work should add additional patterns to our pattern catalogue for analysis and improvement purposes. It should also consider other aspects, such as location, involved business objects, and quality. We used these generic patterns to extend BPMN as an example in this research; similarly, different other business process modelling languages can also be extended in a similar manner. These extended modelling languages must be evaluated in practice as well.

Modelling Tool and Evaluation: We conducted an empirical evaluation in the form of a survey by comparing the traditional methods with our proposed extensions. A detailed evaluation supported by a modelling tool would be more suitable. For this purpose, our proposed extended meta model of BPMN can be used in Eclipse Modeling Framework, AdoXX, or in MetaEdit+ to create modelling language tool or existing modelling language tools can be extended with our proposed patterns by using BPMN-js [1]. The modelling tool can also help to analyse the historical data by presenting the data to the user for identification of deficiencies. In this work, we conducted our empirical study in one company and a general audience, such case studies can be conducted in different organizations. This will help to collect further requirements, which will extend the understanding in this domain.

[1]https://bpmn.io

A. Appendix

A.1 Questionnaire

In the following, we attach the questionnaire which was presented to the participants of two case studies.

Questionnaire

Dear Participant,

Thank you very much for participating in this survey.

The goal of this survey is to compare traditional business process evaluation method (e.g. bar chart, line chart) with a new method for business process improvement. We want to evaluate our proposed method and want to know which elements are appreciated by experts. We also want to take your feedback and want to extend the proposed method for better analysis and improvement.

We keep the anonymity of the participants and information collected will be handled in confidential way. The information is used only for research purpose and used in such a way that participant can not be identified.

The questionnaire will take 20-30 minutes to complete. Thank you in advance.

Azeem Lodhi

* Required

Information

In this section, we want to collect general information and your experience

1. Age?

Mark only one oval.

- ◯ 20 to 30 years
- ◯ 31 to 50 years
- ◯ over 50 years
- ◯ I do not want to provide

2. Gender?

Mark only one oval.

- ◯ Female
- ◯ Male
- ◯ Prefer not to say

3. Education?

Mark only one oval.

- Vocational training
- Under-graduate (Bachelor's)
- Graduate
- Ph.D.
- Other: ______________________

4. Organization affiliation type?

Mark only one oval.

- Company
- University employee
- Freelancer
- Student
- Other: ______________________

5. Current position in the organization? *

Mark only one oval.

- Project Manager
- Manager
- Process Expert
- Business Expert
- Academic Staff
- Student
- Other: ______________________

Performance Evaluation Experience

In this survey, we use the term performance evaluation in order to measure how good the objects are performing in the area under consideration (for example, sales or profit of a company, employee's performance, a particular process performance). Different KPIs (Key Performance Indicators) are used in different fields of business for this purpose.

6. How you rate your general expertise in performance evaluation?

Mark only one oval.

- Basic
- Moderate
- Expert

7. For how many years, you are evaluating performance?

Mark only one oval.

- Less than a year
- 1-4 years
- 5-10 years
- More than 10 years

8. At which evaluation level you are involved in organization? *

Mark only one oval.

- Overall business level
- Department level
- Process level
- Other: ____________________

9. How often you carry-out performance evaluation in a year? Example, No. of projects or frequency of evaluations in a year? *

Mark only one oval.

- less than 5
- 5 to 10
- 10 to 15
- above 15
- Other: ____________________

10. How many processes do these projects/business usually have?

Mark only one oval.

- No process level evaluation
- less than 10
- 10 -- 49
- above than 50

11. Which evaluation methods you normally use?

Check all that apply.

- [ ] Tabular charts (Tables, reports)
- [ ] Performance graphical charts (bar, line charts)
- [ ] Dashboards (textual + grahical mix)
- Other: [ ] ____________________

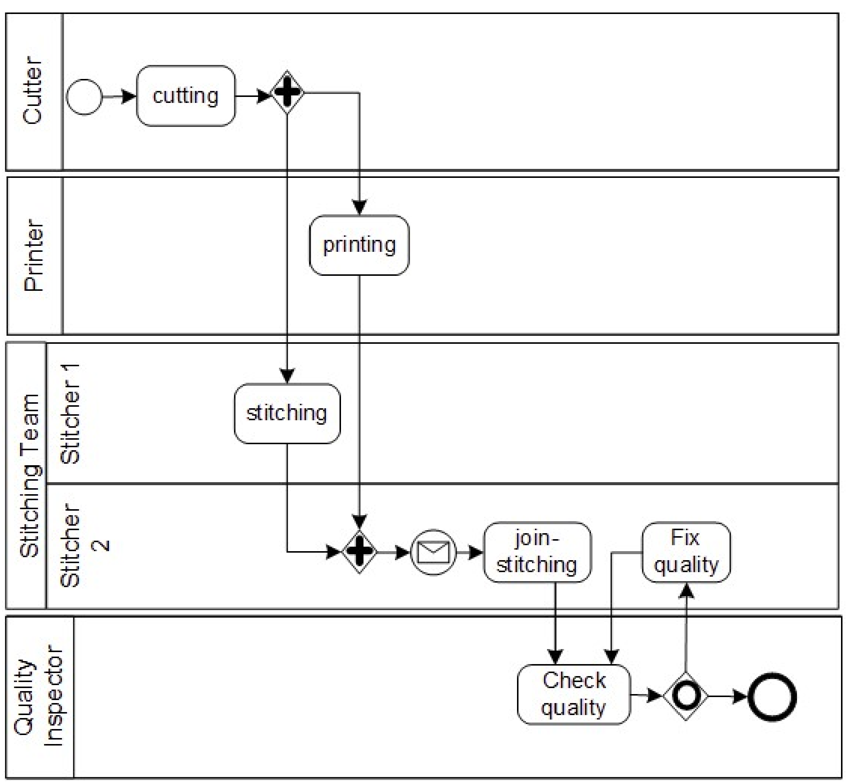
12. Which representations or visualization currently you use for business process analysis and improvement?

Evaluation and Improvement Methods Comparison	In this section, we present a case study that compares two methods by representing performance for process analysis and improvement. The first method is a traditional method (using bar charts, textual tables). In the second method, performance is represented with process models using extended Business Process Model and Notation (BPMN). We want to get your feedback about these two methods.

Scenario: Case Study - Product Manufacturing Example

Assume a company that manufactures soccer shirts according to customer's requirements using the following process. In the first step, raw materials (like fabric) is collected and then provided to workers. After receiving the raw material, it is cut into different shapes for further manufacturing steps. Each of these fragmented pieces correspond to different parts of a shirt e.g. sleeves, neck, back, front. After "cutting", certain pieces segregated from the fragmented bulk go for "printing" while the rest of the pieces go for "stitching" according to the design. In the third step, the printed parts are joined with the stitched parts via the step "join-stitching" to form a complete shirt. Now, the newly made shirt goes through "check quality" step carried out by a quality inspector. If the quality of the shirt meets the specification, then the shirt is packed. Otherwise, the quality is augmented via the sub process ``fix quality''. After raising the quality of the shirt, the cycle of quality control is repeated. This production process is represented using BPMN (Business Process Model and Notation) Standard.

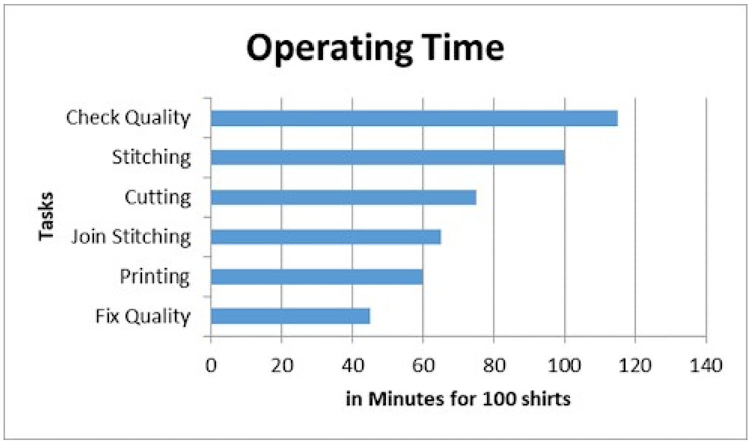
Manufacturing Process in BPMN



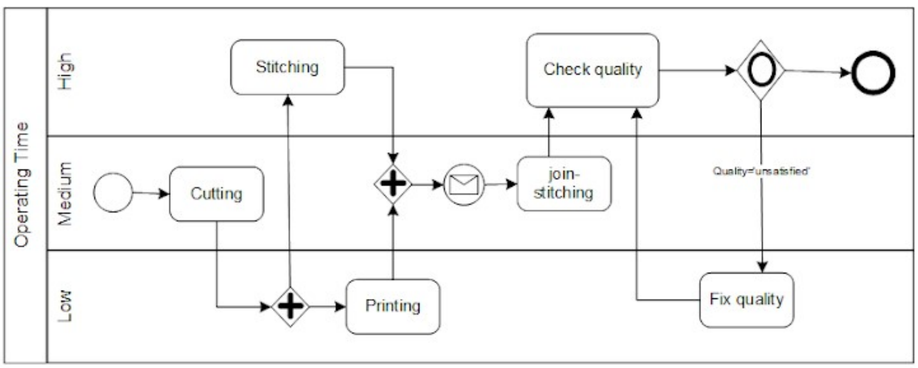
Task: Identify less efficient and less effective activities (from time and cost perspective) for business process improvement

In this evaluation, we will compare traditional bar chart representation and extended BPMN representation from time and cost perspective. First, we will compare from time and cost perspective individually, and then we will analyze them together.

1a) Bar Chart Representation (Time Perspective)



1b) Extended BPMN Representation (Time Pattern): Arranging activities based on time consumed as compared to target time

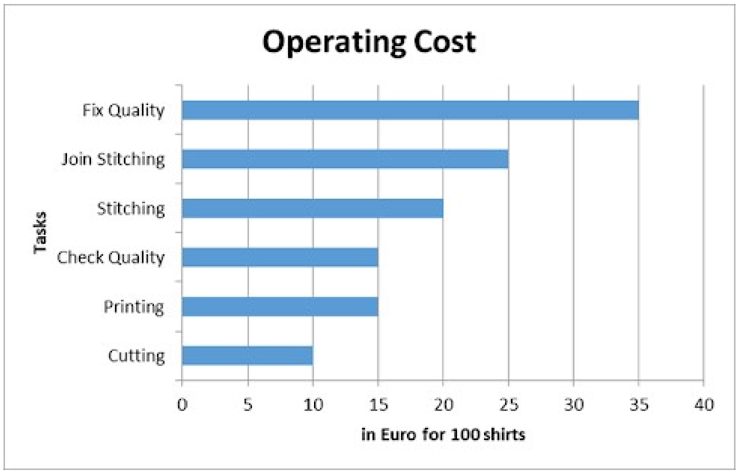


13. From the perspective of business process analysis and improvement, which form of representation is better in your opinion from time perspective? Kindly rate it by using the scale given below.

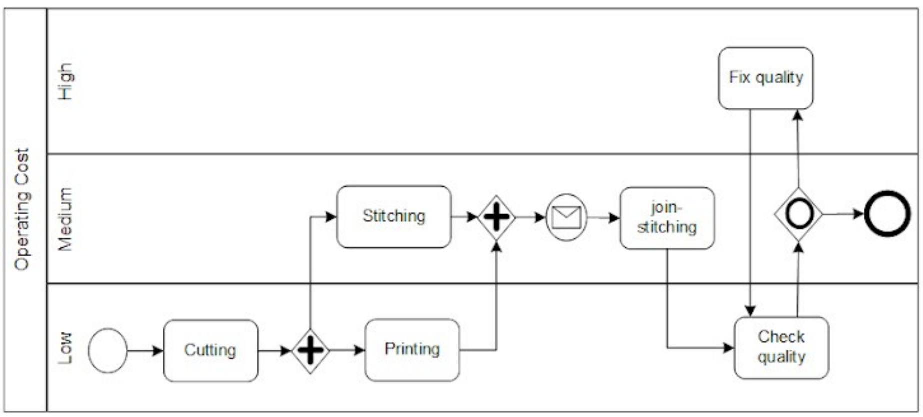
Mark only one oval per row.

	Very Dissatisfied	Dissatisfied	Satisfied	Very Satisfied
Bar chart representation				
Ext. BPMN representation				

2a) Bar Chart Representation (Cost Perspective)



2b) Extended BPMN Representation (Cost Pattern): Arranging activities based on cost incurred as compared to target cost

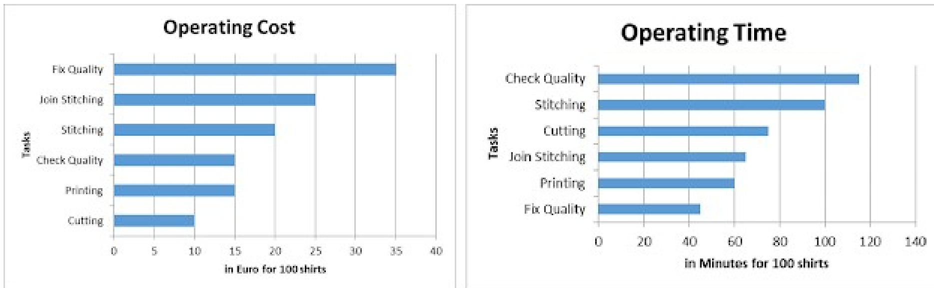


14. From the perspective of business process analysis and improvement, which form of representation is better in your opinion from cost perspective? Kindly rate it by using the scale given below.

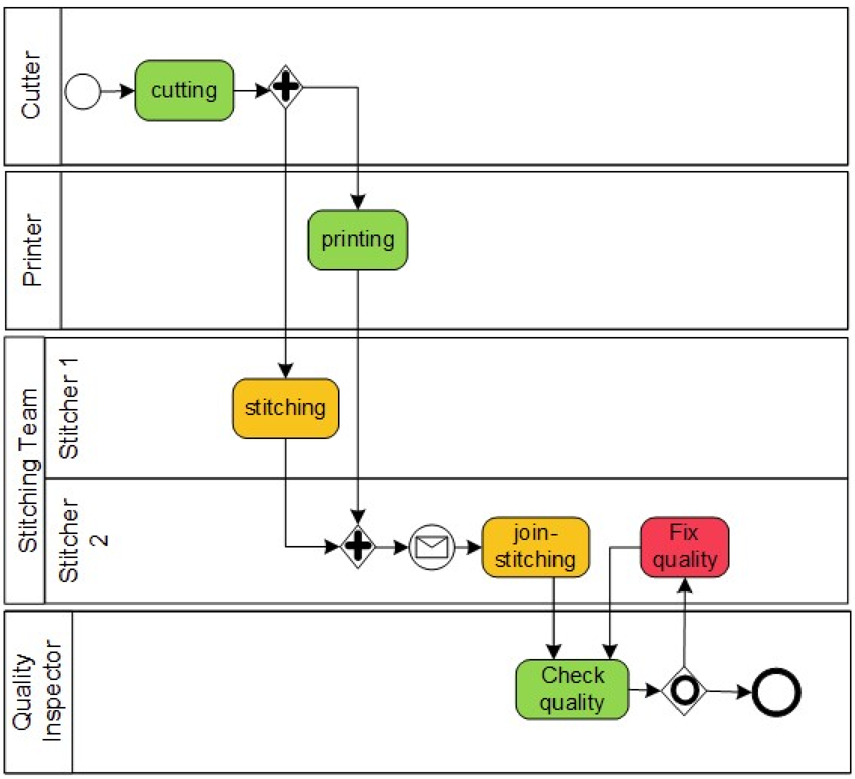
Mark only one oval per row.

	Very Dissatisfied	Dissatisfied	Satisfied	Very Satisfied
Bar chart representation	◯	◯	◯	◯
Ext. BPMN representation	◯	◯	◯	◯

3a) Bar Chart Representation: Evaluation of Activities (Time & Cost combined)



3b) Extended BPMN Representation: Evaluation of activities in Time & Cost perspective (colours representing performance of activities in process)



15. From the perspective of business process analysis and improvement, which form of representation is better in your opinion from time & cost perspective? Kindly rate it by using the scale given below.

Mark only one oval per row.

	Very Dissatisfied	Dissatisfied	Satisfied	Very Satisfied
Bar chart representation	◯	◯	◯	◯
Ext. BPMN representation	◯	◯	◯	◯

Task: Decision Points & Rules Description

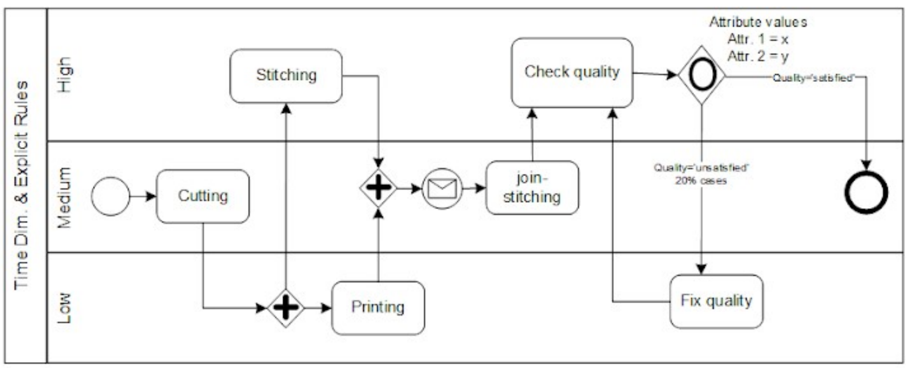
Decision points are stages in a process where certain conditions/rules are evaluated. Based on the results, certain path is selected and activities are carried out.

4a) Rules & Conditions in Documentation

Normally, rules and conditions are written in textual form in process documentation or user manuals. These are written as follow

Quality Check: Attribute 1 <= x and Attribute 2 <= y then "satisfied" else "unsatisfied".
where Attribute 1 and Attribute 2 are quality characteristics like stitching quality, cleanliness of shirt etc. and x & y are threshold values of attributes respectively.

4b) Extended BPMN representation on decision points (Rules Pattern)



16. From the perspective of business process analysis and improvement, which form of representation is better in your opinion from rules & condition perspective? Kindly rate it by using the scale given below.

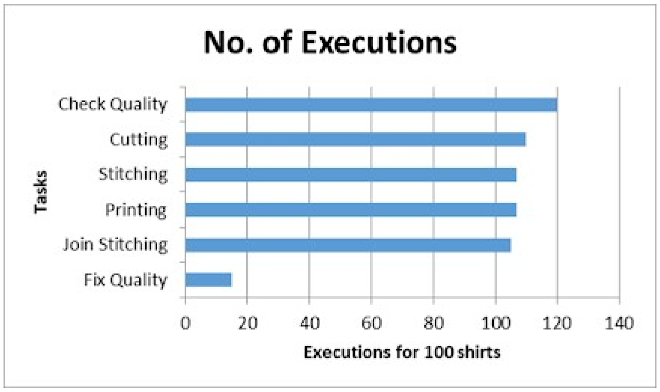
Mark only one oval per row.

	Very Dissatisfied	Dissatisfied	Satisfied	Very Satisfied
Text representation in documentation	⬭	⬭	⬭	⬭
Ext. BPMN representation in model	⬭	⬭	⬭	⬭

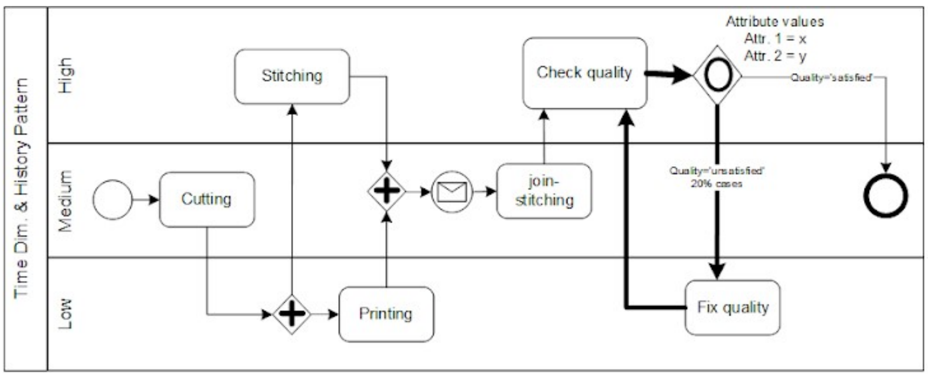
History of process & activities executions

History of a process can also be used for analysis & improvement purposes, e.g., how many times a particular activity or process is executed and it's result. The frequency or history of activities can be represented in the following ways.

5a) Bar chart representation (Frequency)



5b) Extended BPMN representation (History perspective): Arrows thickness



17. From the perspective of business process analysis and improvement, which form of representation is better in your opinion from history & path perspective? Kindly rate it by using the scale given below.

Mark only one oval per row.

	Very Dissatisfied	Dissatisfied	Satisfied	Very Satisfied
Bar chart representation	◯	◯	◯	◯
Ext. BPMN representation	◯	◯	◯	◯

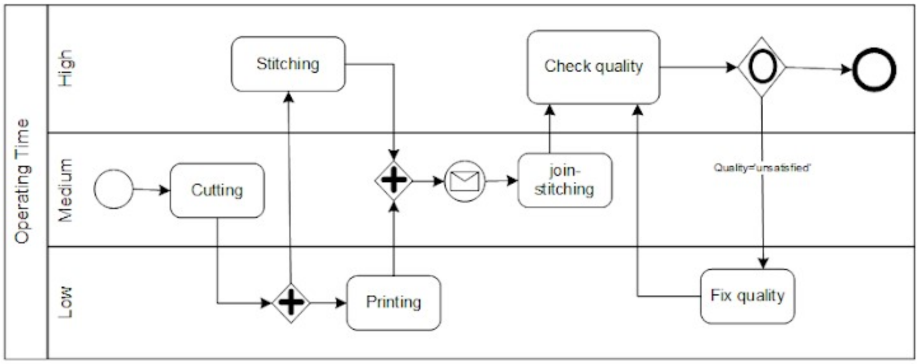
Business Process Evaluation Patterns

In previous section, we asked you about two methods comparisons. Now, we want to know about your experience/opinion regarding the patterns for evaluation and analysis. The above mentioned extended BPMN representations (or patterns) are part of Analytical Business Process Modeling Language (ABPML) and further described in this paper HICSS 2014 (http://wwwiti.cs.uni-magdeburg.de/iti_db/publikationen/ps/auto/LodhiKWST:14.pdf)

1. Time Pattern

Arranging activities in BPMN elements (e.g. Swimlanes) based on their performance in time perspective.

ABPML: Time Pattern



18. How do you rate time pattern and its application for business process improvement?

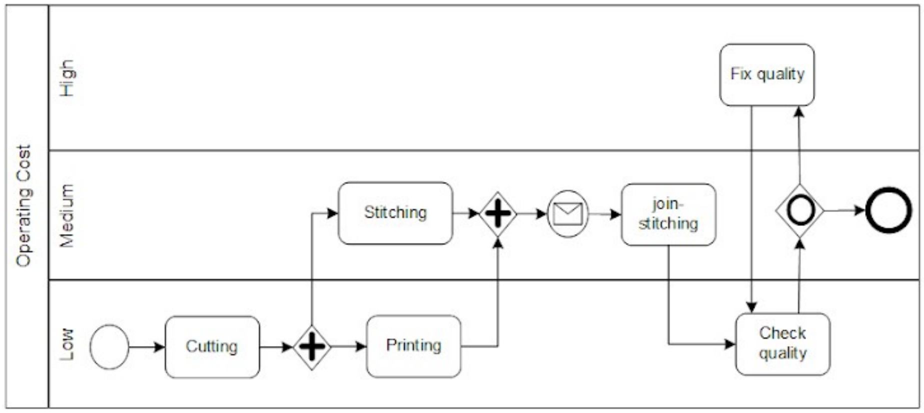
Mark only one oval per row.

	Strongly disagree	Disagree	Agree	Strongly agree
Ability to understand (Understandability)				
Support for the correct and timely decisions (Decision Support)				
Ability to be used in different areas (Scalability)				
Functionality for all managerial levels				

2. ABPML: Cost Pattern

Arranging activities in BPMN elements (e.g. Swimlanes) based on their performance in cost perspective.

Extended BPMN Representation (Cost Pattern)



19. How do you rate cost pattern and its application for business process improvement?

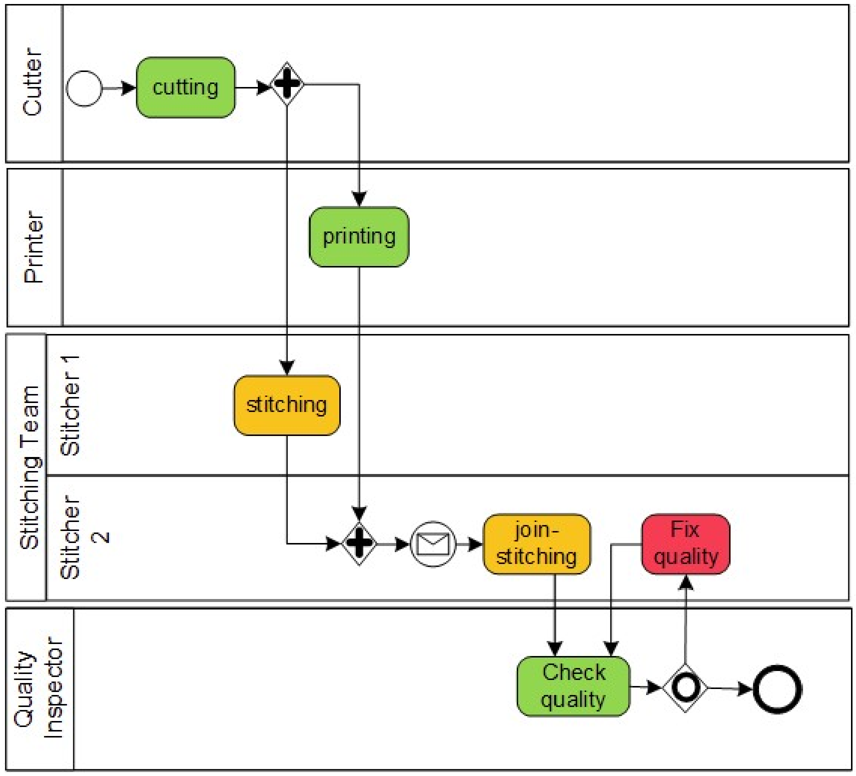
Mark only one oval per row.

	Strongly disagree	Disagree	Agree	Strongly agree
Ability to understand (Understandability)				
Support for the correct and timely decisions (Decision Support)				
Ability to be used in different areas (Scalability)				
Functionality for all managerial levels				

3. ABPML: Colour Pattern

Colouring BPMN elements (e.g. activities, connecting objects) based on their performance in time and cost perspective (productivity).

Extended BPMN Representation: Evaluation of Activities (Colour Pattern)



20. How do you rate colour pattern and its application for business process improvement?

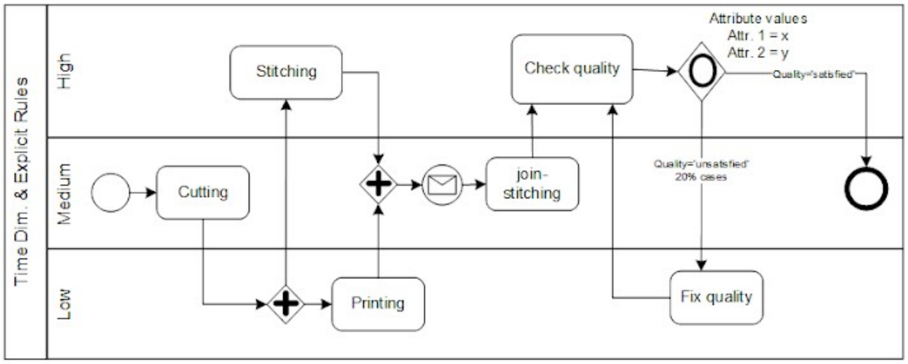
Mark only one oval per row.

	Strongly disagree	Disagree	Agree	Strongly agree
Ability to understand (Understandability)	⬭	⬭	⬭	⬭
Support for the correct and timely decisions (Decision Support)	⬭	⬭	⬭	⬭
Ability to be used in different areas (Scalability)	⬭	⬭	⬭	⬭
Functionality for all managerial levels	⬭	⬭	⬭	⬭

4. ABPML: Rules Pattern

Explicitly stating the information on BPMN elements (e.g. connecting objects, activities) for analysis.

Extended BPMN representation Decision Points (Rules pattern)



21. How do you rate rule pattern and its application for business process improvement?

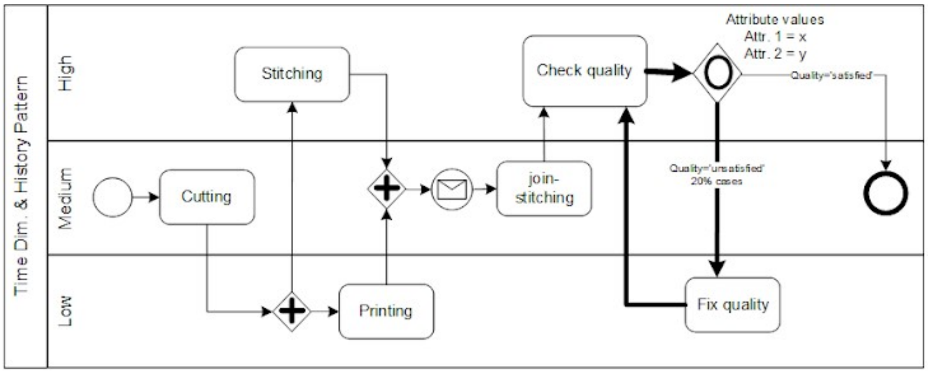
Mark only one oval per row.

	Strongly disagree	Disagree	Agree	Strongly agree
Ability to understand (Understandability)	◯	◯	◯	◯
Support for the correct and timely decisions (Decision Support)	◯	◯	◯	◯
Ability to be used in different areas (Scalability)	◯	◯	◯	◯
Functionality for all managerial levels	◯	◯	◯	◯

5. ABPML: History Pattern

Changing the size and width of BPMN elements (e.g. connecting objects, activities) based on their participation in process.

Extended BPMN representation (History/Path perspective)



22. How do you rate history/path pattern and its application for business process improvement?

Mark only one oval per row.

	Strongly disagree	Disagree	Agree	Strongly agree
Ability to understand (Understandability)	◯	◯	◯	◯
Support for the correct and timely decisions (Decision Support)	◯	◯	◯	◯
Ability to be used in different areas (Scalability)	◯	◯	◯	◯
Functionality for all managerial levels	◯	◯	◯	◯

Completed!

Thank you for your participation.

If you are interested in results of this questionnaire, you can provide your email.

You can also provide your feedback and comments about this questionnaire.

Best Regards,

Azeem Lodhi

23. Comments / Feedback?

24. Your Email ?

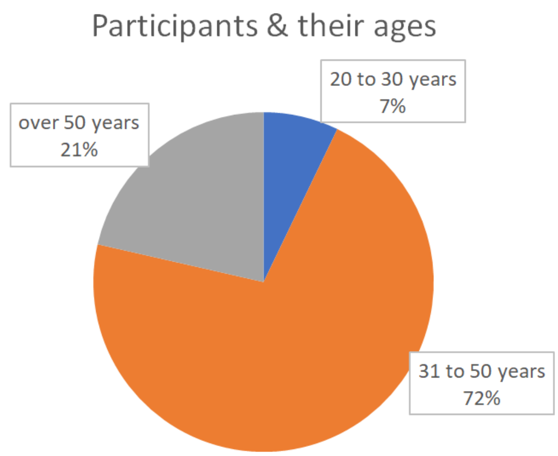


Figure A.1: Case Study 1: Ages of Participants

A.2 Results of Empirical Evaluation

This section shares the detailed results of our empirical evaluation carried out in two case studies (presented in Chapter 6).

A.2.1 Results of the Case Study 1

In the following, we present some further results of Case Study 1 as discussed in Section 6.2.1.

An interesting fact was about the age of the participants in the case study conducted in a organization. Most of the participants were between 31 to 50 years old like 72% whereas 21% were above than 50 years as shown in Figure A.1. Only 7% of participants were less than 30 years which was only one person in absolute numbers. The relation between age and their expertise was also confirmed as 79% participants have more than 5 years of experience.

In the survey, 64% of participants rated their expertise as an Expert-level whereas only 29% participants rated their expertise as moderate level. Only 7% rated their expertise as basic which correspond to the age demography very well. These demographic representations are shown in Figure A.2. Figure A.3 shows the combined representation of experience and their expertise as rated by the participants.

As the case study was carried out in a production company, therefore, most of the participants were involved at process level. Some of the participants were involved at project or organizational level both. However, these experts are mainly related to different projects in company (like maintenance, development, and implementation) and evaluate the performance respectively.

A.2.2 Results of the Case Study 2

In the following, we present some further results of Case Study 2.

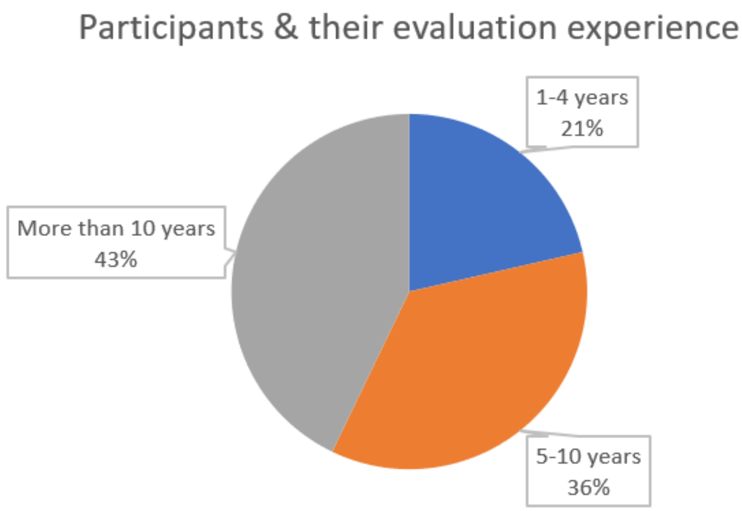


Figure A.2: Case Study 1: Experience of Participants

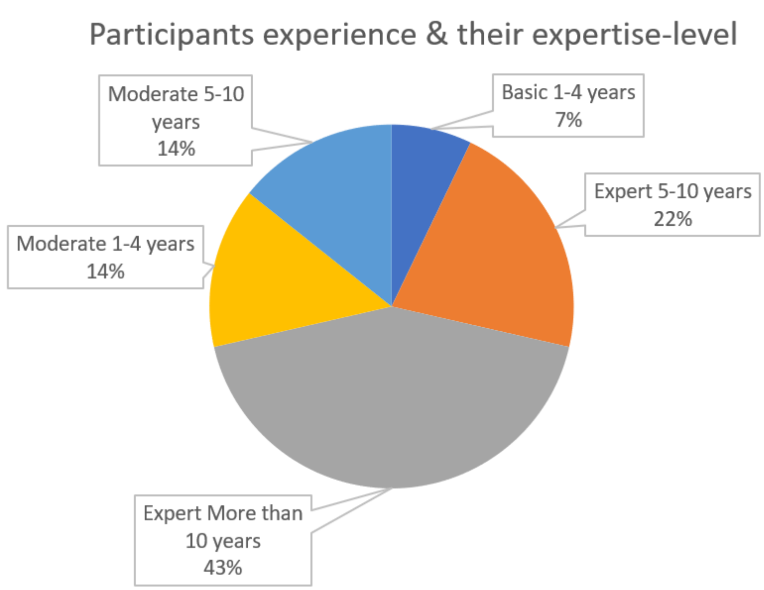


Figure A.3: Case Study 1: Experience and Expertise of Participants

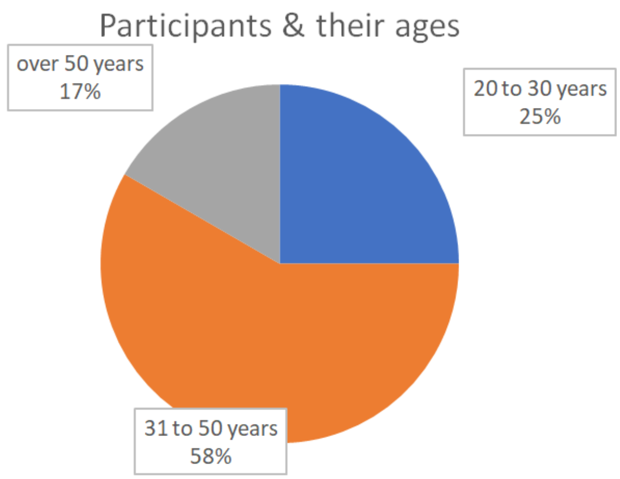


Figure A.4: Case Study 2: Gender Distribution of Participants

Figure A.4 shows that most of the participants (58%) were 31 to 50 years old. The two-age groups of 20 to 30 and over 50 years were represented 25% and 17% respectively. In this survey most of the participants were relevant and their working age including their experiences was above than 50 years. In this survey, 21% participants were student as well.

As discussed earlier in previous Section 6.1.1, the second part is related with experience relation with performance evaluation. Figure A.5 shows that most of the participant rate their expertise at moderate level (58%) and 25% at expert level. Only 17% of participant rate their expertise as basic. In general group, most of the participants are project manager and manager. They use to do evaluation, however, neither at process level nor using business process modelling techniques. This is the reason behind their feedback as moderate-level experience even after years of experience in their fields.

We received responses from participants performing different roles in companies like 29% process and business expert role, 21% projects manager, 21% student, 17% at managerial positions, and academic staff (12%) respectively as shown in Figure A.6.
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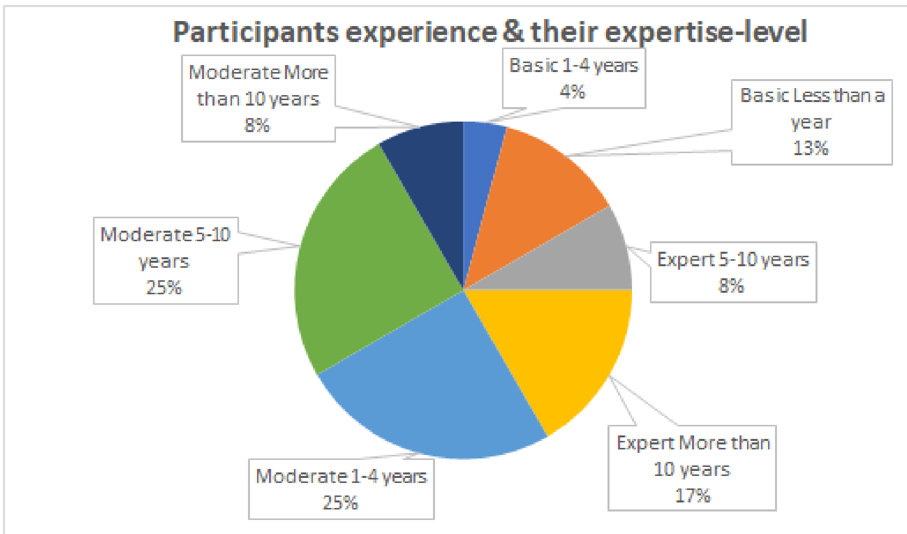

Figure A.5: Case Study 2: Experience and Expertise of Participants

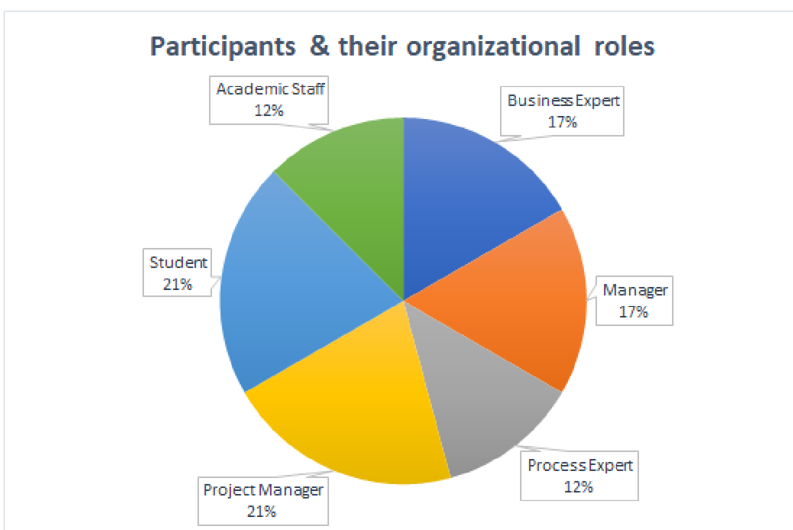

Figure A.6: Case Study 2: Roles of Participants in Organizations

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Ehrenerklärung

Ich versichere hiermit, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe; verwendete fremde und eigene Quellen sind als solche kenntlich gemacht. Insbesondere habe ich nicht die Hilfe eines kommerziellen Promotionsberaters in Anspruch genommen. Dritte haben von mir weder unmittelbar noch mittelbar geldwerte Leistungen für Arbeiten erhalten, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen.

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Azeem Lodhi