Dipartimento di Informatica, Bioingegneria,
Robotica ed Ingegneria dei Sistemi

Investigating business process elements: a journey from the field of Business Process Management to ontological analysis, and back

by

Greta Adamo

Theses Series **DIBRIS-TH-2020-XX**

DIBRIS, Università di Genova

Via Opera Pia, 13 16145 Genova, Italy http://www.dibris.unige.it/

Università degli Studi di Genova

Dipartimento di Informatica, Bioingegneria,

Robotica ed Ingegneria dei Sistemi

Ph.D. Thesis in Computer Science and Systems Engineering
Computer Science Curriculum

Investigating business process elements: a journey from the field of Business Process Management to ontological analysis, and back

by

Greta Adamo

May, 2020

Dottorato di Ricerca in Informatica ed Ingegneria dei Sistemi
Indirizzo Informatica
Dipartimento di Informatica, Bioingegneria, Robotica ed Ingegneria dei Sistemi
Università degli Studi di Genova

DIBRIS, Univ. di Genova
Via Opera Pia, 13
I-16145 Genova, Italy
`http://www.dibris.unige.it/`

Ph.D. Thesis in Computer Science and Systems Engineering
Computer Science Curriculum
(S.S.D. INF/01)

Submitted by Greta Adamo
DIBRIS, University of Genoa and Fondazione Bruno Kessler
`http://www.dibris.unige.it/`
`https://www.fbk.eu/it/`

Date of submission: May 2020

Title:
Investigating business process elements:
a journey from the field of Business Process Management to ontological analysis, and back

Advisors:
Chiara Ghidini, Fondazione Bruno Kessler, Trento, Italy
Chiara Di Francescomarino, Fondazione Bruno Kessler, Trento, Italy
Tutor:
Giorgio Delzanno, DIBRIS, University of Genoa, Genoa, Italy
Ext. Reviewers:
Pawel Garbacz, John Paul II Catholic University of Lublin, Lublin, Poland
Renata Guizzardi, Federal University of Espírito Santo, Vitória, Brasil
Fabrizio Maria Maggi, University of Tartu, Tartu, Estonia

Abstract

Business process modelling languages (BPMLs) typically enable the representation of business processes via the creation of process models, which are constructed using the elements and graphical symbols of the BPML itself. Despite the wide literature on business process modelling languages, on the comparison between graphical components of different languages, on the development and enrichment of new and existing notations, and the numerous definitions of what a business process is, the BPM community still lacks a robust (ontological) characterisation of the elements involved in business process models and, even more importantly, of the very notion of business process. While some efforts have been done towards this direction, the majority of works in this area focuses on the analysis of the behavioural (control flow) aspects of process models only, thus neglecting other central modelling elements, such as those denoting process participants (e.g., data objects, actors), relationships among activities, goals, values, and so on. The overall purpose of this PhD thesis is to provide a systematic study of the elements that constitute a business process, based on ontological analysis, and to apply these results back to the Business Process Management field. The major contributions that were achieved in pursuing our overall purpose are: (i) a first comprehensive and systematic investigation of what constitutes a business process meta-model in literature, and a definition of what we call a literature-based business process meta-model starting from the different business process meta-models proposed in the literature; (ii) the ontological analysis of four business process elements (event, participant, relationship among activities, and goal), which were identified as missing or problematic in the literature and in the literature-based meta-model; (iii) the revision of the literature-based business process meta-model that incorporates the analysis of the four investigated business process elements - event, participant, relationship among activities and goal; and (iv) the definition and evaluation of a notation that enriches the relationships between activities by including the notions of occurrence dependences and rationales.

Dedico questa tesi a colei che mi ha sempre supportata e c'è sempre stata, mia mamma.

Acknowledgements

I would like to thank my advisors from Fondazione Bruno Kessler who supported me during these years of PhD with great professionalism and patience. They provided the necessary knowledge, skills, and passion for research that I sincerely hope to inherit. Thanks also to my tutor from the department of DIBRIS at University of Genoa for all the information always provided to me and to all the PhD students of the program.

Thanks to my institutions, DIBRIS - University of Genoa and Fondazione Bruno Kessler, for giving me the opportunity to become a PhD student and change my life.

I would also like to thank my thesis reviewers whose thoughtful feedback has aided me in making this a more complete work.

The many excellent researchers and research groups who have collaborated with me as well as those who have co-authored the publications during my PhD also deserve thanks. In particular, several researchers at the ISTC-CNR Laboratory for Applied Ontology (LOA) influenced and helped to shape many core ideas expressed through this thesis also within the Knowledge-Aware Operational Support (KAOS) project. Thanks to these collaborations I better understand the value of working together towards common goals.

I would also like to thank the researchers that hosted me during my PhD visiting at University of Amsterdam for giving to me the possibility to grow scientifically and have so many new experiences.

Thanks to all the members of my research unit, Process & Data Intelligence (PDI), my colleagues and friends that accompanied me through these important years of my life with interesting deep (and shallow) discussions and laughter. Together is more fun!

I am also grateful to my partner for his love, great positivity end encouragement, and for believing in me and my ideas. Thanks also for all the fun and adventures that we continue to share together.

Vorrei infine ringraziare mia mamma che, come al solito, non ha mai smesso nemmeno un giorno di essere presente e di credere in me. Lei mi ha insegnato la costanza, l'impegno e ad essere concreta, ma senza mai dimenticare di sognare.

This PhD study has been a fantastic experience. The student that existed, me, has been transformed through these years to become a researcher, me.

Thanks to all of you!

Table of Contents

Chapter 1

Introduction

This Chapter is dedicated to the general introduction of this PhD thesis. In particular, we start the Chapter with the description of the context and the motivations of this research (Section 1.1), then we introduce the goals that guided the thesis (Section 1.2) and how we reached them by means of the research tasks (Section 1.3). We conclude with the structure of the thesis (Section 1.4) and the list of publications (Section 1.5).

1.1 Context and motivations

Business process modelling languages (BPMLs) typically enable the representation of business processes via the creation of process models, which are constructed using the elements and graphical symbols of the BPML itself. A process model is a conceptual\abstract representation of a business process, whose goal is to describe or prescribe a real process by specifying how the process should\could\might be performed.

Business process modelling languages enable the creation of process models by exploiting graphical symbols to denote the key elements to be represented. Examples of elements of a business process are the sequence of activities to be executed (the so-called control flow), the actors involved in the process, the data objects required/manipulated by the activities, message exchanges, and so on. If we focus on typical business-to-consumer (B2C) scenarios, examples of business process modelling languages include well-known imperative languages such as the Business Process Model and Notation (BPMN)[1] [OMG11a], the Unified Modeling Language Activity Diagram (UML-AD)[2] [OMG11b], and the Event-driven Process Chain (EPC)[STA05], as well as

[1] http://www.bpmn.org/
[2] https://www.omg.org/spec/UML/2.0/About-UML/

declarative notations such as the Case Management Model and Notation (CMMN)[3], and DECLARE [PSvdA07].

Despite the wide literature on the execution semantics of business process modelling languages, on the comparison between graphical components of different languages [SAJ+02, LK06, MTJ+10a], on the development and enrichment of new and existing notations, and the numerous definitions of what a business process is (see, e.g., [Dav93, HC93, JMPW93, Wes12b]), the BPM community still lacks a robust (ontological) characterisation of the elements involved in business process models and, even more importantly, of the very notion of business process. While some efforts have been done towards this direction (see, e.g., [SBM14] for an investigation of the ontological commitments of activities and events in BPMN), the majority of works in this area focus on the analysis of the behavioural (control flow) aspects of process models only, thus neglecting other central modelling elements, such as those denoting process participants (e.g., data objects, actors), relationships among activities, goals, values, and so on.

This lack of investigation of a wide set of elements that constitute a business process model is an opportunity for carrying out interesting research. The growth of approaches and tools aiming at supporting business processes in a multi-perspective manner by looking beyond the control-flow view and including other dimensions, such as the data, organisational and goal oriented ones, shows that the time is now ripe to focus on an investigation of different types of process elements also at the conceptual level. Indeed, even though all the most popular definitions of business process contain aspects that go beyond the control flow (see e.g., [Dav93, HC93, JMPW93, Wes12b]), some of these aspects are still neglected, or not clearly described.

This lack of investigation of business process elements also raises several challenges for the Business Process Management community. By looking at the literature we identified the following ones:

1. A reference meta-model that clarifies the elements that constitute a business process is missing. As a result, several heterogeneous meta-models, often based on intuitive and even conflicting semantics, have been proposed in the literature either independently or as the backbone of business process modelling languages. While a certain degree of flexibility between the meta-models of different representation languages can be expected, it would be nevertheless desirable that they would agree on what core modelling elements of business process are. A reference meta-model could help to define what business process in a clear manner.

2. The meaning of business process modelling elements is often unclear and based on an intuitive semantics. As a result certain elements may be semantically overloaded, while others may be semantically unspecified. An example of the first problem is given by the term "event" in well-known business process modelling languages that sometimes is used

[3] https://www.omg.org/spec/CMMN/About-CMMN/

in a similar way than the label "activity". An example concerning the second problem is the label "actor". Indeed, in some notations, it can be used to represent both, the role played by an individual as well as the person. Providing a better understanding of the business process modelling elements we are using is important to have a clearer idea of the world we would like to represent. These clarifications could lead to less ambiguous meta-models and models as well as to the improvement of business process modelling notations which could facilitate the modelling activities.

1.2 Objectives

The purpose of this thesis is to address the challenges mentioned above by providing a systematic and comprehensive study of the elements that constitute a business process by analysing problematic business process elements from an ontological point of view, and by applying these ontological analysis results back to the Business Process Management field so that they can be useful within this community. In a few words, we aim at: (i) picking up some challenging issues concerning business process modelling from the Business Process Management research area, (ii) analysing them using ontological analysis approach, and (iii) bringing the results back to the Business Process Management community so that they can provide a starting point for being useful in practice. More in detail, the research goals of this PhD thesis are:

- **GOAL 1:** *to develop a business process meta-model grounded in the Business Process Management literature which includes the fundamental elements of a business process*;
- **GOAL 2:** *to analyse the meta-model's elements from an ontological perspective*;
- **GOAL 3:** *to apply the results of ontological analysis back to the field of Business Process Management*.

Compared to **GOAL 1** and **GOAL 2**, **GOAL 3** is expressed in broad terms, and indeed resembles more a wish than a real goal. To make it more concrete, in this thesis we do not address **GOAL 3** as such but we replace it with two sub-goals:

- ***GOAL 3.1:*** *to enrich the business process meta-model with the outcomes of ontological analysis*;
- ***GOAL 3.2:*** *to incorporate some results of the ontological analysis into a notation for modellers and analysts and to evaluate its usage*.

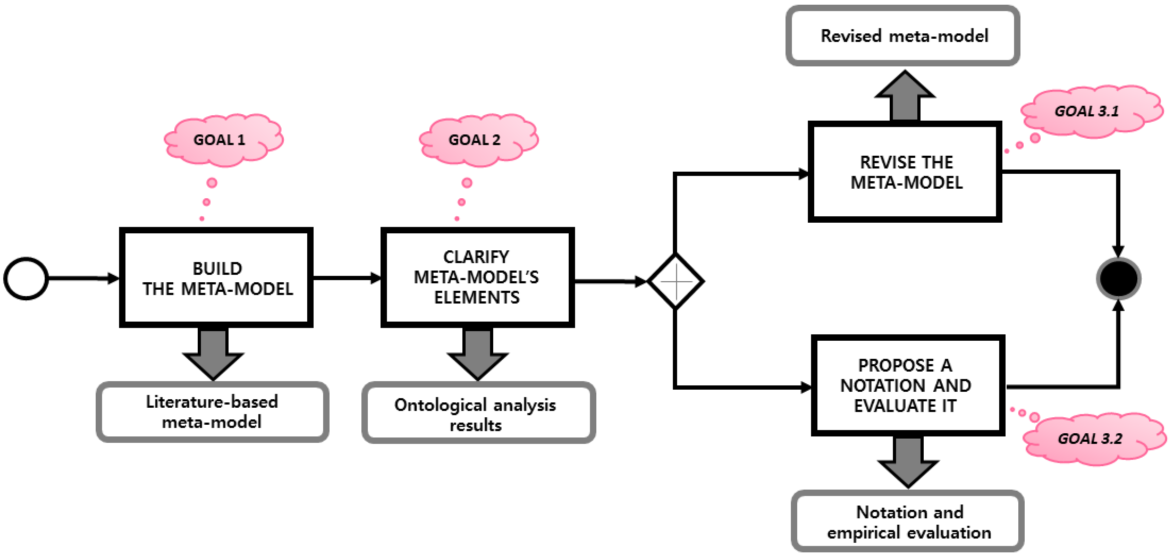


Figure 1.1: Tasks and outcomes of the thesis.

1.3 Realising the goals: tasks, outcomes, and contributions

This Section describes the tasks that we performed to achieve the four goals of this PhD thesis. Each goal is associated with a research ***TASK*** which produces an ***outcome***. Figure 1.1 depicts the process of the four tasks and associated outcomes; moreover each task is connected to a pink cloud which refers to its corresponding goal.

- ***TASK 1:*** The first task is to *build the meta-model* and is associated with **GOAL 1**. Rather than proposing a meta-model from scratch, we decided to first investigate what was available in the literature. We decided to take a systematic data driven strategy which is based on an extensive and Systematic Literature Review (SLR) of existing meta-models found in the literature and then on the extraction of the most recurrent entities and relations from the identified meta-models. The Systematic Literature Review had the objective of identifying a literature-based meta-model (*LB meta-model*) which would act as a starting point to understand and clarify which elements characterise a business process and how they can be understood. The ***outcome*** of this task consists in the construction of the *LB meta-model*.
- ***TASK 2:*** **GOAL 2** is reached by means of the second task to *clarify the meta-model's elements*. The task was defined in order to understand what the typical business process model elements denote. To choose the elements, we decided to start from the ones identified in the *LB meta-model* as problematic. The kind of clarification we offer is ontological: it is focused on the analysis of the entities, their properties\qualities and relations. The ***outcome***

of this task consists in four ontological analysis results. They concern the elements: events, participants, relationships between activities (i.e., occurrence dependences and rationales), and goals.

- ***TASK 3:*** The task *revise the meta-model* is associated with ***GOAL 3.1***. This task has the purpose of refining the *LB meta-model* with some results of the ontological analysis performed in ***TASK 2***. The ***outcome*** associated with this task is the re-factoring of the *LB meta-model* enriched with: a clarification on the use of the label "event" and its relation with activities and states, a revision of the meta-model in its parts that represent the process participants, the addition of different flow elements, and finally the enrichment of the meta-model with the classification of business process goals.
- ***TASK 4:*** The last task of the thesis is to *propose a notation and evaluate it* in order to achieve ***GOAL 3.2***. In this task we are focused on people, in particular modellers and analysts, demonstrating how ontological analysis outcomes, in particular the one concerning the relationships among activities (occurrence dependences and rationales), could facilitate and support them in the activities of business process *redesign* and *comprehension*. The ***outcome***s of this task are a new modelling notation and its evaluation using an empirical study.

Contributions of the thesis. The purpose of this thesis is to provide a systematic study of the elements that constitute a business process, based on ontological analysis, and to apply these results back to the Business Process Management field. The major contributions of this research work that were achieved in pursuing our overall purpose are:

- A first comprehensive and systematic investigation of what constitutes a business process meta-model in the literature, and a definition of what we call a literature-based business process meta-model (*LB meta-model*) starting from the different business process meta-models proposed in the literature. This investigation had the objective of (i) identifying which elements constitute a business process according to the literature; and (ii) how these elements are understood in the BPM research field. Moreover, the production of a single meta-model that combines different conceptualisations of business processes enabled us to identify discrepancies and inconsistencies originated by heterogeneous (and often blurred or conflicting) views on business process elements.
- A thorough investigation of four business process elements, mainly based on ontological analysis. The analysis and clarification of these elements (event, participant, relationship among activities, and goal), which were identified as missing or problematic in the literature and in the literature-based meta-model, can provide a step forward towards a better understanding of what constitutes a business process.

- Two efforts to bring the results of the ontological analysis back to the Business Process Management field. The first effort consists in the revision of the literature-based business process meta-model that incorporates the analysis of the four investigated business process elements - event, participant, relationship among activities and goal. This contribution goes into the direction of producing a reference business process meta-model. The second effort consists in the definition and evaluation of a notation that enriches the meaning of relationship between activities by including the notion of occurrence dependences and rationales. This contribution goes into the direction of producing a notation based on a solid analysis, which can support business process modellers and analysts in the activities of business process (re)design and comprehension.

1.4 Structure of the thesis

Chapter 2 contains an overview of the the background notions necessary to understand the research reported in the thesis. First, we illustrate some fundamental notions in the fields of business process, business process modelling, modelling languages, and meta-modelling. Second, we provide an overview of the Systematic Literature Reviews. Third, we summarise key notions concerning ontologies and ontological analysis. Finally, we provide a short description of empirical studies and evaluations.

Chapter 3 contains the research methodology that we adopted for each task in Section 1.3.

In Chapter 4 we describe the steps we performed in ***TASK 1***. We present the phases of the Systematic Literature Review on business process meta-models and its results. In particular we illustrate the research questions of the study, the protocol of the review, the extraction of business process entities and relations, and how we combine them to develop the *LB meta-model*. We also identify and list the limitations of the Systematic Literature Review, some critical observations concerning the *LB meta-model*, and we provide a comparative assessment of the meta-model using five popular business process modelling languages.

Chapter 5 contains the ontological analysis of the business process modelling elements, which constitutes ***TASK 2***. It starts from the use of the term "event" in the *LB meta-model* and then in the BPM community. This first part allows us to clarify other entities which are related with events, such as activities and states. The second part focuses on the notion of business process participants, their classification and their relations with other entities. The third part is centred on the relationships between business process activities that go beyond the typical temporal sequence flow relationships. The fourth part regards the notion of business process goal. At the end of the Chapter we describe the limitations of the analysis presented in this part of the thesis and we discuss the results by situating them in the context of business process modelling languages.

Chapter 6 is dedicated to ***TASK 3***. We revise the *LB meta-model* by manually adding to it some of the ontological analysis outcomes. This enrichment concerns: (i) the element event and its related elements (activities and states); (ii) the process participants, in particular resources, actors, artefacts, and roles; (iii) the occurrence dependence between activities, as a form of ontological constraint; and (iv) a classification of types of business process goals.

In Chapter 7 we execute ***TASK 4*** by proposing: (i) a new notation that allows us to represent occurrence dependence and rationales between activities; (ii) two use case scenarios that show the usefulness of the new notation for business process *documentation* and *redesign*; and (iii) an empirical *user study* that evaluates the actual effectiveness of the new ontologically-based notation for business process modellers and analysts.

Finally, we provide an overview of the related works in Chapter 8 and we conclude with some further remarks in Chapter 9.

1.5 List of publications

Publications related to the PhD thesis are:

- Under review:
  - **Greta Adamo**, Chiara Ghidini, and Chiara Di Francescomarino. What's My Process Model Composed of? A Systematic Literature Review of Meta-Models in BPM. *International Journal on Software and Systems Modeling (SoSyM)* (under major revision).

    This paper describes the Systematic Literature Review of business process meta-models provided in Chapter 4 and Appendix A.
- Accepted:
  - **Greta Adamo**, Chiara Ghidini, and Chiara Di Francescomarino. Digging into Business Process meta-models: a first ontological analysis. Accepted to *CAiSE 2020*.

    This paper describes the work presented in Chapters 4, 5, and 6, in which we provide: the meta-model inspired from the literature, its analyses, the ontological analyses of "event" and some organisational entities, in particular the resources, and their refactoring.
- Published:
  - **Greta Adamo**, Stefano Borgo, Chiara Di Francescomarino, Chiara Ghidini, and Nicola Guarino. On the notion of goal in business process models. In Chiara Ghidini, Bernardo Magnini, Andrea Passerini, and Paolo Traverso, editors, AI*IA

2018 - *Advances in Artificial Intelligence - XVIIth International Conference of the Italian Association for Artificial Intelligence*, Trento, Italy, November 20-23, 2018, Proceedings, volume 11298 of Lecture Notes in Computer Science, pages 139–151. Springer, 2018.

The research included in this paper concerns the analysis of business process goals presented in Chapter 5.

- **Greta Adamo**, Stefano Borgo, Chiara Di Francescomarino, Chiara Ghidini, Nicola Guarino, and Emilio M. Sanfilippo. Business process activity relationships: Is there anything beyond arrows? In Mathias Weske, Marco Montali, Ingo Weber, and Jan vom Brocke, editors, *Business Process Management Forum - BPM Forum 2018*, Sydney, NSW, Australia, September 9-14, 2018, Proceedings, volume 329 of Lecture Notes in Business Information Processing, pages 53–70. Springer, 2018.

  This paper reports on the ontological analysis of business process activity relationships (occurrence dependences and rationales) that can be found in Chapter 5 and the application scenarios of occurrence dependences and rationales for business process documentation and redesign which inspired part of Chapter 7.

- **Greta Adamo**, Stefano Borgo, Chiara Di Francescomarino, Chiara Ghidini, Nicola Guarino, and Emilio M. Sanfilippo. Business processes and their participants: An ontological perspective. In Floriana Esposito, Roberto Basili, Stefano Ferilli, and Francesca A. Lisi, editors, *AI*IA 2017 Advances in Artificial Intelligence - XVIth International Conference of the Italian Association for Artificial Intelligence*, Bari, Italy, November 14-17, 2017, Proceedings, volume 10640 of Lecture Notes in Computer Science, pages 215–228. Springer, 2017.

  This paper investigates the notion of business process participants, which is part of Chapter 5. It also contains some background notions of business processes and business process modelling included in Chapter 2. The comparative analysis of the *LB meta-model* (see Chapter 4 and Appendix C) found in this thesis is the evolution, extension, and application of the comparison between business process modelling languages from this paper.

- **Greta Adamo**, Stefano Borgo, Chiara Di Francescomarino, Chiara Ghidini, Nicola Guarino, and Emilio M. Sanfilippo. Business process languages: An ontology-based perspective. In Stefano Borgo, et al., editors, *Proceedings of the Joint Ontology Workshops 2017 Episode 3: The Tyrolean Autumn of Ontology*, Bozen-Bolzano, Italy, September 21-23, 2017, volume 2050 of CEUR Workshop Proceedings. CEUR-WS.org, 2017.

  In this paper we further extend the work on business process participants and we introduce the contextual analysis between participants and business process modelling languages[4] as found in Chapter 5. Part of this work is also used to introduce some no-

[4]Note that the contextual analysis between business process participants and business process modelling languages

tions on the fields of business processes and business process modelling (see Chapter 2). The paper presents the comparison between the business process modelling notations that represents the initial development for the comparative analysis performed between the *LB meta-model* and the notations shown in Chapter 4 and Appendix C.

Works not related with the PhD thesis:

- Leysan Nurgalieva, Marcos Baéz, **Greta Adamo**, Fabio Casati, and Maurizio Marchese. Designing interactive systems to mediate communication between formal and informal caregivers in aged care. *IEEE Access*, 7:171173–171194, 2019.
- **Greta Adamo**, Mark Mushiva, and Max Willis. Persuasion and Empathy in Computer Games, An Ontological Perspective. *In The 12th International Conference on the Philosophy of Computer Games*, 2017.[5]
- **Greta Adamo**, Stefano Borgo, Chiara Di Francescomarino, Chiara Ghidini, and Marco Rospocher. BPMN 2.0 choreography language: Interface or business contract? In Stefano Borgo, et al., editors, *Proceedings of the Joint Ontology Workshops 2017 Episode 3: The Tyrolean Autumn of Ontology*, Bozen-Bolzano, Italy, September 21-23, 2017, volume 2050 of CEUR Workshop Proceedings. CEUR-WS.org, 2017.

has been further developed in this thesis compared with the one included in this paper.

[5]The paper "Persuasion and Empathy in Computer Games, An Ontological Perspective" was presented at a conference without proceedings.

Chapter 2

Background

THIS Chapter introduces the notions that stand behind this research thesis. Since the topic of the thesis lies across different research areas, the content of this Chapter spans across different theoretical and application oriented fields.

The Chapter is articulated as follows: Section 2.1 provides a cliffs note of the basic concepts concerning the business process modelling field. Section 2.2 describes what a Systematic Literature Review is. Section 2.3 deals with the role of ontology in philosophy, in computer science, and as a methodological tool. Finally, Section 2.4 outlines the main aspects related to empirical studies.

2.1 Business process modelling

This Section introduces: the most popular and recent definitions of business processes; the main techniques and paradigms proposed in literature focusing on specific notations. The final part of the Section is dedicated to an overview of meta-modelling in business process modelling.

2.1.1 On the definition of business process

The notion of what a business process is has changed over time according to the way business processes were understood both in research and in the actual organisations [LDL03].

Davenport [Dav93] defines a business process as:

> *a structured, measured set of activities designed to produce a specific output for a particular customer or market. [. . .] 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.

Another definition is provided in Hamer and Champy in [HC93] where business processes are:

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

A similar perspective is taken by Johansson [JMPW93] who defines a business process as:

a set of linked activities that take an input and transform it to create an output. Ideally, the transformation that occurs in the process should add value to the input.

Finally, a more modern and comprehensive definition is presented by Weske in [Wes12b] where business processes are:

a set of activities that are performed in coordination in an organizational and technical environment. These activities jointly realize a business goal. Each business process is enacted by a single organization, but it may interact with business processes performed by other organizations.

By analysing these definitions we can divide them in two groups. The first three see a business process as composed by a set of (ordered) *activities* that aim to transform an *input* in an *output* which is of *value* for (or is desired by) a customer or market. The most recent definition replaces this notion of "output for someone" with the stronger notion of business *goal*, thus better empowering and taking into account also the goals of the organisation where the process is enacted together with the desires of the customer(s) and markets.

2.1.2 Business process modelling languages

All the elements that constitute business processes as defined in the previous Section are captured by business process *models* specified in a business process modelling *language*. In past years, there has been a growing effort in providing business process modelling techniques, methodologies, as well as tools and approaches for the representation of business process models [As04]. In order to identify and capture the complexity of business processes and select aspects and concepts which are important in business process models, different business process modelling languages have been proposed [Had06, MTJ^{+}10b].

In the literature, several classifications of business process modelling languages exist [LK06, RRIG09, KLL09, NLM07]. To provide an illustration of the variety of categorizations, and of the modelling differences among business process modelling languages, we illustrate here the following ones:

1. **Descriptive languages VS formal languages.** Descriptive languages are a class of diagram-based languages. Examples are EPC [STA05], UML-AD [Spe07] and BPMN [Mod11]. The diagrams specify the process definition and are often conceived as user-friendly languages which lack of a semantic formalization [DvdAtH05]. Formal languages are based on mathematical or logic-based languages and present a clear formal semantics. Being formal, they provide the basis for a precise formal analysis but they are not easy to use for business practitioners (e.g., Petri-net, Pi-Calculus).

2. **Imperative languages VS declarative languages.** Declarative languages specify business processes through a set of constraints (e.g., DECLARE and CMMN[1]) [PSvdA07]. In contrast, in imperative processes all the states are explicitly specified (e.g., BPMN, EPC, UML-AD).

3. **Data-centric languages VS activity-centric languages.** Data-centric languages are focused on the representation of the life-cycle of data entities [CH09] (e.g., CMMN). Activity-centric languages represent business processes primarily as flow of activities (e.g., BPMN, UML-AD, EPC).

In the following we illustrate the five business process modelling languages (BPMLs) we mostly use in the thesis. We have chosen these languages as they are a mixture between highly popular languages and languages that follow different approaches towards modelling.

BPMN (2.0). It is a standard language, proposed by the Object Management Group (OMG), to design business processes. BPMN [Mod11] defines a Business Process Diagram (BPD) which includes a set of graphical constructs divided in: (i) flow objects, (ii) artefacts, (iii) connecting objects, and (iv) swimlanes. Flow objects define the behaviour of a business process. They are divided into events, activities and gateways. Events represent things that happen during a process; they are classified into start, intermediate and end events. An activity is a generic term that is used to indicate the work to be performed. It can be either atomic (task) or compound (sub-process). A gateway determines the forking, merging or joining of paths. Artefacts in BPMN are: text annotation, group, and data object, including its explicit modelling components (e.g., data inputs, data output and data stores). Flow objects are inter-linked through connecting objects which are not further discussed here. Swimlanes are used to specify who is responsible for the execution of a certain activity.

Following the classification provided before, the BPMN 2.0 is a descriptive and imperative language which is mainly focused on an activity-centric representation.

[1] https://www.omg.org/spec/CMMN/About-CMMN/

UML-AD. It is one of the diagram families of the OMG standardized UML language [Spe07][2], whose purpose is to describe the control and data flow as a sequence of activity nodes connected by activity edges. The nodes responsible for describing the control flow are the action nodes and the control nodes. While the former represent atomic steps within an activity, the latter allow for controlling the execution flow by means of the AND, OR or XOR logical operations. Additional control flow nodes are used to depict the initial and final nodes of process models. Object nodes and object flows are the main UML-ADs constructs describing the data flow. The former represent objects at a given point of the flow and, as such, they can also have an associated state. The latter are instead used for connecting object nodes to actions. Activity partitions are a mechanism for grouping activity nodes that have common characteristics. They are mainly used to define organizational units. Finally, the notation allows for specifying activity pre- and post-conditions, for instance, by annotating activity edges with guards.

The UML-AD, similarly to BPMN, is a descriptive and imperative language that provides an explicit representation of the organization and it is centred on the representation of activities (activity-centric).

EPC. It is a modelling language developed in the early 1990s as part of the Architecture of Integrated Information Systems (ARIS) framework [Sch02b]. Three types of nodes are responsible for describing the control flow: function, event and logical operators. Function nodes represent atomic activities and can be considered as the "active" part of the control flow; event nodes stand for the states in which a process happens to be and can be therefore considered as the "passive" part of the control flow. Functions and events alternate, capturing the intuition that states lead to activities, while activities generate states. Finally, the XOR, AND and OR logical operators allow for controlling the execution flow.

According to the above classification, EPC is an imperative and descriptive language which is focused on representing the sequences of activities in a business process (activity-centric).

CMMN. It is a OMG standard for the declarative representation of process models. Its main modelling construct is the case, which is described by a case diagram. Differently from the previous languages, CMMN follows a declarative approach. Thus, rather than describing all the allowed flows of a process from the start to the end, it models cases composed of process segments (called stages) and tasks. A case plan model contains: (possibly discretionary) tasks, stages, milestones, event listeners, connectors, and sentries. A task is a unit of work. Stages are plan fragments which can be composite or atomic. A milestone represents an accomplishment which occurs during the execution of a case. Events represent something that can happen to a plan construct (e.g., a task is cancelled) or in general (timer and user event listener). Connectors are used to link different plan items. Finally, sentries represent the entry / exit criteria for path items and can direct the control flow mimicking the AND and OR logical operators.

Following the classification reported before, CMMN is a declarative and data-centric language.

[2]https://www.omg.org/spec/UML/About-UML/

TEMPLATE	NOTATION	DESCRIPTION
init(A)	init A	A must occur as a first activity
not coexistence(A,B)	A B	If A occurs, B must not occur and viceversa
precedence(A,B)	A B	B can occur only if A has occurred before
response(A,B)	A B	if A occurs, then B occurs after A

Figure 2.1: DECLARE patterns

DECLARE. It is one of the most popular declarative languages for modelling business processes [PSvdA07]. It grounds on the finite-trace semantics of LTL and aims at capturing variable cases by means of the so- called patterns (see Figure 2.1). These are particular LTL formulae that have been singled out for process modelling taking inspiration from [DDM14]. Combinations of patterns, such as precedence and not-coexistence, can be used to mimic the control flow using the AND, OR, and XOR logical operators.

DECLARE is a formal and declarative language which provides a representation of the activities of business processes.

2.1.3 Meta-models in business process modelling

Meta-models can be developed to describe specific modelling languages or can be independent from specific notations as a way to capture typical aspects of a domain. However, meta-models are very often associated with a specific modelling notation, and they allow us to capture general conceptual architectures rooted in the notations [Gui06], by quoting Weske in [Wes12a] (pg. 76):

> "Models are expressed in metamodels that are associated with notations, often of graphical nature. For instance the Petri net metamodel consists of places and transitions that form a directed bipartite graph. The traditional Petri net notation associates graphical symbols with metamodel elements. For instance, places are represented by circles, transitions by rectangles, and the graph structure by directed edges."

Thus, the business process modelling language of Petri net provides two constructs, *places* and *transitions*, and rules them to create directed bipartite graphs. Circles, rectangles, and directed edges are instead the graphical elements that a specific notation employs to denote the available constructs and their relations.

Due to the number of BPMLs available in literature, a number of associated meta-models exist. These meta-models can vary greatly, reflecting the expressive power of the language, its characteristics in terms of the specific sub-domain it may focus on or the particular modelling paradigm

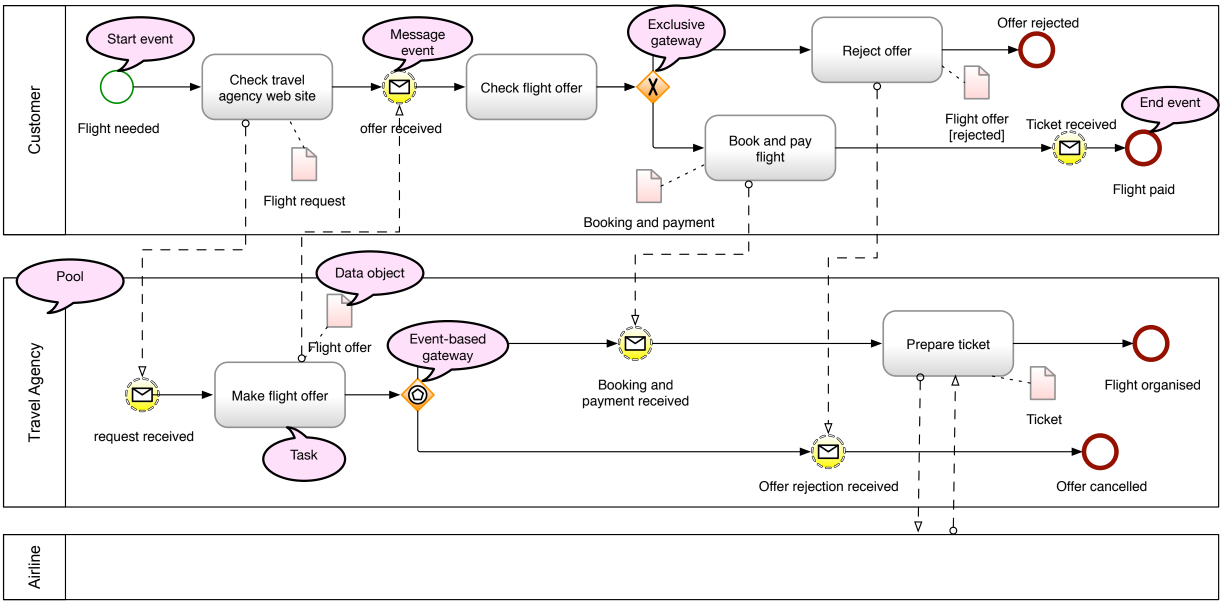


Figure 2.2: BPMN 2.0 diagram.

and approach the BPML adheres to. Think for instance of the different representations that could be provided by declarative vs imperative BPMLs, by activity centric vs data centric BPMLs, by formal-based vs descriptive-based BPMLs, just to mention some. Meta-models are also defined in literature independently from specific BPMLs with the aim of "navigating" across the different BPMLs, bridge the gap across them, foster a common ground across different notations, and promote interoperability, thus further increasing their overall number.

Take as an example the processes represented in Figures 2.2 and 2.3, they capture a simple scenario of buying a flight ticket from a travel agency using BPMN 2.0 and EPC.

For the sake of clarity, we "annotate" the diagrams with speech balloons to explicitly indicate the graphical constructs. By looking at the diagrams, we observe that both languages allows for representing the activities (e.g., *make flight offer*). The situation changes as soon as we move to the specification of the business *goal* or to the representation of the *world's states*. EPC, indeed, allows for explicitly representing in the graphical language *states* (event entities) and somehow the *goals*. BPMN, instead, leaves implicit in the mind of the modeller and of the reader the goal the activities that contribute to realise it, as well as the effects of the activities and the state of the world. On the other hand, BPMN enables a detailed representation of the communication between different actors, by means of message events, which is left unspecified in EPC. These differences between modelling languages are reflected and represented in the meta-models of the two languages.

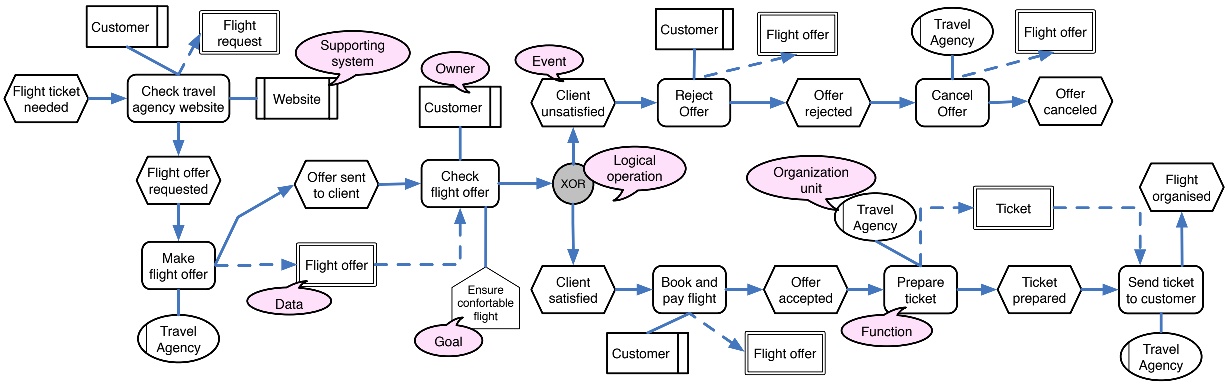


Figure 2.3: EPC diagram.

2.2 Systematic literature review

In this Section we summarise what a *Systematic Literature Review* (*SLR*) is following the works in [Kit04, KC07]. According to [KC07] pg.3, a SLR is:

> "[...] (often referred to as a systematic review) is a means of identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest."

A SLR is commonly conceived as a *secondary study*, which means a study of the *primary studies*. Yet, what is very relevant in performing a SLR is the *procedure* that needs to be followed to obtain the results. There are three main activities that compose a SLR:

1. *Planning the review*: This phase concerns the identification of the needs for the specific SLR, depending also on the existence of other reviews on the same topic, its objectives, the development of the research questions, and the organisation of the review according to the protocol of review. The protocol guarantees that the SLR is conducted according to non-subjective criteria in order to minimise possible research biases.

2. *Conducting the review*: This phase concerns the identification of the relevant papers, their selection criteria, the completion of the quality assessment study, the extraction of data and their synthesis and classification.

3. *Reporting the review*: This final phase concerns the writing and submission for publication of the SRL.

In the following we describe the activities of *planning the review*, *conducting the review*, and *reporting the review*, which is the outcome of the SLR that will take the form of a document.

Planning the review A SLR should always start with a clear reason why it should be performed. This phase concerns the *need for a systematic review* which is included in the activity of planning the review. The inquiry regarding the need(s) for a systematic review could start either from the necessity to propose a SLR in a specific topic, if it is missing, or from the existence of other SLRs partially covering the same topic, but out of date. Other need(s) could raise from well-established challenges in the literature.

Once the need(s) for a systematic review has been clearly identified, the second important phase of the planning is the development of the *research questions* (RQs). The research questions are the guide for the SLR. The work in [KC07] (pp. 9-12) describes a few guidelines to support the development of appropriate RQs that will lead the review in the direction of the expected results.

The last phase included in the planning concerns the *protocol of the review* which is composed of all the tasks required to complete the SLR. The protocol of the review includes standard practices on how to perform the SLR. Examples of items that should be included in the protocol of the review are: research questions, inclusion and exclusion criteria, quality assessment lists, data extraction strategy and analysis, timetable of the study.

Conducting the review Once that the protocol is established, it should be followed in order to select the primary studies and answer the research questions. When selecting the primary studies is important to: try different combinations of boolean strings for the queries, find the data repositories for the field, and search into the proceedings of the main conferences\journals. For instance a list of data repositories can be found in [BKB+07a].

In conducting the research, the researcher could face biases ([KC07], pp. 15-16) in selecting the primary studies. Positive biases could be directed to include positive results, but also influential authors in the fields, the use of popular frameworks or formalisms. On the contrary, negative biases could exclude from the primary studies works with negative results (e.g., the tool x is not useful for the purpose p).

The primary studies should be selected according to the inclusion and exclusion criteria (ICs\ECs) identified during the protocol of the review. The ICs\ECs usually involve some general information (e.g., publication year, venues, language, availability of the paper, peer-reviewing), or specific issues. For instance, whether or not the paper belongs to the field under examination, or whether or not the paper is relevant according to the RQs.

After having identified the primary studies, a *quality assessment* is conducted. The quality assessment criteria are identified during the phase of the protocol and refer to publication qualities aspects. For example whether or not the study has been evaluated, whether or not the data analysed is comprehensive enough, whether or not the study is well-situated in the literature.

The final step, *reporting the review*, is to provide an analysis based on the extracted information and answer to the RQs.

2.3 Ontology and ontological analysis

This Section is focused on the description of the notion of ontology in the fields of philosophy (Section 2.3.1) and computer science (Section 2.3.2). These two different views of ontology are often denoted with the terms “Ontology” (with the capital “O”) and “an ontology” (with the lower-case “o” with the indeterminate article) [GG95]. The final Section addresses the role of ontology in terms of methodological approaches (Section 2.3.3).

2.3.1 Ontology in philosophy

In the philosophical field Ontology (with capital “O” [GG95]) is generally understood as the study of what there is [Smi03]. The term “Ontology” is a Greek neologism that unifies *on*, *einai*, (i.e., “to be”) and *logos* (i.e., “saying something", “talking about”) [Hen08].

The term “Ontology” was introduced in the seventeenth century, when it appeared in an independent manner in two philosophical works, by Rudolf Göckel (Goclenius) and Jacob Lorhard (Lorhardus) [Hen08, Smi03]. Ontology is often associated with studies in the field *metaphysics*, which date back to Aristotle. Then if we take metaphysics into account, the origin of the notion of Ontology is more ancient[3] [Hen08, Smi03]. Aristotle refers to metaphysics as the *first philosophy*, which is the study of what it is (i.e., the being as such) and its characteristics [Hen08, Smi03, GOS09].

Ontology in philosophy aims at studying “the nature and structure of “reality”” [GOS09]. In this sense Ontology deals with the development of a classification system of the elements that exist in the “world”, their properties, and relations [Smi03]. Examples of topics considered in Ontology [Gui05] are: identity, causality, dependence, mental dependent entities, time and change.

Differently from applied sciences which have the purpose of studying particular elements (e.g., molecules, illnesses, plants), Ontology is centred on the analysis of reality from a more general and abstract perspective [GOS09, Hen08, San17]. Entering even more into details, this distinction between general Ontology and particular sciences leads to the discussion concerning *formal* and *material* Ontology [San17, GG95, Var11], while the former deals with identification of the formal structure of the entities and the reality, the latter is focused on the study of particular entities belonging to a specific domain or field. For example, formal Ontology investigates the general relations among entities (e.g., instantiation) as well as the classification of the general entities of the world (e.g., abstract entities, events), instead material Ontology could analyse the specific relations among domain entities (e.g, among illnesses) and classify specific entities (e.g., illnesses, plants).

[3] Here we do not focus on the distinction between Ontology and metaphysics [Var11].

2.3.2 Ontology in computer science

In the last 20 years, ontology[4] experienced a heyday in computer science. As reported in [Gui05], Smith and Welty [SW01] classify three areas that contributed to the expansion of ontologies in computer science: database and information systems, software and domain engineering, and finally Artificial Intelligence (AI).

The most popular, and likely most widely quoted definition of an ontology (with the lower-case "o" and the indeterminate article [GG95]) in computer science is provided by Gruber in [Gru95]:

> *An ontology is an explicit specification of a conceptualization.*

This definition captures the role of an ontology in terms of conceptualisation, which can be understood as an abstract model of the world (or pieces of the world) [Fen00]. Another definition of an ontology as been provided in [Gua98]:

> *An ontology is a logical theory accounting for the intended meaning of a formal vocabulary, i.e. its ontological commitment to a particular conceptualization of the world. The intended models of a logical language using such a vocabulary are constrained by its ontological commitment. An ontology indirectly reflects this commitment (and the underlying conceptualization) by approximating these intended models.*

This more articulated definition states that an ontology is a formal object and is based on an ontological commitment (i.e., "intensional first order structure" [GOS09]) of (a conceptualisation) of the world. An ontology represents domain elements and relations using a vocabulary which is committed to a certain conceptualisation [GOS09] and has specific capabilities in terms of expressivity. Yet, an ontology is also somehow language dependent as it is developed following some languages' constraints. For instance, although first-order logic is neutral in terms of ontological commitment[5][Gua98], it is still bound by its expressive capabilities.

Often an ontology takes the form of an engineering artefact that formally represent the world [Gua98]. This engineering artefact is an implementation that is dependent upon machine-readable languages (e.g., OWL, the Web Ontology Language [MvH04]). Because of this, an ontology has assumed a strong pragmatic role in computer science by helping to foster a "shared and common understanding of a domain that can be communicated between people and heterogeneous and widely spread application systems" [Fen00].

Several different ontologies have been produced in computer science, with different aims and different representation characteristics. This plethora of artefacts has originated different attempts

[4]Here we are using the term "ontology" in a general manner.

[5]In general, logic does not help us to clarify the ontological status in the formulas [Gua09]

to classify them (see e.g., [UJ99, RPKC11, RGdAF+17]). An important way to classify ontologies is in terms of *generality* [Gua98, RGdAF+17]. In this classification ontologies are distinguished in: top-level ontologies and foundational ontologies, domain ontologies, task ontologies, and finally application ontologies. *Top-level* ontologies represent general entities which are domain-independent (e.g., time, event). Another kind of ontology is called *foundational*, which is a top-level ontology based on solid ontological choices [BH18]. *Domain* ontologies are focused on the description of specific domain (e.g., the business processes domain, the biology domain). *Task* ontologies define notions of a certain domain activity or performance (e.g., government processes, clinical trials). Often, domain and task ontologies are aligned with the top-level elements. *Application* ontologies captures the role that some domain and task ontologies elements play in a certain context and activity (e.g., a resource plays the role of information).

Top-level and foundational ontologies are often used to develop more robust domain ontologies (and also task and application ontologies) so that the entities of the domain inherit the characteristics of the top-level or foundational entities. In this case the top-level and foundational elements provide the general backbones for the domain elements [Smi03].

Many ontologies have been proposed. Focussing on the top-level and foundational ones, examples are *SUMO* (Suggested Upper Merged Ontology) [NP01], *DOLCE* (Descriptive Ontology for Linguistic and Cognitive Engineering) [MBG+03], and *UFO* (Unified Foundational Ontology) [GW04b]. SUMO is developed merging many other ontologies and it is extended with several domain ontologies. It includes cognitive and realist aspects [FB04] and is the largest domain-independent ontology (1000 terms and 4000 axioms without considering the domain ontologies) [MCR07]. DOLCE has a cognitive approach, and captures aspects of natural language and common-sense. DOLCE is an ontology of *particulars* and includes several extensions and refinements. DOLCE follows been aligned with WordNet[6] and there are available in several formats [BM09]. Finally, UFO is based on several theories drawn from cognitive science, linguistics and philosophical logics [GWAG15]. The UFO ontology is composed of three parts: UFO-A, UFO-B, and UFO-C. Roughly speaking, UFO-A is an ontology of endurants (e.g., physical objects), UFO-B represents perdurants (e.g., events), and finally UFO-C describes the social realm (e.g., social entities) [GW04b].

Domain-dependent ontologies can be found across a wide swathe of research territory. In the following we mention only few of these domains. For example, the *BWW* (Bunge Wand and Weber ontology) [WW90b] is developed in the contexts of information systems and conceptual modelling. Many domain ontologies are developed in the manufacturing domain, such as, MASON [LSDS06], ADACOR [BL07], and PSL [Grü09]. Also the medical domain produced several ontologies, for example, SNOMED-CT[7], GALEN [RSN+95], GENE [BCA+00]).

[6] https://wordnet.princeton.edu/
[7] http://www.snomed.org/

2.3.3 Ontological analysis as practice

In the previous two Sections, we have introduced what ontology is in the fields of philosophy and computer science. However, ontology can also assume the role of a method, not only for developing solid engineering artefacts, but also to support formal and informal theoretical analysis. This methodological role of ontology is sometimes called *ontological analysis*[8].

Often ontological analysis uses ontological knowledge and reference ontologies as a foundational guide to clarify, align, compare, and evaluate more specific notions, such as domain elements, with the ones of the reference framework. Several papers in the literature describe ontological analyses focussing on some foundational choices for ontologies and taxonomies (e.g., [GW04a, GGMO01, GW00]), on specific domains (e.g., [SBB+18, FG08]) and on on modelling languages and techniques (e.g., [SAG10, OHS02, GR99, RGI04, GM02, WW88, GW04b]). In the following paragraphs we restrict two ways of conducting ontological analyses on specific domains and notations, one using existing *ontologies* and another one using the *ontological literature*.

Ontological analysis using ontologies. Ontological analyses can be performed using reference ontologies, such as top-level and foundational ontologies, as well as more specific domain ontologies. These kinds of ontological analyses can be applied to domains (or aspects of such domains), but also to particular notations.

Using existing ontologies it is possible to investigate the semantics of domain notions and sometimes enrich them (see e.g., [SBB+18, FG08]). Let us assume that the considered domain field is business processes and "activity" is one of the core domain entity to be investigated. In order to clarify the meaning of such entity and enrich it we could use the explicit semantics adopted for the entity "activity" in a reference ontology. Existing ontologies can also be adopted to compare and evaluate the explicit or intended semantics of the domain elements using the ones of the selected ontology. In this case the elements of the domains are assessed on the basis of the ontology.

Similarly, reference ontologies can also be used to investigate and enrich specific modelling notations' semantics, and to provide a comparative framework to evaluate the expressivity of the notations (see e.g., [SAG10, OHS02, GR99, RGI04, GM02, WW88, GW04b]).

Ontological analysis on the basis of the literature. Domain notions and specific notations can be analysed using existent theoretical studies from the ontological literature. Usually these ontological works investigate specific entities and aspects and are often based on explicit philosophical positions. For instance, the literature provides ontological positions on: parts and wholes of the

[8] The term *ontological analysis* is mostly used in computer science, however it is applicable also in ontological philosophy.

objects [Var00], causation [Gal12b], events [CV08, Dav69], particular relations [Cor08, Fin94], abstract objects [Low95] ans so on.

In order to perform an ontological analysis using the literature one must know the overall ontological topics provided by the philosophical corpus of knowledge. Indeed on each topic there are many ontological positions and then it is important to be familiar with the related works on that particular aspect (e.g., events). There are also some open and reliable philosophical resources which provide an initial picture concerning the topic and a starting point for identifying the relevant works on the topic. Examples of these resources are: the Stanford Encyclopedia of Philosophy[9] and the Internet Encyclopedia of Philosophy[10].

Once the related works have been explored and properly understood, the researcher can select the ontological position suitable for the study and then can contextualise the analysis with the domain notions or with the elements of the notations which are under investigation. These kinds of ontological analyses promote the semantic enrichment of the domain notions and the notations' semantics.

2.4 Empirical studies in BPM

In this thesis we include the empirical evaluation with human subjects of one specific outcome of the ontological analysis investigation. For this reason, in this Section we focus on empirical studies and the techniques used for conducting them with human subjects. Moreover, since in this thesis we perform an empirical evaluation of business process redesign and comprehension tasks (see Chapter 7), Section 2.4.2 and Section 2.4.3 reports some of the background concepts related to the factors impacting this type of tasks and the metrics used in these tasks.

2.4.1 Empirical studies

Most of the material below is based on [WHH03, WRH+12].

Empirical methods. Depending on the purpose of the evaluation and on the context in which the empirical investigation is carried out, we can identify different types of empirical methods: *qualitative methods* and *quantitative methods*. The former are focused on capturing the understanding of human subjects, their reasons, and explanations. For instance, a qualitative study could be interested in investigating the "mental states" of the subjects concerning a specific use of a product. The latter are devoted to collect numerical data allowing a more easy quantification

[9] https://plato.stanford.edu/
[10] https://www.iep.utm.edu/

of the results. Indeed these kinds of methods are also suitable to extract statistics. Note that often, these two kinds of studies co-exist, indeed they offer a multifaceted way to *interpret* the data [WHH03].

Moreover, as classified in [KBR08] in the context of design studies, these types of investigations can be conducted: (i) as field trials also known as "in the wild" research (e.g., [BRS11]), (ii) in the gallery or showroom[11], where the situation is "naturally" present or can be easily re-proposed (see e.g., [WDAZ17]), (iii) in addition to lab-based studies, where almost all the factors can be controlled.

In practising empirical research it is also necessary to identify the kinds of investigation suitable for the study. For instance, *game* and *gamified* techniques are often used to promote the collection of information from the subjects in an informal settings [HK13]. A *survey* is also an empirical research technique that is based on past experiences of the subjects collected using questionnaires or interviews [WHH03]. *Case studies* are another example of empirical strategy often used for monitoring projects and activities through the collection of data and their (statistical) analysis.

Experiments are another, more controlled form of empirical investigation. Experiments are usually conducted in labs, i.e., in an artificial environment in which the selected parameters are manipulated and measured by researchers. Usually the participants to the experiment are randomly assigned to groups (or assigned to groups by researchers in case of *quasi-experiments*) to evaluate the effects of the manipulation of the controlled variables.

Since in this thesis we used experiments with human subjects, in the following we report the key concepts of experiments.

Experiments. Usually, researcher(s) conduct experiments in order to evaluate an *intuition*, for instance whether or not using a modelling tool (tool x) is more effective than the old one (tool y) on the productivity of the modellers.

When conducting an experiment researchers want to study the outcome, i.e., the dependent variable(s), when varying some of the input variables, i.e., the independent variables [Pat08]. The independent variables are the variables under examination that can be manipulated by the scientists. The dependent variables are influenced instead by the independent variables. For instance, in the case of modelling tool, the dependent variable is the productivity of the modellers and the independent variable is the modelling tool. The experiment studies the effect of the independent variables (factors) on the dependent variables [WRH$^+$12]. A treatment is one particular value of an independent variable. For instance, in the example, the independent variable is the modelling tool and the treatments are the old (tool y) or the new tool (tool x).

Experiments have **objects** and **subjects** of the study. The former are documents, models to be

[11]Here "gallery" or "showroom" mean an environment that is close to the field, although it is somehow artificial [KBR08].

used to carry on the experiments; the latter are the individuals that will be part of the study. For instance the object of a study could be a process description to be modelled and the subjects involved in the study could be a group of users with a background in Business Process Modelling [WRH+12]. It is important to identify a sample of the population for the study. The sample must present characteristics of the population. For instance, the population of a study could be the citizens of a certain city, the process modeller that use a specific notation, business analysts, and so on. The sample can be selected by the researcher or can be randomly extracted [WHH03].

When running an experiment, researcher(s) design the so called **tests** by dividing in groups the subjects and assigning to them a task on the object. The tests are organised based on the different treatments assigned to the groups of subjects. Then for instance, suppose that there are 40 subjects and the object is a model to be designed, 20 are randomly assigned to the treatment 1 (e.g., model tool x) and the second group of 20 people is assigned to treatment 2 (e.g., model tool y) [WHH03, WRH+12].

Experimental phases. Experiments must follow some standard guidelines to ensure the quality of the results and avoid biases. The phases of the experiment are: (i) scoping; (ii) planning; (iii) operation; (iv) data analysis; and finally (v) presentation [WHH03, WRH+12].

In the first phase (*scoping*), the hypothesis of the research, as well as the objectives and goals are investigated. For instance, the hypothesis could be "the modelling tool x improves the activity of modelling in terms of modellers productivity". In this phase the fundamental framework of the study, which is composed of *objectives*, *goals*, *quality focus*, *perspectives*, and *context*, is defined. The **objectives** of the study help to make it clear what is the target of the research (e.g., investigate the impact of using the modelling tool x). The **goals** are the final reasons why the study is performed (e.g., to improve the modelling activity). The **quality focus** is related to the results studied (e.g., the productivity of modellers in terms of models designed per day). Usually these studies are interested in testing the research focusing on a specific population of subjects (e.g., process modellers), who represent the so called study **perspective**. Finally, the **context** is the place, also virtual, where the study is executed (e.g., the Company C, The University U) and the objects used to carry on th experiment (e.g., the specific model used).

The second phase is called *planning*. In this phase the context must be decided and the hypothesis formally established. In general, what the experiment aims at demonstrating is the non-validity of the null hypothesis ($\mathbf{H}_0$), which is the one that denotes that there is no impact of independent variables (e.g., the modelling tool) on the dependent ones (e.g., the modelling productivity). The variables (independent and dependent) are defined together with the kind of scale to measure them. The last important step for the planning is related to the design of the experiment, including deciding the instruments, the objects and the metrics. For instance, the experiment can be designed so as to have an experimental and a control group. The experimental group is provided with the experimental treatment (e.g., the modelling tool x), while the control group deals with the control treatment (e.g., the modelling tool y), i.e., an established method that is used to compare its results with the ones of the method that we want to evaluate.

In the *operation* phase the study is prepared, executed and the data are validated. In preparing the study the researcher(s) must introduce the subjects to the objects and materials. In this phase, the forms for the data collections and the informed consent are also provided.

Once the experiment has been carried out, the data is analysed. It must be well-formed and correct. Usually, the first data analysis is performed descriptively (e.g., data entry in Excel sheets) with the support of data visualisation tools. Note that it is important to carefully annotate all the unexpected values in order to analyse them. To test the hypothesis it must be considered the influence of independent variables on the dependent ones.

Once the results have been collected, possible threats affecting its validity have to be analysed. Validity threats can be classified in: *internal*, *external*, *conclusion*, and *construct*. The internal validity is related to factors external to the control of the researcher that could have impact on dependent variables. The generalisation of the study is considered pertaining to its external validity. Since it is also important that the results of the experiment and the treatments are correlated, it is important to consider the conclusion validity to certify the findings of the study. Finally, the construct validity considers the compliance of the theory with the experimental practice [WHH03].

Finally, there are the **presentation** and **package** phases. In these phases the documentation is prepared to be delivered either as a publication or as a report. Together with the lessons learned, a thoughtful reflection is necessary to identify the limitations as well as biases and improve potential future experiments.

2.4.2 Business process redesign

In this Section we focus on the main aspects of business process redesign, such as its performance dimension and its "best practices" [RM05, MR07, DRMR13, SRvB12].

Business process models are artefacts designed to capture "real" world phenomena called business processes. These phenomena are part of socio-technical organisational settings which are subject to changes. Then, often, business process models need to be *redesigned* in order to fulfil new management needs [RM05, MR07]. Business process redesign deals with the re-organisation of business processes [Rei05]. For instance, a redesign of a business process model could be required because of a re-organisation of the resources, or because the life-cycle of the process is too slow due to bottlenecks. *Time*, *cost*, *flexibility*, and *quality* (the so called *devil's Quadrangle*) are the main performance dimensions usually involved in a redesign effort [DRMR13]. Besides these dimensions, more recently some "green" dimensions to support sustainable practices have also been introduced [SRvB12]. The Quadrangle has been indeed expanded with a fifth dimension of *sustainability* (including, for instance, renewable energy and reduction of carbon footprint) and has been called *Devil's Pentagon*.

Although business process redesign can be considered more as an art than a science, during the years some "best practices" that impact the redesign and a framework that guides the implementation of each best practice for the redesign have been identified [RM05, MR07]. The framework is composed of the following elements: *customers*, *products*, *operation view*, *behaviour view*, *organisational structure*, *organization population*, *information*, *technology*, and *external environment*.

The elements of this framework can be used to: (i) classify the best practices, and (ii) to evaluate the effects of these on the basis of the redesign [RM05]. For instance, the behavioural view is associated with two kinds of best practices, i.e., *resequencing* and *parallelism*. The former consists of evaluating whether it could make sense "moving the activities to more convinient places", while the latter consists in evaluating what "can be executed in parallel" [DRMR13].

The best practices are meant to help practitioners in redesign. In particular, these two best practices are usually recommended to reduce the overall cycle time of a procedure [DRMR13], i.e., the overall time required by the procedure.

Time, as well as the other performance dimensions driving the effort towards business process redesign, can be used as metrics for evaluating the quality of the outcome of the redesign activity.

Other factors that can be considered when evaluating the business process redesign are related with the (perceived) quality of the models [KVDD09].

2.4.3 Understandability in business process modelling

A definition of understandability is suggested by Figl and Laue [FL11] by re-formulating the definition of understandability in computer programs proposed in [BMW93]:

> *A person understands a BPM*[12] *when they are able to explain the BPM, its structure, its behavior, its effects on its operational context, and its relationships to its application domain in terms that are qualitatively different from the tokens used to construct the BPM in a modeling language.*

The BPM understandability is a cognitive response that is manifested through the capability of learning, grasping, and internalising conceptual and procedural notions on business process modelling. Note that the understandability of a business process model is tested following the experimental paradigm and practice in science introduced in the previous Section (see Section 2.4).

[12] Here "BPM" stands for *business process models*.

Since in our empirical evaluation we focus on the business process redesign and comprehension tasks, in the following we report some useful concepts related to the main factors impacting these tasks and to the metrics used to evaluate them [DTD18, HFL14].

Understandability factors. The understandability (and redesign) of business process models is influenced by many factors, both external and thus related to the model itself (e.g., complexity of the model, language characteristics), which are called *model factors* and internal to the modellers (e.g., background and domain knowledge), which are called *personal factors*. Due to the number of factors that could influence the comprehension of the process models it is necessary to identify them to analyse their correlation with the understandability metrics [DTD18]. For the sake of simplicity we grouped the model factors into three sets: *conceptual factors*, *quality model factors* and *design factors*.

Conceptual and cognitive factors: many conceptual factors could influence the understandability; some of them are related to the use of a specific *notation* (e.g., BPMN and EPC [RD07], UML-AD [RRS+11]) and the modelling *symbols* that they include in the representation [FMS13].

Also the notation approach (see Section 2.1.2) impacts the understandability of the process models. For instance, it seems that the imperative approach is more understandable compared to the declarative one [PWZ+11].

Another factor impacting understandability is the quality of labels [Fra11]. For instance, some findings underline that the use of *verb-object* labels is not only one of the most popular approach for labelling in many modelling techniques [MR08], but it is also more understandable than other styles (e.g., action-noun) [MRR10].

Semantically annotating business process models could also impact the quality and the understandability of the process. Semantic annotations allow for reasoning and querying on business process models and then bridging the gap between BPM and the Semantic Web [Fra11]. Semantic annotations contribute also to facilitate understandability, for instance in [DFRGV14] a user study evaluation that confirms that models semantically annotated are more understandable than the ones without annotations has been performed.

Quality model factors: one of the first process model characteristic that interferes with the understandability is *complexity*. In [Car06] process model complexity is defined as: “the degree to which processes are difficult to analyze, understand, or explain”. The control-flow is a part of the process that often suffers from complexity issues. The control-flow complexity is usually computed taking into account gateways (AND, OR, XOR) [Car06, ACG+09]. Complexity is also related to the block-structure and block-structuredness of the process models [DRM+12]. Another aspect of complexity involves the relations, connections and separateness between elements [FL11]. A final example of complexity is related to the size of the models.

A process has *modules* when it can be decomposed in sub-processes (see for instance the sub-process element in BPMN [TRV+16]). Modules allow us to reuse parts of the business process models and also to perform multiple grouped activities during an execution [RM08]. While in some cases the modularity could increase the understandability by "packing" and structuring the information, in other cases the modules create a splitting of attention in people, thus increasing the cognitive load [DTD18].

Visualisation\aesthetics factors: some factors are related with the graphical and visual characteristcs of the business process models. The *design of the element* and its aesthetic is correlated with its semantic transparency [FRM13]. The design of the elements is important also for perceptual discriminability and immediacy, the visual expressiveness, and the graphic parsimony [FMSR10]. Also the *colour* of the process models components could impact the understandability, as described in (see [RFME11]) focused on the syntax highlighting colours use in workflow nets.

Another important factor is the *visualisation perspective* (or view) taken by looking at the models. In fact the same model can encapsulate many perspectives, such as the control-flow, the information, and the organisational one. For example in [KKU13] the visualisation style of the process models (single view, multiple-view, multiple views in connection with linking and brushing) has been analysed. As a result it emerged that the multiple views together with linking and brushing are the preferred choice of the subjects. This is in line with the necessity of decreasing the complexity of the model by reducing the number of symbols. Finally, the *visual layout* of business process models is connected with the factors that influence understandability. Indeed, since process models are usually graphically depicted, the way in which the models are visually returned to the users (e.g., length of edges, amount of ending points, shape of the model) affects the model comprehension [BS15].

All the factors described above concerns the model, however the understandability is also widely influenced by personal factors. In the following we introduce the personal factors that could impact on the understandability [RM11, DTD18]. Examples of personal factors impacting the model understandability are the **theoretical background** of the subjects, i.e., their knowledge of process modelling, of the notations used for the task and of the domain knowledge, the amount of past and every-day **practice** in performing process modelling, the third factor is the **educational** setting, as well as the **cognitive** (e.g., use of abstraction), **motivational** (e.g., intrinsic and extrinsic motivations), and **learning style** (e.g., sensing and intuitive learners).

Understandability indicators. In the literature there are two main *indicators* adopted to quantify and measure the understandability: (i) *objectively measured understandability* and (ii) *perceived understandability* [DTD18]. In the first case there are two aspects that are taken into account, the first is the *effectiveness*, the other is called *efficiency* [Moo03].

- **Effectiveness:** the understandability is evaluated on the basis of the correctness of the task (or the questions of the answers) according to the hypothesis that have to be evaluated.

- **Efficiency:** In this case the understandability is calculated considering the time that was spent to complete the task (or to answer to the questions) without calculating the positive\negative results of the task (or of the answers).

Concerning the perceived understandability of the models, there are four main indicators: one is related to a cognitive science theory (*Cognitive load*), while the other three are focused on the *Technology Acceptance Model* (TAM) [Moo03], which is one of the methods to evaluate design techniques in information systems (*perceived ease to use*, *perceived usefulness*, *intention to use*).

Cognitive load: The amount of information that the memory (a.k.a. working memory) has to process matters in accomplishing one or more tasks (*problem-solving* skills) [Swe88]. This happens because the memory has a finite capability to process information in a time. This assumption is based on the *Cognitive Load Theory* [Kir02]. When the information given to a cognitive agent exceeds a certain limit, the memory overload creates a decrease of the performance in achieving the tasks.

Technology Acceptance Model (TAM): The *perceived ease to use* is related to the perception about how easy it is using, for instance, the new system, adopting the new modelling elements, and the new paradigm. The *perceived usefulness* in performing a specific activity evaluates the perception of the utility of the new system, elements, and paradigm. Finally, the *intention to use* is referred to the "intention" of the agent to use in the future the proposed system, element, paradigm.

Chapter 3

Research methodology

The purpose of this Chapter is to describe the research methodologies embraced in this PhD thesis. The structure of this Chapter reflects the goals widely described in Chapter 1.

In the next Sections we provide a description of the methodologies embraced for each task (see Section 1.3 and Figure 1.1). In particular, in Section 3.1 we describe ***TASK 1*** and how we developed a business process meta-model from a Systematic Literature Review. Moreover in this Section we list the steps we developed to assess the extracted meta-model. In Section 3.2 we address the methodological steps for ***TASK 2*** that make use of the ontological analysis. In Section 3.3 we explain the methodology we followed to revise the meta-model (***TASK 3***). Finally, in Section 3.4 we describe the methodological steps of ***TASK 4*** which involved the proposal of a new notation for the representation of occurrence dependences among activities and its empirical evaluation.

3.1 Methodology for *TASK 1*

TASK 1 was designed in order to achieve **GOAL 1** which aims at developing a business process meta-model grounded in the literature and its fundamental components. The Systematic Literature Review (SRL) was the research strategy we decided to adopt in order to accomplish this task. The SLR was motivated by the decision of exploring what was already available in the literature.

SRLs are typically used in order to have a comprehensive view on a topic. They are performed by gathering selected data, by studying and analysing those data, and finally by synthesising the results. A generic description of how to conduct a SLR is provided in Section 2.2. We performed an SLR in the area of business process meta-models with the aim of extracting the components of business processes as presented in literature and then build from those a *literature-based meta-model* (*LB meta-model*) which represents the ***outcome*** of ***TASK 1***.

During the execution of ***TASK 1***, we decided to assess the *LB meta-model* by comparing its elements with the ones contained in specific business process modelling languages (BPMLs). We selected five popular BPMLs, which are BPMN 2.0, UML-AD, EPC, CMMN, and DECLARE and extracted their components. These five languages were selected as a representative sample of the available notations and follow different approaches to the modelling of business processes. They are described in Section 2.1.2. We compared the elements of the *LB meta-model* with the ones of BPMLs in order to verify whether the *LB meta-model* was "in line" with the popular notations or not.

3.2 Methodology for *TASK 2*

TASK 2 had the aim of achieving **GOAL 2** and thus to clarify the ontological status of business process modelling elements. The approach we adopted to do so is the one of ontological analysis. This approach is often used to have a better understanding of the entities involved in a specific domain by defining their properties\qualities and their relations with other entities. An extensive explanation of the use and applications of ontological analysis can be found in Section 2.3.3.

We decided to focus our analysis on those entities that were: (i) poorly represented in the *LB meta-model*, or (ii) missing when comparing the *LB meta-model* with the five business process modelling languages named in the previous Section. Concerning group (i) we clarified the use of the label "event", the notion of participants belonging to the organisational and data component of a business process, and the element goal. Focussing on group (ii) we provided an analysis of the flow relationships among business process activities. The analysis of these four elements are contained in Sections 5.1-5.4. Here we report, for each element, a summary of what was done and the reference ontological views that we adopted.

- **Event:** The first ontological analysis was focused on the disambiguation between different uses of the term "event" in the *LB meta-model*, which reflects different understandings of this term in the BPM community. More specifically, we summarised some of the meanings of the label "event" in this field, and in the *LB meta-model*, and we compared them with the way an event is commonly understood in the ontology field. We used the work of Galton as reference ontological view [Gal12a, Gal12b]. This reference work did allow us to clarify that at the type (i.e., conceptual) level the label "event" is referred to (kinds of) activities. Moreover, the analysis of the term "event" involved the study of the notion of state, especially when represented by pre-postconditions, and their ontological status.
- **Participants:** The second ontological study aimed to unravel some confusions on the notion of business process participant that emerged from the *LB meta-model* in particular concerning the ontological status of actor, artefact, and resource. In this work we defined a taxonomy of participants, and investigated their relations and properties (or qualities).

The DOLCE ontology [MBG+03] has been used as a domain independent ontology for this analysis, together with its extension to social concepts and descriptions contained in [MVB+04] and [BF09]. The UFO ontology has also been adopted for the study of the notion of resource and roles [Gui05, GW04b].

- **Flow:** The third ontological analysis was focused on the relations among business process activities, which were completely absent in the *LB meta-model*. We started this analysis by observing that most business process modelling languages focus only on sequence flow relationships which merely capture the temporal aspect of a relationship between activities. In our analysis we identified occurrence dependences between activities and rationales which is in part inspired by the literature on ontological dependence following the work described in [Cor08, Fin94].

- **Goal:** The last study was conducted on the goal element. Although goals are mentioned in popular definitions of a business process (see Section 2.1.1), the BPM literature on goals very limited. Therefore we started our analysis by investigating the notion of goal in other research areas, such as multi-agent systems, philosophy, psychology, planning systems, and requirement engineering. We selected the most popular definitions of goal and their related classifications and from that we made an attempt to investigate the notion of goal in the context of business processes.

The results of these four ontological analyses are the ***outcome*** generated from ***TASK 2***.

3.3 Methodology for task *TASK 3*

TASK 3 consisted in an enrichment of the business process meta-model extracted from the literature with the ontological analysis outcomes of ***TASK 2***.

To perform this task we did not follow a specific methodology. Rather we decided to *manually* incorporate the results that were useful to solve some of the shortcomings that we found in the *LB meta-model*. These enrichments consisted in: (i) the notion of event, activity, and state; (ii) the notions of resources, roles, actors, and artefacts and their relations; relationships between activities to capture both the temporal connections and occurrence dependence aspects; and (iv) goals. These four re-factorings constitute the associated ***outcome*** of ***TASK 3***.

3.4 Methodology for *TASK 4*

TASK 4 aims at introducing a new notation and validate it to achieve ***GOAL 3.2***. For this task we proposed the following methodological strategies:

- The development of the new notation was performed by graphically annotating BPMN process models with information on occurrence dependences and rationales. We decided to use annotations as they enable to enrich existing notations without being too disruptive. We decided to focus on BPMN because of its popularity, but the idea of the annotation could be applied, in principle, to other business process modelling languages.

The evaluation made use of different instruments:

- Two use cases scenarios were used to show the usefulness of the new notation for business process *documentation* and *redesign* purposes;
- An empirical *user study* was conducted in two settings: (i) the first setting aims at evaluating the effectiveness of the new notation in the tasks of *redesign* and *comprehension*;(ii) in the second setting we performed a more qualitative analysis focused on the costs of introducing the new notation during the modelling activity.

Chapter 4

The literature-based business process meta-model

THE fist contribution of the thesis is to develop a business process meta-model which includes the fundamental components of a business process (**GOAL 1**). This contribution has been achieved by performing ***TASK 1***. Business process meta-models are used in the literature to capture the types of *entities* included in a notation and the way these entities can be *related* to each other. They can also make explicit the specific view of business process (e.g., instance level, model level), or the specific sub-domain (dimension) they focus on (e.g., organisation-oriented, information-oriented, behaviour-oriented, and so on). For these reasons we deemed important to propose a meta-model as a way to contribute to the investigation of what constitutes a business process.

Rather than proposing a meta-model from scratch, we decided to first investigate what was available in the literature. Indeed several meta-models were proposed in the literature, both Business Process Modelling Language (BPML) dependent and BPML independent with different aims such as: "navigating" across the different BPMLs, bridge the gap across them, foster a common ground across different notations, and promote interoperability. Therefore we considered already existing business process meta-models a crucial source of knowledge on the constructs and rules which allow us to better understand what a business process is.

This initial search made us aware of the existence of several meta-models, which needed to be investigated and compared in depth. In addition, we realised that a framework that categorises and provides a general rationale of all the business process meta-models described in literature was still absent. Indeed, while several Systematic Literature Review (SLR) and surveys on Model Driven Engineering (MDE), and Model Driven Architecture (MDA) existed (see e.g., [dS15, SJV+12, LIA10, GC14, NKKT15]), a systematic investigation on the different types of meta-models available in the field of BPM was still lacking. This lack of a descriptive categorisation had several negative consequences: the first, and obvious one, was the lack of a comprehensive and easily accessible overview of what has been produced so-far in literature; the second consequence was the danger of over production of *quasi same* meta-models across the community of Business Process Management (BPM); a third consequence was the lack of a framework to categorise and compare the different proposals, which can act as a comprehensive common ground where to place new proposals of meta-models; and, finally, an investigation was missing on the characteristics, strengths and limits of the current meta-models, so as to identify gaps that may originate further investigations.

As a consequence of these observation, rather than selecting only few meta-models from the literature and use them as a starting point for proposing a "yet another meta-model" we decided to take a systematic data driven strategy which is based on an extensive and Systematic Literature Review (from now a SRL) of existing meta-models found in the literature and then on the extraction of the most recurrent entities and relations from the meta-models identified. This SLR had the objective of identifying a literature-based meta-model (*LB meta-model*) which would act as a starting point to understand and clarify which elements constitute a business process and how they can be understood.

This SRL of business process meta-models follows the guidelines for conducting a SLR proposed in [Kit04, KC07] and follows the approach introduced in Section 3.1. In this Chapter we describe the results that emerged from the SLR concerning the components of the identified meta-models. These results are organised as follows: in Section 4.1 we present the research questions that drove the review and the protocol of the review; in Section 4.2 we describe the findings of the review, in particular in Sections 4.2.2 we explain the process of extracting the entities of various meta-models, while in Section 4.2.3 we report the extraction of the different relations. In Section 4.3 we combine entities and relations thus composing the *LB meta-model*; in Section 4.4 we discuss some open issues including of the *LB meta-model*; in Section 4.5 we provide an assessment of the *LB meta-model*; ultimately, in Section 4.6 we focus on the contributions and the limitations of the Chapter. Finally, by conducting the SLR we were able to address some further research questions concerning the characteristics of the proposed meta-models that are not directly linked with the achievement of **GOAL 1**. These results are condensed in Appendix A.

4.1 Planning the review of business process meta-models

Following the guidelines proposed in [Kit04, KC07], this SLR is divided in three pivotal phases, graphically summarised in Figure 4.1: *planning* the review; *conducting* the review; and *reporting*.

This Section is focused on the description of the *planning* of this SLR with particular emphasis to the definition of the research questions and the specific protocol adopted. The *conduction* of the review, and its results are described in the next three sections, while this work, and the additional material linked in [AGF19], constitutes the SLR *report*.

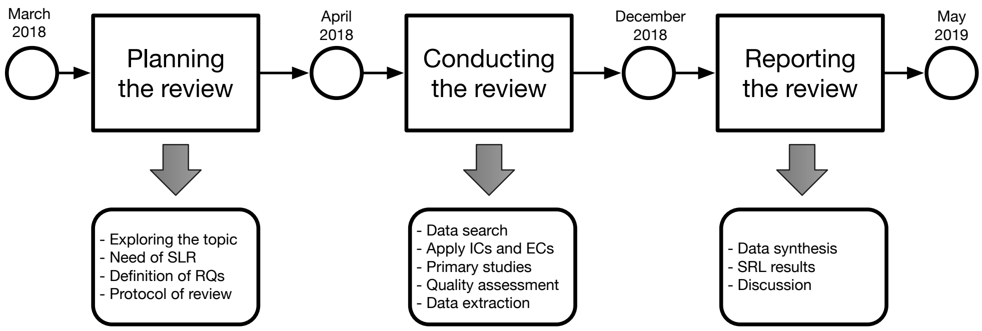


Figure 4.1: Method used for the SLR

The research questions. Starting from the needs identified and described in the previous section we have formulated a generic research question further detailed in two specific ones. They are:

- **RQ 1.** How can we extract a meta-model from the literature?
  - *RQ1.1* What are the business process entities recurring across business process meta-models?
  - *RQ1.2* What are the relations between those entities?

The aim of *RQ1.1* is the identification of the entities and components of business processes that occur in meta-models. Besides providing a photograph of the different components, this research question aims at investigating which are the elements of a business process that are (more) often represented in meta-models and whether these elements correspond to the ones that often occur in the definition of a business process. Focusing on the *RQ1.2*, RQ1.2 is designed with the purpose to find the most recurrent relations between the entities.

The protocol of review. The protocol of review was designed around four main phases: (i) data source and strategy; (ii) inclusion and exclusion criteria; (iii) development of the quality assessment; and finally (iv) data extraction strategy and analysis.

In the phase of *data source and strategy* we selected the paper repositories and we created the search queries to be used in our SLR. We decided to perform two different types of searches. First, we decided to targeted paper repositories, and retrieve papers by means of keyword-based queries. Second, we decided to targeted proceedings of relevant conferences.

The paper repositories we decided to target are DBLP[1], Scopus[2], and Web of Science[3] (WoS). Scopus and WoS were considered because of their extensive coverage on well established scientific

[1] https://dblp.uni-trier.de/
[2] https://www.scopus.com/search/form.uri?display=basic
[3] https://login.webofknowledge.com/error/Error?PathInfo=2F&Error=IPError

Scopus	`("metamodel" OR "meta-model") AND ("business process" OR "process model")`
DBLP	`metamodel|meta-model AND business process|process model`
WoS	`((TS ="metamodel" OR TS="meta-model") AND (TS="business process" OR TS="process model")) AND LANGUAGE:(English)`

Table 4.1: Key-words on Scopus, DBLP, and WoS.

literature, especially journal papers. DBLP was included because of its extensive coverage of papers on computer science including papers published in peer reviewed conference and workshop proceedings. To formulate the keyword-based query we queried the three paper repositories in an iterative manner considering several combinations of keywords (e.g., process, process model, business process, business process modelling languages, meta-model, metamodel) connected by the logical operators AND and OR. The result was the adoption of the query

$$\texttt{metamodel OR meta-model AND business process OR process model} \tag{4.1}$$

whose actual implementation in the syntax of the three repositories is shown in Table 4.1.

The proceedings we included in the data sources are the ones of the two reference conference venues in the BPM research area, namely the *Business Process Management* (BPM) conference series[4] and the *Conference on Advanced Information Systems Engineering* (CAiSE) series[5].

The next step of the protocol was to define some relevant *inclusion and exclusion criteria* (ICs\ECs) in order to evaluate the appropriateness of the papers returned as query results for this study and thus filter them.

Inclusion (IC) and Exclusion (EC) criteria are reported in Table 4.2. In order to be included papers had to satisfy all inclusion criteria IC 1 – IC 3. Moreover, they were excluded if they satisfied at least one of the exclusion criteria between EC 1 and EC 8. Basically, all these inclusion and exclusion criteria focus on removing duplicate, incomplete or not scientifically valid papers or refer to the primary criterion of this review, i.e., the paper has to present a meta-model of business processes. Moreover, to maintain the SLR focused, and the amount of papers manageable, we restricted ourselves only to papers where the business process aspect is the main / exclusive focus of the paper, thus excluding papers mainly devoted to enterprise (meta-)models or service oriented (meta-)models.

In this phase we decided not to consider ECs limiting the papers selection according to the date of publication. The reason for this choice lies in the fact that this is the first SLR in this field. Thus, we felt we had to consider the maximum number of papers available in literature.

[4] https://link.springer.com/conference/bpm
[5] https://link.springer.com/conference/caise

IC 1:	The paper proposes a meta-model of business processes or BPMLs.
IC 2:	The meta-model is either originally developed or originally adapted by the authors.
IC 3:	The paper focuses mainly / exclusively on business process aspects.
EC 1:	The paper is not available.
EC 2:	The paper is duplicate.
EC 3:	The paper does not belong to the BPM field.
EC 4:	The paper does not mainly consider the business process view, but rather it is focused on organisational\entrepreneurial aspects without touching the business process level.
EC 5:	The paper either was not under peer-review, or it is a technical report.
EC 6:	The paper is almost the “same copy" of others of the same author(s).
EC 7:	The paper either does not include a wide analysis of related works or does not position in the state of the art.
EC 8:	The paper is not long enough to present a complete meta-model.

Table 4.2: Inclusion and Exclusion Criteria.

The last phase of the protocol is defining the *quality assessment* (QA) criteria. The four quality assessment criteria we planned and used in this SLR are:

QA1: Is a well-defined methodology used?

- Yes: The study relies on a methodology, which is clearly described in the study.
- Partially: The study relies on a methodology, but the methodology is not clearly described in the study.
- No: No methodology is used in the study.

QA2: Is the study clearly positioned within the state-of-the-art landscape?

- Yes: The study is inserted in the state-of-the-art landscape, which is well documented in a dedicated related work section.
- Partially: The study is inserted in the state-of-the-art landscape, but a proper related work section is missing in the paper.
- No: The study is not inserted in the state-of-the-art landscape and a proper related work section is missing in the paper.

QA3: Is the goal of the study elucidated?

- Yes: The goal of the study is clearly defined and supported by results.
- Partially: The goal of the study is clearly defined but it is not supported by results.

- No: The goal of the study is not defined.

QA4: Was the study evaluated\validated?

- Yes: The primary study was evaluated\validated through a case study.
- Partially: The primary study was evaluated\validated through a simple example.
- No: The study was not evaluated\validated at all.

We decided to use QA1–QA4 to mark papers with three possible scores: *Yes (Y)*, *No (N)*, and *Partially (P)*, weighted 1, 0 and 0.5 respectively. The actual conduction of the SLR and its results are widely described in Section 4.2.

4.2 Conducting the Systematic Literature Review and answering the RQs

The extraction of the primary studies and the answer to the research questions *RQ1.1* and *RQ1.2* are described in this Section. More specifically, this Section is organised as follows: the identification of the primary studies is described in Section 4.2.1; the recurring entities contained in the meta-models are is presented in Section 4.2.2 where we answer *RQ1.1*; the recurring business process relations are presented in Section 4.2.3 where we answer to *RQ1.2*.

4.2.1 Extraction of the primary studies

This section briefly describes the extraction of the primary studies according to the protocol, and the outcomes of each single step in the process (data search, application of inclusion and exclusion criteria, and quality assessment).

Papers were selected using the keyword-based queries in early April 2018. Their numbers are reported in the first column of Table 4.3. 1398 papers were returned (1005 from Scopus, 367 from WoS, and 26 from DBLP), which were reduced to 1306 after the deletion of collections (e.g., entire proceedings) which were not considered as a single item in this survey. All 452 papers from the BPM conferences (starting from 2003 to 2018) and all 1065 papers published in the CAiSE conferences (starting from 1990 to 2018) were also included in the initial set of papers to be considered[6]. The resulting 2823 papers were pruned from duplicates (papers appearing

[6]We have not considered papers related to keynotes speeches and tutorials from both the BPM and CAiSE proceedings.

Source	Query Results	No Collections	No Duplicates	After IC/EC	In Primary Studies
Scopus	1005	913			31
WoS	367	367			16
DBLP	26	26			5
CAiSE		1065			4
BPM		452			0
Total		2823	2463	36	

Table 4.3: Query results and selection of Primary Studies.

more than once in the same data source or in at least two data sources) and retracted articles thus reducing the total number of candidates to 2463[7].

The next step was to apply the IC/EC described in Table 4.2 to these 2463 papers that constitute our starting data collection. IC/EC have been applied by looking at the title and the abstract and by inspecting the paper, when the information in the abstract was not informative enough. As a result of this step, 36 papers were retained. These 36 papers constitute our primary studies and are listed in Table 4.4 classified as workshop, conference (symposium), and journal publications. While their venue of publication is reported in Table 4.5[8].

Year	Workshop Reference	Conference Reference	Journal Reference
2002		Söderström et al. [SAJ+02]	
2003			Papavassiliou and Mentzas [PM03]
2004		Momotko and Subieta [MS04]	
2005	Grangel et al. [GCSP05] Thom et al. [TIM05]	Russell et al. [RvdAtHE05]	
2006		List and Korherr [LK06] Weigandet al. [WJA+06]	
2007		Combemale et al. [CGC+07] Korherr and List [KL07]	Axenath et al. [AKR07] Farrell et al. [FSB07]
2008		Holmes et al. [HTZD08] La Rosa et al. [LDtH+08]	Rosemann et al. [RRF08]
2009			
2010		De Nicola et al. [DMPS10]	Mili et al. [MTJ+10b]

[7]Details of all the retrieved papers, and of the ones removed in each step can be found in the CSV (Comma Separated Values) files accessible starting from the folder at https://drive.google.com/drive/folders/1_mdJBCtfQg2triqUb01AoMu7OBfahIZz?usp=sharing

[8]The venues marked with ** are classified as Quartile 1 (Q1) or A/A* according to the Scopus journal ranking 2017 and the CORE conference ranking 2017, respectively. The venues marked with * are classified as Quartile 2 (Q2) or B according to the Scopus journal ranking 2017 and the CORE conference ranking 2017, respectively.

		Hua et al. [HZS10] Santos Jr. et al. [SAG10]	
2011	Heidari et al. [HLK11] Natschläger [Nat11]	Brüning and Gogolla [BG11] Weißand Winkelmann [WW11]	Strembeck and Mendling [SM11]
2012			
2013		Bouneffa and Ahmad [BA13] Heidari et al. [HLBB13]	Cherfi et al. [CAC13] Damaggio et al. [DHV13] Mosser and Blay-Fornarino [MB13]
2014	Kunchala et al. [KYY14] Ruiz et al. [RCE^{+}14]	Rospocher et al. [RGS14]	
2015		Sprovieri and Vogler [SV15]	Martins and Zacarias [ZMG17]
2016		Ben Hassen et al. [BTG16] Krumeich et al. [KZM^{+}16]	Arévalo at al. [ACRD16]
2017		Ben Hassen et al. [BTG17] Dörndorfer and Seel [DS17]	Zacarias et al. [MZ15]

Table 4.4: The Primary Studies.

Journal	Paper
Information and Software Technology**	[ACRD16, SM11]
International Journal of Business Process Integration and Management	[AKR07, RRF08]
Journal on Data Semantics*	[CAC13]
Journal of Knowledge Management	[PM03]
Information Systems**	[DHV13]
Science of Computer Programming	[MB13]
Procedia Computer Science*	[MZ15]
Group Decision and Negotiation*	[FSB07]
Conference & Symposium	**Paper**
International Conference on Business Informatics	[HLBB13]
International Conference on Intelligent Systems Design and Applications	[BTG16]
International Conference on Database and Expert Systems Applications*	[DMPS10]
International Conference on Conceptual Modeling**	[LDtH^{+}08]
International Conference on Information Systems**	[HZS10]
East European Conference on Advances in Databases and Information Systems	[MS04]
International Conference on Enterprise Information Systems	[KL07, BA13]
International Conference on Advanced Information Systems Engineering**	[SAJ^{+}02, RCE^{+}14, RvdAtHE05, WJA^{+}06]
European Conference on Model Driven Architecture-Foundations and Applications	[HTZD08]
International Conference on Enterprise Systems	[SV15]
Hawaii International Conference on System Sciences	[WW11]
International Enterprise Distributed Object Computing Conference*	[BG11]
Multikonferenz Wirtschaftsinformatik	[KZM^{+}16]
Internationale Tagung Wirtschaftsinformatik	[DS17]
ACM Symposium on Applied Computing*	[LK06, SAG10]
International Symposium on Business Modeling and Software Design	[BTG17]
Workshop	**Paper**
International Workshop on Personalization and Context-Awareness in Cloud and Service Computing	[KYY14]
Workshop on Enterprise and Organizational Modeling and Simulation	[HLK11]
Workshop on Business Process Intelligence	[GCSP05]
Workshop XML for Business Process Management	[TIM05]
International Workshop on Business Process Modeling Notation	[Nat11]

Table 4.5: Primary Studies' Publication Venues.

As summarised in the last column of Table 4.3, 31 of these 36 papers were extracted (at least) from Scopus, 16 (at least) from WoS, 5 (at least) from DBLP, 4 (at least) from CAiSE.

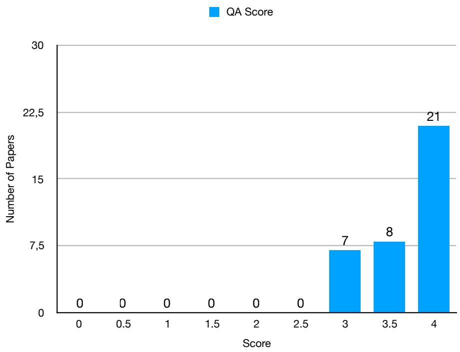


Figure 4.2: Results grouped by paper.

	QA1	QA2	QA3	QA4
Yes	36	34	36	23
Partially	0	2	0	6
No	0	0	0	7
Total Score	36	36	36	36

Table 4.6: Results grouped by QA.

A summary of the quality assessment evaluation is reported in Figure 4.2 and Table 4.6. All papers scored high on most of the questions, with 21 papers scoring *Yes* in all four questions, 8 papers scoring 3.5 in total and 7 papers scoring 3 in total (see Figure 4.2). The only *No* answers concerned the evaluation, where 7 papers out of 36 had a negative score as they did not report any evaluation (see Table 4.6).

4.2.2 Recurring business process entities

The aim of *RQ1.1* is to present an overview of the *entities*[9] involved in the primary studies' meta-models. In answering this question we have read the paper and extracted 374 single entities. We considered as single entities only those that are not collections of other entities. For instance "business process", "process" and "control flow" were not included in this analysis. These entities have been grouped in 12 sets of recurrent constructs across the classes of meta-models. These 12 sets identify macro-entities that appear in the primary studies' meta-models, and are: *activity*, *event*, *state*, *sequence flow*, *time*, *data flow*, *data object*, *actor*, *resource*, *value*[10], *goal*, and *context*. Out of the 374 single entities we kept only the ones appearing in at least two meta-models, thus reducing the number of entities to 91.

[9]Here, we take the terminology "entity" as in *Entity-Relationship* (ER) language [Che76].

[10]Although the explicit entity "value" only occurs in one of the meta-models of the primary studies [WJA+06] and hence does not explicitly appear among the entities of the *value* group, all the entities included in this group refer to measurable aspects related to the value of a business process.

Table 4.7 reports the 91 entities, organised according to the 12 macro-entities[11]. Note that, entities labelled as *events* have been classified either as events with a BPMN-like semantics, i.e., “something that happens during the course of a process” [Mod11] (`event-BPMN`) or as events *à*-la EPC, i.e., in terms of pre-postconditions (`event-EPC`). The table also reports the number of meta-models in which the entity occurred (reported in round brackets), when it is applied. For instance, the entity `time point` occurred in (2) meta-models. Entities with the same (very similar) meaning but with different names, i.e., syntactic variables, have been all classified under a single name. The table also reports in round brackets, for each macro-entity, the number of entities per category together with the total number of occurrences of macro-category entities. For example, the macro-entity *state* includes 5 different entities for a total of 27 occurrences of those entities.

From the analysis we identified four main groups of macro-entities: *activity*, *sequence flow*, *data object* and *actor*. The *sequence flow* macro-entity is the most articulated one with its 18 entities and 91 occurrences. An interesting group is the one of *data object*, showing 17 entities, even though their appearance is not as frequent as the one of the other three groups. The second largest group is *activity* with its 64 occurrences. Also this group is very diversified including many kinds of “activities”. This group also contains the most recurrent entity in the meta-models, i.e., `activity` (27). Another key area of business processes is the *actor*/organisational aspect. Indeed, also in the meta-models, we found several occurrences of organisational-related entities (72). We also surprisingly found that other groups of entities appearing in existing business process definitions, as for instance *goal* and *value*, do not occur very often in the meta-models. In particular *goal* is considered as central in one of the most recent business process definition proposed by Weske in [Wes12b], however the entity `goal` appears only few times in the meta-models. Yet, also some time-related entities are not very represented. For instance only five entities are considered in the macro-entity *state* and also the entity `state` itself appears in only 4 meta-models. We also observed that five entities are considered as members of more than one group, such as `information`, `position`, `role`, `application`, and `process participant`. In this sense, the macro-entity *resource* is the most interconnected having entities in common with the group *actor* and *data object*. This aspect is mainly due to the fact that some entities could play several roles in a business process (model). For instance `information` could be conceived as a resource but also as a data object.

Overall, only 14 entities of the extracted ones occurred in at least the 25% of the meta-models. These entities are reported in bold in Table 4.7. The only entity that appeared in more than half of the meta-models is `activity`.

[11] Appendix B contains, instead, the correspondence between each element and the primary studies in which it appears

Macro-entity	Entity
activity **(9/64)**	**activity** **(27)**, **atomic activity** **(9)**, **compound activity** **(13)**, activity instance **(4)**, manual activity **(2)**, automatic activity **(2)**, collaborative organisational activity **(2)**, critical organizational activity **(2)**, cancel activity **(3)**
event **(10/41)**	**event-EPC** **(4)**, **event-BPMN** **(9)**, event sub-process **(3)**, throw event **(2)**, interrupting **(2)**, start event **(6)**, intermediate event **(3)**, end event **(8)**, message event **(2)**, event location **(2)**
state **(5/27)**	state **(4)**, **precondition** **(9)**, postcondition **(8)**, data input **(3)**, data output **(3)**
sequence flow **(18/91)**	conditional control flow **(4)**, sequence **(3)**, multimerge **(2)**, multi choice **(2)**, syncronisation point **(2)**, connecting object **(7)**, sequence flow **(7)**, condition **(2)**, merge **(2)**, join **(2)**, fork **(2)**, **gateway** **(16)**, complex gateway **(2)**, event-based gateway **(2)**, **parallel gateway** **(12)**, **inclusive gateway** **(9)**, **exclusive gateway** **(11)**, flow operator **(4)**
time **(3/6)**	time point **(2)**, cycle time duration **(2)**, temporal dependency **(2)**
data flow **(6/19)**	message flow **(5)**, data flow **(5)**, association **(3)**, conversational link **(2)**, knowledge flow **(2)**, assignment to an actor **(2)**
data object **(17/48)**	**artefact** **(9)**, physical artefact **(2)**, data object **(5)**, message **(3)**, conversation **(3)**, call conversation **(2)**, information **(3)**, physical knowledge support **(2)**, internal knowledge **(2)**, tacit knowledge **(2)**, external knowledge **(2)**, explicit knowledge **(2)**, procedural knowledge **(2)**, knowledge **(3)**, document **(2)**, artefact instance **(2)**, data store **(2)**
actor **(14/72)**	**actor** **(14)**, collective agent **(4)**, organisation **(6)**, organisation unit **(6)**, human expert **(2)**, internal agent **(2)**, external agent **(2)**, client **(4)**, position **(4)**, application **(4)**, **role** **(15)**, process owner **(2)**, process participant **(4)**, person **(3)**
resource **(8/50)**	**resource** **(13)**, material resource **(3)**, immaterial resource **(3)**, information **(4)**, position **(4)**, **role** **(15)**, application **(4)**, process participant **(4)**
value **(2/5)**	measure **(3)**, cost **(2)**
goal **(2/8)**	organisational objective **(2)**, goal **(6)**
context **(2/4)**	context **(2)**, business area **(2)**

Table 4.7: Recurring entities in meta-models.

4.2.3 Recurring business process relations

RQ1.2 is answered by examining the relations between the business process entities that: (i) either occurred in at least the 25% of the primary studies (i.e., the ones reported in bold in Table 4.7)[12]; or (ii) occurred at least 6 times in the macro-category *goal*. These criteria guarantee that most of the macro-entities include their most recurrent components. In total 15 entities were hence considered: activity, atomic activity, compound activity, event-BPMN, event-EPC, gateway, AND (parallel gateway), OR (inclusive gateway), XOR (exclusive gateway), precondition, artefact, actor, role, resource, and goal.

[12]For the entity *event*, we considered the global frequency of the *event* label given by the sum of the frequencies of the two entities event-BPMN and event-EPC.

Among these entities, we manually inspected the papers and identified 89 relations. Some of these relations exhibited a similar semantics and were hence merged; others had a very generic semantics (e.g., *is_related_with*) and were hence removed - unless they were the only representative relation between a pair of entities. As result of this filtering, a total of 57 different types of relations between business process (modelling) entities were taken into account. Table 4.9 reports these resulting 57 relations and the number of meta-models in which the relation occurred (among round brackets), in the case these relations occur in more than one meta-model The list of the 57 relations with cardinalities and references can be found in Table 4.8. Concerning the cardinalities, when two or more relations did overlap, we kept the less restrictive one. In Table 4.9, we grouped business process modelling entities acting as domain and codomain of the relations into the three basic business process modelling language categories (BEHAVIOURAL, ORGANISATIONAL, and DATA) and a fourth GOAL category characterizing the entities related to the goal of the process. Relations are organized such that each block collects the list of relations having as domain an entity belonging to the category in the row and as codomain an entity belonging to the category in the column[13]. For instance, the relation *involves* between activity and actor lies in the cell at the cross between the BEHAVIOURAL row (as activity is a BEHAVIOURAL entity) and the ORGANISATIONAL column (as actor is an ORGANISATIONAL entity).

Relation	Domain (with cardinality)	Codomain (with cardinality)	Reference
composed_of	one or two activity	at least one activity	[LK06]
transition(CF)	0,n activity	0,n activity	[RvB15]
initiated_by	at least one activity	zero or more event-BPMN	[LK06]
creates	1 or more activity	1 or more event-EPC	[SAG10]
predecessor	0 or more activity	at least one event-EPC	[KZM+16]
successor	0 or more activity	at least one event-EPC	[KZM+16]
requires	exactly one activity	0 or more precondition	[HLBB13]
is_performed_on	no specified activity	no specified artefact	[KYY14]
manipulates	0 or more activity	0 or more artefact	[RvB15][14]
invokes	0 or more activity	0 or more artefact	[RvB15][15]
involves	no specified activity	no specified actor	[RCE+14]
performed_by	no specified activity	no specified actor	[BA13]
under_the_responsability	no specified activity	no specified role	[PM03]
requires	no specified activity	no specified resource	[CAC13]
inputs	at least one activity	at least one resource	[SAJ+02]
outputs	at least one activity	at least one resource	[SAJ+02]
supports	0 or more activity	0 or more goal	[RvB15]
is_a	atomic activity	activity	[HLBB13, AKR07] [LK06, CAC13] [ACRD16, TIM05, MS04]
belongsTo	exactly one atomic activity	at least one compound activity	[HLBB13]
is_related_to	no specified atomic activity	at least one artefact	[MS04]
performed_by	zero or more atomic activity	at least one actor	[LK06]
produces_or_consumes	zero or more atomic activity	at least one resource	[LK06]
is_a	compound activity	activity	[HLBB13, AKR07] [LK06, TIM05, CAC13]

[13]The entity resource is used both in terms of human resource, i.e., ORGANISATIONAL resource and in terms of DATA resource, so the relations having resource as domain or codomain are duplicated in the table.

[14]This meta-model includes the relation *invokes* App(lication) to connect activity *manipulates* artefact.

[15]This meta-model includes the relation *manipulates* artefact to connect activity *invokes* App(lication).

			[MS04, ACRD16]
composed_of	no specified `compound activity`	no specified `activity`	[TIM05]
refined_by	at least one `compound activity`	0 or more `activity`	[LK06]
composed_of	at least one `compound activity`	exacctly one `atomic activity`	[HLBB13]
composed_of	0 or more `compound activity`	no or one `compound activity`	[HLBB13]
performed_by	no specified `compound activity`	no specified `actor`	[BA13]
activates	one or more `event-EPC`	one or more `activity`	[SAG10]
successor	at least one `event-EPC`	0 or more `activity`	[KZM+16]
predecessor	at least one `event-EPC`	0 or more `activity`	[KZM+16]
is_a	`gateway`	`activity`	[MS04, BG11]
is_related_with	no or one `gateway`	0 or more `compound activity`	[BG11]
is_a	`AND`	`gateway`	[HLK11, LK06]
			[SAG10, DMPS10]
			[PM03, KZM+16]
			[MS04, Nat11, LDtH+08]
is_a	`OR`	`gateway`	[HLK11, LK06]
			[SAG10, DMPS10]
			[PM03, KZM+16]
			[Nat11, BG11, LDtH+08]
is_a	`XOR`	`gateway`	[HLK11, LK06]
			[SAG10, DMPS10]
			[TIM05, PM03]
			[KZM+16, MS04]
			[Nat11, LDtH+08, BG11]
is_required_by	exactly one `precondition`	0 or more `activity`	[HLBB13]
enables	no specified `precondition`	no specified `activity`	[SV15]
carriesOut	one or more `actor`	0 or more `activity`	[SAG10]
carriesOut	no specified `actor`	no specified `activity`	[RCE+14]
is_associated_with	exactly one `actor`	no or one `actor`	[ACRD16]
inherited_role	0 or more `actor`	0 or more `role`	[SM11]
is_a	`actor`	`role`	[PM03]
uses_owns	no specified `actor`	no specified `resource`	[PM03]
achieves	no specified `actor`	no specified `goal`	[RCE+14]
enacts	no specified `role`	no specified `activity`	[CAC13]
inherited_task	0 or more `role`	0 or more `activity`	[SM11]
responsible	exactly one `role`	at least one `activity`	[SAJ+02]
temporal_relationship	no specified `role`	no specified `activity`	[HZS10]
is_a	`role`	`actor`	[RCE+14]
subordinated_of	0 or more `role`	0 or more `role`	[TIM05]
is_a	no specified `role`	no specified `resource`	[SAJ+02]
assigned_to	no specified `resource`	no specified `activity`	[AKR07]
is_a	`resource`	`precondition` (of data, action)	[RCE+14]
is_a	`resource`	`artefact`	[WJA+06]
satisfies	no specified `resource`	no specified `actor`	[RCE+14]
is_a	`resource`	`role`	[PM03]
is_composed_of	no or one `goal`	0 or more `goal`	[RvB15]

Table 4.8: Meta-models relations and cardinality.

The analysis of Table 4.9 shows that relations among entities in existing meta-models are relatively few with respect to the number of retrieved entities. Furthermore, most of the relations appear in only one meta-model, as for instance the relation *assigned_to* between `resource` and `activity`. In contrast, a very small set of relations occurs in more than one meta-model, as for instance the *is_a* relation between `atomic activity` and `activity` as well as between `compound activity` and `activity`.

By looking at the table, we can observe that the BEHAVIOURAL entities are mostly disjoint from

	BEHAVIOURAL			ORGANISATIONAL			DATA			GOAL		
	Domain	Codomain	Relation	Domain	Codomain	Relation	Domain	Codomain	Relation	Domain	Codomain	Relation
BEHAVIOURAL	activity	activity	*composed_of, transition(CF)*	activity	actor	*involves, performed_by*	activity	artefact	*invokes manipulates, is_performed on*	activity	goal	*supports*
	activity	event-EPC	*creates, predecessor, successor,*	activity	role	*under_the_ responsibility*	activity	resource	*requires, input, output*			
	activity	event-BPMN	*initiated_by*	activity	resource	*requires, input, output*	atomic activity	artefact	*is_related_to*			
	activity	precondition	*requires*	atomic activity	resource	*produces_or consumes*	atomic activity	resource	*produces_or_ consumes*			
	atomic activity	activity	*is_a(7)*	atomic activity	actor	*performed_by*						
	atomic activity	compound activity	*belongs_to*	compound activity	actor	*performed_by*						
	compound activity	activity	*is_a(7) composed_of refined_by*									
	compound activity	atomic activity	*composed_of*									
	compound activity	compound activity	*composed_of*									
	event-EPC	activity	*activates successor predecessor*									
	gateway	activity	*is_a*									
	gateway	compound activity	*is_related_ with*									
	AND	gateway	*is_a*(9)									
	OR	gateway	*is_a*(9)									
	XOR	gateway	*is_a*(11)									
	precondition	activity	*is_required_by enables*									
ORGANISATIONAL	actor	activity	*carries_out(2)*	actor	actor	*is_associated_ with*	actor	resource	*uses/owns*	actor	goal	*achieves*
	role	activity	*enacts, inherited_task, responsible, temporal_ relationship*	actor	role	*inherited_role, is_a*	resource	artefact	*is_a*			
	resource	activity	*assigned_to*	actor	resource	*uses/owns*						
	resource	precondition	*is_a (data/action)*	resource	role	*is_a*						
				resource	actor	*satisfies*						
				role	actor	*is_a*						
				role	role	*subordinated _of*						
				role	resource	*is_a*						
DATA	resource	activity	*assigned_to*	resource	actor	*satisfies*	resource	artefact	*is_a*			
	resource	precondition	*is_a (data/action)*	resource	role	*is_a*						
GOAL										goal	goal	*composed_of*

Table 4.9: Recurring relations in meta-models.

the ORGANISATIONAL/DATA and GOAL categories. We can indeed identify two main clusters of relations: the one having domain and codomain entities in the BEHAVIOURAL category (top left cell of Table 4.9); and the one with domain and codomain entities in the ORGANISATIONAL\DATA categories (central cells in Table 4.9). Besides these two main clusters, we can identify few relations at the cross between the BEHAVIOURAL and ORGANISATIONAL/DATA categories and very few relations involving the GOAL category (and corresponding `goal` entity).

Looking at the entities, we can also observe that some of them are scarcely connected through relations. For instance, the entity `goal` acts as the domain of only one reflexive relation (`goal` *composed_of* `goal`) and as codomain of only two further relations (*achieves* and *supports*). Entities such as `artefact`, `AND`, `XOR`, `OR` and `event-BPMN,EPC` are other examples of entities that are poorly connected to other entities. In contrast `activity` is shown to be the most interconnected entity: it is the domain of 17 types of relations and the codomain of 19 types of relations. In the group of ORGANISATIONAL entities, the entity acting as domain for most of the

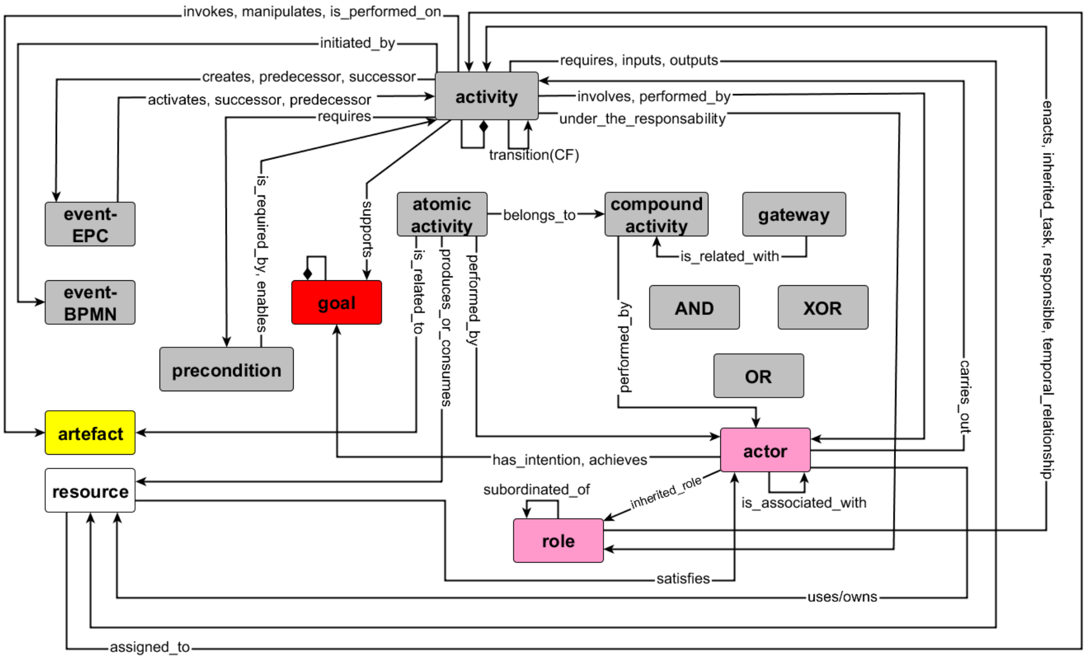


Figure 4.3: Literature-based meta-model

relations is instead `actor`, having as codomain mainly ORGANISATIONAL and DATA entities. By looking at the number of different relations between pairs of entities, we can observe that, also in this case, while most of the pairs of entities have at most one relation, the highest number of different relations can be found between `activity` and `event-EPC` and `event-BPMN` as well as between `role` and `activity`. Finally, a handful of entities display a finer level of granularity being composed of simpler entities, e.g., `activity`, `compound activity` and `goal`.

Summing up, more than 10% of the types relations occurred more than once in state-of-the-art meta-models: the *is_a* relation between `atomic activity` and `activity`, between `compound activity` and `activity`, between `AND` and `gateway` as well as between `OR`, `XOR` and `gateway`; and the relation *carries_out* between `actor` and `activity`. Slightly more than 63% of the relations included the entity `activity` either as domain or codomain. Around 42% of the relations have both domain and codomain in the BEHAVIOURAL entities, more than 17% involve ORGANISATIONAL/DATA domains and codomains, while out of the remaining of the relations, 35% is at the intersection of the two and roughly 5% of the relations deals with the GOAL entity.

4.3 The literature-based meta-model

The extraction of the entities and the relations described in the last two sections allows us to outline those aspects of business processes (models) deemed most important by the scholars who have proposed business process meta-models in the literature. This section answer **RQ1** by combining the extracted entities and relations and merging all of them in a unique meta-model, the so called *literature-based business process meta-model* (*LB meta-model*). Note that the *LB meta-model* is composed of: (i) the entities selected for the extraction of the relations (entities that occurred in at least the 25% of the primary studies or that occurred at least 6 times in the macro-category *goal*) and (ii) the relations occurring among these entities summarised in Table 4.9. This meta-model together with its critical analysis and assessment contained in the next sections, represents our contribution towards the achievement of **GOAL 1**.

When combining parts of different meta-models together into a unique conceptual model, we were fully aware of the fact that some discrepancies or inconsistencies could arise. Indeed, it was clear to us that different meta-models had heterogeneous views on (part of) business process components. Nevertheless we decided to create this unique *LB meta-model* as a way to identify these discrepancies and contradictions.

Figure 4.3 depicts the literature-based meta-model in UML without the taxonomical relations. In the meta-model the grey boxes represent the BEHAVIOURAL entities, the pink boxes denote the ORGANISATIONAL entities, the yellow boxes represent the DATA entities, and the red box depicts the unique GOAL entity. Finally, the `resource` entity, which is shared by the ORGANISATIONAL and DATA components, is depicted in white. Each entity is connected to the other entities according to the relations reported in Table 4.9. We chose to report on the connecting edges the label of *all* the relations connecting the two entities.

In the process of creating the meta-model, a problem we had to overcome was the establishment of the semantics of its components (i.e., the labels' semantics) or, at the very least, the clarification of their intended meaning. In fact, only few authors included explicit meta-model (formal or not) semantics (e.g.,[DHV13, SAG10, WJA+06]), while in most of the cases it was either lacking or provided only in terms of common-sense descriptions. Since our overarching meta-model is generated from the ones available in the surveyed papers, in order to avoid bias, we also opted to use an intuitive semantics for business process (modelling) components (e.g., `https://www.businessprocessglossary.com`).

Behavioural part. Observing the meta-model in Figure 4.3, it is immediately clear that `activity` is the most important entity. It is directly connected with almost all other entities, that is reasonable given its centrality for business processes. Moreover, most of the entities of the BEHAVIOURAL component (e.g., `atomic activity`, `compound activity`, `gateway`) are related through *`is_a`* relations to `activity` (see next Section 4.3). Differently from `activity`,

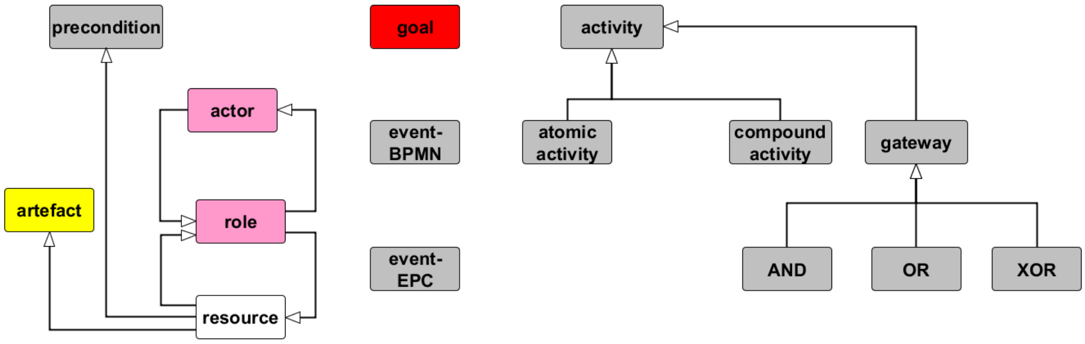


Figure 4.4: Literature-based meta-model taxonomy

more than half of the BEHAVIOURAL entities (e.g., `event-BPMN`, `event-EPC`, `gateway`, `AND`, `OR` and `XOR`) are almost disconnected from the other categories. This lack of connection with other components is particularly surprising for `gateways` that we would have expected to be connected not only with BEHAVIOURAL but also with DATA entities, considering the fact that they deal with control and decision flow.

Organisational\data and goal parts Looking at the DATA and ORGANISATIONAL entities, we can also notice that, despite the importance of data and organisational aspects in business processes, a unique DATA entity - `artefact` - and two ORGANISATIONAL entities - `actor` and `role` - appear in the meta-model, besides the shared `resource` entity. The `artefact`, which has several relations with the `activity` (and its sub-classes) and an *`is_a`* relation with `resource`, is only indirectly related to the other entities. For instance, it is indirectly connected to the `actor`, through the `activity` entity: the `actor` *`carries_out`* an `activity`, which, in turn *`manipulates`* an `artefact`. An `actor`, besides *`performing`* `activities`, has also other *agentive capabilities*, e.g., it *`uses and owns`* `resources`, as well as *`achieves`* `goals`. The `resource` entity also presents a number of relations, many of which are *`is_a`* relationships. Lying at the cross between the DATA and ORGANISATIONAL boundaries, indeed, it has been classified using different terms, e.g, as a *`precondition`*, as an *`artefact`* and as a *`role`*.

Last but not least, the meta-model in Figure 4.3 reveals the marginal role of the GOAL category and of the `goal` entity, which appears as an auxiliary entity that *`is_composed_of`* other `goals`, *`supports`* `activities` and is achieved by `actors`.

Taxonomy of the literature-based meta-model To conclude this section we provide a brief description of the taxonomy of the *LB meta-model* (Figure 4.4). Looking at the BEHAVIOURAL component, we can observe two main subsumption blocks, where an entity is specialised into entities with a finer level of granularity: `atomic` and `compound activity` are sub-classes of `activity`, and parallel (`AND`) inclusive (`OR`) and exclusive (`XOR`) gateways are sub-classes of `gateway`. Instead, `event-BPMN` and `event-EPC` are floating within the taxonomy. Moreover, besides reconfirming the centrality of the `activity`, we can also notice that all the BEHAVIOURAL entities - except for the `event-BPMN`, `event-EPC` and `precondition` - are subsumed directly or indirectly by the `activity` entity. Differently from what we found, we would have expected that at least the `event-BPMN`, being a "dynamic" entity, i.e., an entity with a duration, was classified as a behavioural component.

Considering the ORGANISATIONAL and DATA components, these are not integrated with the BEHAVIOURAL part. The *`is_a`* relations are intricately articulated: `resource` *`is_a`* sub-class of `role`, `artefact` and `precondition`; moreover `role` is an `actor` and vice-versa. As a consequence, a `resource` is a sub-class of `actor`. Finally, looking at the GOAL component, the `goal` entity is completely disconnected from any other components in the taxonomy.

4.4 Observation on the literature-based meta-model

The analysis carried out in the previous section reveals that the extracted meta-model is not very well balanced: some parts have richer descriptions, while others are only roughly specified. The entities and relations extracted from the primary studies reveal a good level of maturity in the BEHAVIOURAL component both in terms of entities and relations among entities. Also some of the ORGANISATIONAL and DATA entities, such as `actor`, `resource` and `artefact`, are quite well investigated although their semantics and relations are still quite unclear. The GOAL component, instead, is under-investigated and represented both in terms of entities and relations. The relations between entities across different categories are also rather limited, thus leaving the BEHAVIOURAL, the DATA/ORGANISATIONAL and the GOAL components poorly connected. Also within the same category, we can find a disproportion among entities: for instance, in the BEHAVIOURAL category, `activity` has been largely studied and is well connected to almost all the other entities, while entities as `event-BPMN` and `event-EPC` are less investigated and also disconnected from the other entities. In our opinion these points denote a lack of a mature answer to the fundamental question of "what constitutes a business process" and an evidence of the fact that most works have mainly addressed business processes just looking at control flow related aspects, somehow neglecting a comprehensive investigation which takes into account all the characterising aspects of this notion.

The imbalance among entities and categories in the *LB meta-model* is even more critical when taking into account their importance in business processes. For instance, according to Weske, a business process is "a set of activities that are performed in coordination in an organizational and technical environment. These activities jointly realize a business *goal* [emphasis added] [...]." [Wes12b]. By looking at the *LB meta-model* and at its taxonomy, however, we can clearly notice that the `goal` entity, besides being under-investigated in the literature, is also scarcely connected. This can be due to the lack of a graphical construct for representing goals in most of the business process modelling graphical notations. Indeed, only few notations include an explicit symbol for the representation of goals [ABF+18a].[16] Thus, while it seems to be "extremely clear and well agreed that business processes realise a business goal", as recently highlighted in [ABF+18a], it appears to be more difficult to leverage state-of-the-art business process meta-models to state exactly what this business goal is and which characteristics it detains, as recently highlighted in [ABF+18a]. Similarly, *value*, which appears in several business process definitions, does not appear at all in the *LB meta-model*.

A second criticality that we can observe in the *LB meta-model* revolves around event (and its two semantics) and `precondition`. The same label, indeed, is used in the literature for denoting two different concepts. The `event-BPMN` is commonly understood as "something that happens during the course of a process" [Mod11], that is, as an exogenous activity. The `EPC-event` is intended instead as "describing preconditions and postconditions of functions" [Men08], that is, in terms of state. This overloading of the same label, as well as the lack of a clear relation between `event-EPC` and `precondition` reveals a non-agreed understanding of these notions and of their relations within the community. This criticality is further confirmed when looking at the relations between the two notions of event and `activity`. While the *causality* essence of the *`initiated_by`* relation between `activity` and `event-BPMN` reflects the *active* nature of the `event-BPMN`, the *`predecessor`* and *`successor`* relations between `activity` and `event-EPC` confirms their *temporal* characterisation, the *`activates`* relation between `activity` and `event-EPC` is tricky. A state, indeed, is a passive entity, that cannot activate or cause anything by itself. The *`activate`* relation, however, refers to the complex notion of ARIS EPC event, which combines the two notions of `event-EPC` and `event-BPMN`.

Another issue emerging from the taxonomy extracted from the *LB meta-model* is related to the ORGANISATIONAL/DATA components. Indeed, the model reveals subsumption cycles between `actor`, `role` and `resource`, thus resulting in the equivalence of the three entities. These subsumption cycles and the consequent equivalence relation, due to the way in which entities and relations extracted from the literature have been composed in the *LB meta-model*, reveals that the community does not completely agree yet on the semantics of some ORGANISATIONAL/DATA entities and on the relations among them. This is especially true for the `resource` entity that in the taxonomy of the *LB meta-model* shows a hybrid nature. Indeed, besides its ORGANISATIONAL (a `resource` *`is_a`* `role`) and DATA nature (`resource` *`is_an`* `artefact`), the `resource` entity has also a BEHAVIOURAL nature (`resource` *`is_a`* `precondition`).

[16] Some versions of EPC, the ARIS modelling language [Sch02a], and Guard-Stage Milestone (GSM) notation [DHV13] include goals.

4.5 Assessing the *LB meta-model* against popular business process modelling languages

In this Section we provide a comparative assessment of the *LB meta-model* by comparing its components with five business process modelling languages (BPMLs). The assessment has been performed by following three steps: (i) extract the graphical components of five BPMLs (Section 4.5.1); (ii) group and systematise those components (Section 4.5.2); and (iii) compare the BPMLs graphical components with the entities of the *LB meta-model* (Section 4.5.3). The focus of this comparison is limited to the meta-model entities since the BPMLs not always have explicit relations in their notations.

The goal of this assessment was to understand the relationship between the meta-model entities and the ones proposed in mainstream BPMLs and from that to assess the coverage of typical components available in BPMLs (which intuitively represent different entities of business processes).

4.5.1 Extraction of the languages' graphical components

The languages considered for this study are: BPMN 2.0, UML-AD, EPC, CMMN, and DECLARE. These languages are already fully described in Section 2.1.2, however for a sake of presentation we summarise the main notations' constructs that we extracted for this study below:

- **BPMN 2.0:** The elements are divided in: (i) flow objects, (ii) data (i.e., artefact), (iii) connecting objects, and (iv) swimlanes:
  - Flow objects: events (start, intermediate, end), activities (task, sub-process), gateways (AND, OR, XOR),
  - Data: data objects, data inputs, data output, data stores,
  - Connecting objects: sequence flow, message flow, association,
  - Swimlanes: lane, pool.
- **UML-AD:** action node, object node, control node (decision node, fork, initial and activity final node, flow final node), activity partitions.
- **EPC:** function, event, logical operators (XOR, AND, OR), input and output data, material, services or resource objects; owners; organization units; supporting systems. In some versions there is represented also the element of goal.
- **CMMN:** tasks, stages (composite, atomic), milestones, event listeners, connectors, sentries (AND, OR).

- **DECLARE:** task, connectors, and patterns. For instance, precedence(A, B) is a pattern, A and B are task and the precedence connector is the relationship between A and B.

4.5.2 Grouping and systematization of the languages' components

We divided the modelling languages' components in three groups: *Behavioural* (BEV), *Data* (DT), and *Organizational* (ORG). The behavioural is further grouped in: *Functional*, *Flow*, *Event*, and *State*. The result of this grouping is summarized in Table 4.10.

In commenting Table 4.10, we can note that all the imperative languages, namely BPMN, EPC, and UML-AD, provide distinctive constructs to indicate the start and the end of a process. CMMN specifies only exiting conditions while DECLARE allows (but does not force) only the specification of the initial activity. Not surprisingly, all five languages have graphical symbols for atomic activities. Instead, subprocesses and generic groups of activities are foreseen in all languages but EPCs and DECLARE. Other common constructs are routing nodes, connectors and data objects. CMMN does not have specific constructs for routing nodes; nevertheless a combination of sentries and connectors can be used to route the control flow mimicking the logical operators. Similarly, also in DECLARE, where dedicated routing constructs are missing, DECLARE patterns are used to this purpose. The level of details of connectors can vary. Besides the one used to denote connections of the control flow, common to all languages, BPMN, EPC, and UML-AD provide symbols to denote the connections between actors (data) and activities, or the messages exchanged between different activities. Also, the level of detail of data objects can vary; e.g., EPC is particularly rich in defining a taxonomy of data objects. Alternative (OR, XOR) routing nodes can incorporate guards, i.e., conditions that specify which branch to follow, in all languages but EPC, where this role can be taken by states. Actors and organizational constructs are present in imperative languages, although using different notations.[17]

A distinction that is present in BPMN (and to some extent also in CMMN) is between active tasks, explicitly performed by the actor specified in a corresponding swimlane, and passive events that occur independently from the actor itself. Other distinctive aspects are (i) the explicit presence of pre- (activation) and post-conditions on activities, which is one of the characteristic features of CMMN and is also foreseen in UML-AD; (ii) the explicit presence of a state, which is a characteristic feature of EPCs where states and functions (tasks) have to interleave, and is also present in CMMN in the form of milestones.

[17] Note that CMMN allows to associate organizational entities to cases during the run-time phase.

		BPMN	UML-AD	EPC	CMMN	DECLARE
BEV	Func	Task Subprocess	Action node Activity	Function Process path	Task Stage	Task
BEV	Event	Start/End Intermediate Send/receive	Start/End node Accept event action Send signal action	–	Timer User Event Listener	–
BEV	Flow	Gateway Sequence Flow Message Flow	Control node Control Flow Object Flow	Logical operators Control Flow Info Flow	Connector Sentry	Connector Pattern
BEV	State	Guard on gateway	Guard on control node Pre- Post-condition on activity	Event Start/End event	Sentry Milestone	–
DT		Data object Data input data output data store	Object node	(I/O) data object	Case file item	–
ORG		Pool, Lane	Activity Partition	Organization Activity Owner	–	

Table 4.10: BPML's graphical components

4.5.3 Comparing the *LB meta-model* entities with the notations' components

Focusing on the comparison between the *LB meta-model* and the BPMLs, first we investigate which entities of the *LB meta-model* occur in the different BPMLs; then we focus on the opposite direction by analysing the components of the BPMLs which are, and are not contained in the *LB meta-model*.

Table 4.11 summarised the assessment of which entities of the *LB meta-model* occur in which BPMLs. In this Table we can note that the central entity of the *LB meta-model*, `activity` is considered in all BPMLs. Moreover all languages except EPC and DECLARE also consider activity elements of different granularity, corresponding to the ones of `atomic activity` and `compound activity`. Concerning the element *event* let us first consider the one *à*-la BPMN, that is `event-BPMN`. This element is included in BPMN, in a detailed and granular specification much greater than the one contained in the *LB meta-model* (see Table 4.10), in UML-AD and CMMN. The graphical element of event *à*-la EPC is instead only included in EPC. However in BPMN, UML-AD and CMMN it is possible to combine the symbols, such as states and events, to emulate the `event-EPC`. Regarding the entity `gateway`, the majority of the languages have either a representative component for the control nodes or a way to capture it. Continuing with the BEHAVIOURAL aspects, the entity `precondition` is included in most of the BPMLs either as a guard for the decision points or as a condition for the next activity.

Shifting the attention on the ORGANISATIONAL and DATA aspects, it is evident that only the imperative languages, BPMN, UML-AD and EPC, have building blocks-specific for the entities `actor` and `artefact`[18]. Instead the entity `role` is mostly implicit or absent. The five BPMLs do not have a specific graphical component for `resource`, only EPC names artefacts "resource object" (i.e., information and material). However also in this language there is no distinction

[18]Excluding CMMN which has the symbols for the artefacts.

	LB meta-model	BPMN 2.0	UML-AD	EPC	CMMN	DECLARE
BEH.	`activity`	Yes	Yes	Yes	Yes	Yes
	`atomic activity`	Yes	Yes	Yes	Yes	Yes
	`compound activity`	Yes	Yes	No	Yes	No
	`event-EPC`	No	Somehow	Yes	Somehow	No
	`event-BPMN`	Yes	Yes	No	Yes	No
	`gateway`	Yes	Yes	Yes	Somehow	Somehow
	`AND`	Yes	Yes	Yes	No	No
	`OR`	Yes	Yes	Yes	No	No
	`XOR`	Yes	Yes	Yes	No	No
	`precondition`	Yes	Yes	Yes	Yes	No
ORG.\DT.	`actor`	Yes	Yes	Yes	No	No
	`role`	Somehow	Somehow	Somehow	No	No
	`resource`	No	No	Somehow	No	No
	`artefact`	Yes	Yes	Yes	Yes	No
G.	`goal`	No	No	Somehow	Somehow	No

Table 4.11: Comparison between *LB meta-model* and BPMLs

between a data object and a resource object. Finally, although milestones in CMMN are considered as accomplishments, they seem to be more similar to states than to goals. The only language that explicitly contains a `goal` construct is (one of the variants of) EPC. Thus, we can say that most BPM languages leave implicit in the modeller's (and the reader's) mind the goal the activities contribute to realise.

By examining which BPML constructs belong to the *LB meta-model*, we have summarised the results in Table 4.12, instead Appendix C shows a more complete mapping between BPML and *LB meta-model* entities. In this table the BPML' graphical constructs are labelled **Y**es, **S**omehow and **N**o depending on whether they occur in the *LB meta-model* or not. As the table summarises, all the *Functional* and *Event* elements of all BPMLs are represented in the *LB meta-model*, sometimes with differences in granularity, as already discussed above for the `event-BPMN` entity. When it comes to the *Flow* constructs we can notice that some elements of the BPMLs are completely lacking in the *LB meta-model*. For example while all notations include some sort of sequence\data flow (i.e., connecting arrows), the *LB meta-model* does not include them. Here we can also report that while almost all the languages only characterise sequence flow arrows in terms of a generic "before-after" temporal connection between activities, DECLARE instead enables the representation of a wider set of (temporal) relations between activities. Concerning the *State* elements, most BPML elements can be considered represented by the precondition entity of the *LB meta-model*. What the *LB meta-model* lacks is the ability to capture also the guards for the decision points. For the DATA part, some notations allow to depict the data input\output, while the *LB meta-model* considers only the entity `artefact`. Finally, both imperative languages and the *LB meta-model* consider the actors executing activities, yet the *LB meta-model* lacks to represent the organisation while instead EPC mostly does.

To sum up, by looking at Tables 4.11 and 4.12 we can observe that: (i) overall there is a

		BPMN	UML-AD	EPC	CMMN	DECLARE
BEV	Func	Task (**Y**) Subprocess (**Y**)	Action node (**Y**) Activity (**Y**)	Function (**Y**) Process path (**N**)	Task (**Y**) Stage (**Y**)	Task (**Y**)
	Event	Start/End (**S**) Intermediate (**S**) Send/receive (**S**)	Start/End node (**S**) Accept event action (**S**) Send signal action (**S**)	–	Timer (**S**) User Event Listener (**S**)	–
	Flow	Gateway (**Y**) Sequence Flow (**N**) Message Flow (**N**)	Control node (**Y**) Control Flow (**N**) Object Flow (**N**)	Logical operators (**Y**) Control Flow (**N**) Info Flow (**N**)	Connector (**N**) Sentry (**S**)	Connector (**N**) Pattern (**S**)
	State	Guard on gateway (**S**)	Guard on control node (**S**) Pre- Post-condition on activity (**Y**)	Event (**Y**) Start/End event (**Y**)	Sentry (**Y**) Milestone (**S**)	–
DT		Data object (**Y**) Data input (**N**) data output (**N**) data store (**N**)	Object node (**Y**)	(I/O) data object (**Y**)	Case file item (**Y**)	–
ORG		Pool, Lane (**Y**)	Activity Partition (**Y**)	Organization (**S**) Activity Owner (**Y**)	–	

Table 4.12: Comparison between BPMLs and *LB meta-model*

correspondence between the entities of the *LB meta-model* and the components of the five BPMLs; especially when focusing on the behavioural part; (ii) the *LB meta-model* represents better the entities of imperative languages, namely BPMN, EPC, and UML-AD, than the declarative ones. This is not particularly surprising as imperative languages are more widely used and investigated and therefore more present in literature; (iii) the *LB meta-model* contains entities such as `role`, `resource` and `goal` that are not widely represented in the five BPMLs; (iV) on the other hand the *LB meta-model* lacks important constructs such as "sequence flow", and "(data) input/output" that are well represented in most of the five BPML.

In the next Chapter, we take our analysis further, investigating components of the *LB meta-model* (including the ones for which misalignments with the BPMLs exist) more in depth.

4.6 Contributions and limitations of the Chapter

In this Chapter we provide an *LB meta-model* built starting from the different business process meta-models proposed in the literature. The Systematic Literature Review we performed do build the *LB meta-model* enabled us to (i) identify which elements constitute a business process, and (ii) how they are understood in the BPM field. The Chapter also provides a discussion of the proposed *LB meta-model* and a comparative assessment using five popular business process modelling languages.

The main limitations of this study are mostly related with the Systematic Literature Review and consist of (i) flaws in selection of the papers; (ii) imprecisions introduced in the extraction of data from the selected works; (iii) potential inaccuracies due to the subjectivity of the analysis carried out.

We mitigated these limitations by following the guidelines reported in [KC07, Kit04]. We applied the standard procedures reported to ensure the correctness of a SLR, such as the identification of the proper keywords to perform the data search, the selection of the appropriate sources and repositories for the field under investigation, the definition of clear inclusion and exclusion criteria, as well as of the quality assessment parameters. In particular, we relied on well reputed literature sources, such as Scopus, Web of Science, and DBLP and we expanded the search by manually inspecting two important conferences in the field of BPM. To further improve the reliability of the SLR, we put some effort in guaranteeing the reproducibility of the queries by other researchers, although ranking algorithms used by the source libraries could be updated and could provide different results.

We are aware that our investigation did not include meta-models of popular business process modelling languages, such as Petri-nets and DECLARE, as they were not retrieved by our data search. This may be something to consider for further work.

A further limitation of this study lies in the fact that only one researcher selected the candidate primary studies, and furthermore one researcher worked on the data extraction. Nevertheless, both aspects have been mitigated by the fact that another researcher checked the inclusion and the exclusion of the studies, and a second researcher checked the data extraction, as suggested in [BKB+07b].

Concerning the limitations of the *LB meta-model* itself, these are mainly related to the way in which it has been built. As we outlined in the previous Section (see Section 4.4), indeed the construction of the *LB meta-model* starting from the literature resulted in a meta-model in which some parts are more articulated than others, and other parts that are completely missing.

Chapter 5

An analysis of business process components from an ontological perspective

The **GOAL 2** of the thesis, that is, to analyse the meta-model's elements from an ontological perspective, was defined in order to understand the meaning of the typical elements of a business process model. In order to achieve this goal we carried on ***TASK 2*** of the thesis. Instead of making our own list of elements to analyse, we decided to start from the ones identified as problematic in the *LB meta-model*, or completely missing according to the comparison of the meta-model with the BPMLs (see 4.5.3). This choice was made for two reasons: first, the *LB meta-model*, as seen in the previous Chapter, contains typical elements that compose a business process; second, clarifying the (intuitive and sometimes unclear) meaning of these elements can contribute to a better understanding of the elements themselves, and to a revision and improvement of the *LB meta-model*.

Despite the wide literature on the semantics of business processes, often investigated in terms of process execution in terms of comparison between the graphical constructs of different modelling languages [SAJ+02, LK06, HLBB13, MTJ+10b], the BPM community still lacks a robust *ontological characterisation* of the entities involved in business process models. While some efforts have been done towards this direction (see, e.g., [SBM14] for an investigation of the ontological commitments of activities and events in BPMN), the majority of works focus on the analysis of behavioural aspects of process models, thus neglecting other central modelling constructs, such as those denoting process participants (e.g., data objects, actors), relationships among activities, goals, values, and so on.

In this Chapter four different types of elements are analysed and these investigations are our contributions towards the achievement of **GOAL 2**. While the long term goal of this work would be to investigate many more entities and their relations, the limited time-frame of my PhD forced us to make choices. Although these studies do not resolve all the issues discussed in Sections

4.4 and 4.5, we believe that the analysis described here contributes to clarify some controversial challenges. Below we provide the motivations that stimulated the choice of the elements to investigate and the approach we have taken in the investigation.

1. *Event.* While the behavioural aspects of business processes are the most explored in literature, we choose to further expand the analysis of events in its usages. This decision was motivated by the different use of the label *event* in different business process modelling languages which created some ambiguities in the *LB meta-model*. This analysis facilitated the clarification of the distinction between event $\grave{a}$-la BPMN and $\grave{a}$-la EPC.

2. *Participants.* Business process participants are often represented in business process modelling notations, thus showing the importance of their usage in modelling. Yet participants are: (i) not as explored in the literature as the behavioural components, and (ii) their interrelations are still not so clear. A witness of the lack of clarity of the notion of participants in business processes can be found in the "confusing" loop involving actor, artefact, role, and resource in the ORGANISATIONAL$\backslash$DATA components of the *LB meta-model*.

3. *Relationships among activities.* This study was motivated by the importance that activities and activity sequences have in the business process notations and at the same time by the lack of the element *sequence flow* in the *LB meta-model*. In fact, despite the emphasis on the fact that activities must compose in sequences in order to achieve a business process goal, most BPMLs simply allow for connecting activities using precedence relations without considering ontological constraints which encompass the temporal dimension. The purpose of this study is to make explicit some of these constraints using the notions of occurrence dependences and rationales of these dependences.

4. *Business process goals.* The analysis of the notion of goal started as we observed its relevance in most business process definitions and its blurriness in the *LB meta-model* and business process modelling languages. Due to the lack of studies focused on the understanding of what goals are in the context of business processes, we felt that a deep ontological analysis of this notion was still premature. We focused instead on a first categorisation of classes of goals that pertain to business process, identifying the ones that concern the process itself, the ones that concern the behavioural part, the ones that pertain to participants, and the ones that refer to the business process meta-level.

The Chapter is organised as follows: the study of event $\grave{a}$-la BPMN and $\grave{a}$-la EPC is described in Section 5.1; the ontological analysis of business process participants is provided in Section 5.2; the investigation of business process activity relationships using the notions of occurrence dependence and rationale is described in Section 5.3; the study of business process goals is placed in Section 5.4. In Section 5.5 we investigated how the results of the analysis of Sections 5.1-5.4 are present in the five modelling languages previously used to evaluate the *LB meta-model*. Finally, in Section 5.6 we conclude by outlining the contributions and the limitations of this Chapter.

5.1 Event $\grave{a}$-la BPMN and $\grave{a}$-la EPC

Behavioural elements are well studies in literature, with a particular focus on the meaning of event and other control-flow related components (e.g., activities and states). Examples are: [SAG10, SBM14, GWdAF+13, GGA16, PV00, Gal90, Ven57, Gal05, Bac80, Try07]. Yet, in the BPM community the use of *event* is sometimes semantically overloaded[1]. An example of this overload is the use of the label "event" in the *LB meta-model*, where the same term is referred to different semantics ($\grave{a}$-la BPMN and $\grave{a}$-la EPC). In this Section we will provide an examination of these two different event constructs and how they are correlated with other behavioural components.

This thesis embraces some of the ontological positions explained in a work by Galton [Gal12a], where events are understood in terms of instances that occur, then events reside at token level. The ontological status of the *event types* can be better explained as "pattern of behaviours" than as *activity types*[2], which are abstract entities [Gal12a][3]. Activity types can be realised at token level by event occurrences. For instance, the event token "make the pizza" is the realisation of the activity type "making the pizza". The latter can be repeated again and again to make other pizzas.

The different meta-models analysed in Chapter 4 associate two different semantics to the term "event" at type (i.e., conceptual) level, which we resolved by explicitly renaming these terms into `event-BPMN` and `event-EPC`. This overloading would become even more complex if we would take into account also the token (i.e., execution) level (mentioned for instance in [SAJ+02]), where the term event is used to denote specific executions of activities and is close to the meaning of event as used in an "event log". In this thesis we concentrate our analysis mainly on the way "event" is used. Nonetheless, as mentioned above, from an ontological point of view, events are often understood as elements happening at token level, that is, specific occurrences in time (see e.g., [Gal12a]). Then, what are `event-BPMN` and `event-EPC`?

Event $\grave{a}$-la BPMN. By looking at the language specification of BPMN, `event-BPMN` can be explained in terms of "a pattern of behaviour", that is, an activity type, which is an abstract entity [Gal12a]. Indeed `event-BPMN`, similarly to activities in that language, can be realised at token level by event occurrences (they happen in time), and can be repeated in several process executions. What seems to differentiate the two notions of event and activity in BPMN is more the fact that events "happen" in the world while activities are terms for descriptions of works that

[1] See e.g., the definitions of event at https://www.businessprocessglossary.com/11516/event.

[2] "Token" is hereby synonym of a occurrence (an instance of a type). While a token occurs at a specific time, a type is an abstract entity with no specific temporal location (see e.g., the distinction between Activity (type) and ActivityOccurrence (token) in the Process Specification Language (PSL) [Grü09]).

[3] The work of Galton [Gal12a] considers the differences between events and processes, the latter are the general counterpart of activities (see e.g., [Mou78]).

a company (or a process owner more in general) should perform. Our proposal, therefore, is to borrow some concepts from the domains of statistics, biology, and planning and conceive event *à*-la BPMN as a sort of *exogenous* activity type, in contrast to the activities that happen within the process owner boundaries, which we rename as *endogenous* activity type. This is a first analysis that may be further refined as these boundaries in BPMN are not always clear and events in BPMN are used to denote both elements with an "active" flavour (e.g., sending a message) as well as elements with a more "passive" flavour (e.g., exceptions or timers), whose differences should be accounted for. Nonetheless, we consider `event-BPMN` as an activity type as all these elements would be considered as "a pattern of behaviour" at type level according to [Gal12a] and not elements happening at token level.

Event *à*-la EPC. When we move to `event-EPC`, the analysis is slightly more complex. On the one hand, this element is used as pre-(post-)conditions which seem to be conceived as states. On the other hand, `event-EPC` is also described as an *activator* of activities. These two views are, from an ontological point of view, incompatible, as states cannot have causal power characteristics. Indeed, although states can be involved in causal relations, they cannot cause anything per-se [Gal12b]. For example, in a loan application process [DRMR13], "To have the credit history" is a state which acts as precondition for the "assess eligibility" activity, but that precondition alone cannot cause the assessment of eligibility.

Since the notion of `event-EPC` appears to be related to the notion of state, we need to clarify what a state is. States have been classified as occurrents, which are "entity that 'happen in time"' and are "extend in time by accumulating different 'temporal parts"' [MBG+03]. Occurrents are *cumulative* and *homeomeric* [MBG+03][4]. Cumulative means that, two states of the same type are still the same state. For instance, the result of the sum of two instances of "standing by" is still a "standing by". Focusing on homeomericity, a state holds the same description during its manifestation. For instance, all temporal parts of "standing by" are describe as "standing by". However in some views states are treated as continuants\endurants, which are wholly present in time [MBG+03], such as physical objects. For instance, in the BFO ontology (see e.g., [GS04] pg. 151) states are considered more as SNAP ("snapshot of the world") then in terms of continuants. More specifically, in [GS04] states are considered dependent continuants, such as roles.

From this analysis states can be considered both as occurrents and as continuants. However both views face some issues. For instance, it is complicated to define a boundary between a state and a quality\property of a thing [Ste18, Gal05]. While, it makes sense to say that "standing by" is a state, how far can we go? Is "being a human being" [Ste18] still a state or is it a quality that someone has? We could assume that while states change more quickly, qualities\properties do not [MW18], and then are not a state. Some other challenges arise from the use of the terms. In fact while "standing by" can be considered a state, if we consider also the object in stand by,

[4] For a detailed explanation see also http://isao2016.inf.unibz.it/wp-content/uploads/2016/06/bolzano-notes.pdf.

things get more uncertain. Indeed, "the PC is in standing by" could appear to be a description of the object's quality.

To solve these issues that arise when we view a state as continuant and\or as an occurrent, in this thesis we propose to consider states in business processes in a very similar way than activities. Then, states are abstract "pattern of staying" ("way of staying"). These abstract states can be realised at token level as instances of states. These "pattern of staying" can be more or less specific[5] according with who and what participates in the states. For instance, while "standing by" is a generic state, "the PC is in standing by" is treated as a specific state since the object is specified (i.e., PC).

Then an `event-EPC` is a state (e.g., postcondition) in the terms explained above, yet an `event-EPC` can also (potentially) "activate" something. This means that the ontological status of this element is complex and includes states and triggers having causal characteristics (e.g., agents). Although this notion of trigger is interesting, it was not possible to investigate it in the time-frame of this thesis. We propose to further expand this research for future works, in order to fully characterise the notion of `event-EPC`.

5.2 Business process participants

While some analysis of the behavioural components of business processes exist in literature, an ontological investigation of participants is less developed. We then decided to provide a study of business process participants. This study allows to clarify also several components of the *LB meta-model*, such as actor, artifacts, role and resources.

Business process participants are exposed to a dichotomy: on the one hand they are among the main entities in a business process (diagram) and a fundamental component of an informative process model; on the other hand they are emblematically neglected when explaining or illustrating the very notion of process. In fact, for instance, what is the identity of a data object, i.e., whether different actors deal with the same or different data objects, or what is the status of a data object throughout the process execution, remain unclear. In this Section of the thesis we overcome the above paradox, offering an ontological analysis of the various kinds of process participants that will hopefully contribute to the ontological foundations of BPM and an elucidation of the participants involved in the *LB meta-model*.

To investigate business processes from this viewpoint, we firstly need to clarify what is an action and what are its participants. Recall that in the BPM literature actions (at the token level) refer to intentional transformations from some initial state (of the local world at stake) to some other state. Their participants are the entities that take part in the transformations [BM13]. In the terminology of [MBG$^+$03], action tokens are *events*, while their participants are *objects*. Generally speaking,

[5] This explanation concerning states is a further rework of the paper of Galton [Gal12a].

objects are in time at moment of existence, events are extended across time. As we shall see, the very same action may involve several types of objects as participants: physical objects (e.g., a knife used to cut a piece of bread); information objects (e.g., personal data involved in submitting a request); agents and/or organisations playing certain roles (e.g., an administrative employee receiving a form).

From a general perspective, participants can be *physical* or *non-physical*: both exist in time, but only the former are located in the physical space. A person is an example of physical participant, whereas an *information object* such as the content of a person's ID (not its physical support) is a non-physical participant.

Information objects (a.k.a. *data objects*) are rather common in business processes and, as seen in the previous sections, modelling notations include different constructs for them. In applied ontology, only a few systems [SC15, MVB+04, BDLBR15, MT17] have attempted a formal treatment of information objects. These ontologies agree in distinguishing between information objects and their physical carriers like paper sheets or computer files; also, the same information object may be encoded in multiple carriers while retaining its identity. For example, John's and Mary's copies of the *Divine Comedy* are two different carriers of the same information object. Generalising, we consider an information participant as a non-physical participant that is somehow 'manipulated' during a process. Additionally, we consider information participants as *dependent* entities that, in order to participate in a process, have to be encoded in at least one carrier. Note also that all the actions performed within a particular process occurrences are ultimately physical actions involving physical participants, so that information objects are actually *indirect* participants, which participate in the process by means of *information-bearing objects* containing their physical encodings.

Regarding physical participants, we may distinguish between *material* and *immaterial* entities. Material participants have some physical body (e.g., a human body or a metallic frame), differently from immaterial objects like holes [Var19], which in some cases may still be considered as participants (e.g., in a process including a pin to be inserted in a hole). Holes belong to the broader class of *features*, which are dependent entities like information objects. Indeed, both holes and information objects require a host to "exist".

Another crucial distinction in BPM is between *agentive* and *non-agentive* participants. The former are indirectly represented in BPMN, whose pools and lanes refer to participants that are committed to and are responsible for the execution of the depicted process. Notoriously, the definition of agency is largely debated in AI. For our purposes, we take the view that an agent is an entity with sensors, actuators and the capability to act on itself or on the environment [NI02]. Human beings and organisations, such as "customer" and "travel agency", are clearly agents. In a manufacturing domain, a lathe machine is an agent when, e.g., it has sensors by which it acquires data from the objects to be manufactured and acts upon them by elaborating these data through some software. So, in general, a cyber-physical system is an agent, while a traditional mechanical late is not an agent.

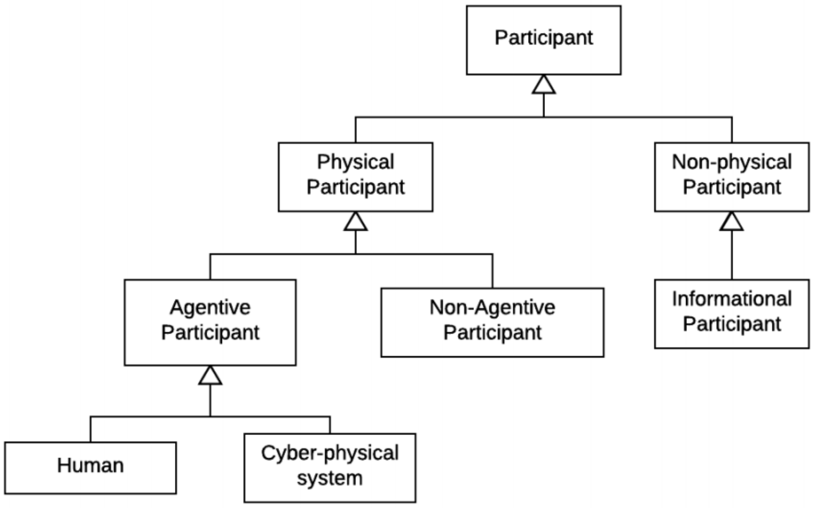


Figure 5.1: Taxonomy of participants

A taxonomy of process participants based on some of the distinctions discussed so far is reported in Figure 5.1. Notice that the agentive/non-agentive dichotomy only applies to physical participants, since we assume that non-physical ones lack the capability of interacting with the environment. Note also that some of the distinctions discussed above are orthogonal to those shown in the figure, so that they have not been reported explicitly. In particular, we assume that all agentive participants are material, while non-agentive participants may be either material or immaterial. Moreover, all physical participants may (or may not) be information-bearers.

Apart from the classification above, all participants can play *roles*. Non-agentive participants may be distinguished according to whether they undergo a change during an action. If so, they are called the *patients* of the action; otherwise, they may play the role of *instruments* or *resources*. We assume that roles can be ascribed to any type of participant represented in Figure 5.1, including information objects.

Focusing on resources, the BPM community has defined them in many different ways, such as: "[...] items necessary for a team to understand a problem and implement solutions [...]", "Agent used to perform activities [...]", "People, equipment, or materials required or used to accomplish an activity. [...]", and "Asset that is consumed in the operations [...]"[6]. State-of-the-art ontological analysis in the context of Enterprise Modelling and manufacturing has classified resources in terms of *roles* that entities play within the context of an activity [AIA+15, FFG94, SBB+18]. While an in-depth analysis of the notion of role is beyond the scope of this thesis we can rely on the ones that have already been undertaken in literature, such as [MGV+05, MVB+04]). What we can retain here is the assumption that roles are dependent upon other entities for their existence and

[6]See e.g., the definitions of resource at: https://www.businessprocessglossary.com/8450/resources.

can be played, in context and time, by agentive (e.g., a person, an organisation) and non-agentive (e.g., a data object, information) participants. Thus, roles can be conceived in different ways, such as *social concepts* that *describe* what that role is, or in terms of *relations* [MGV+05, MVB+04].

Then, participants are objects and they *participate* in activities and events. For instance, the actor "chef" participates in the activity "making the pizza". The characteristics of the participants are usually linked to *capabilities* associated to performances, such as activities [AIA+15, SBB+18]. For instance, the chef has some physical capabilities that allowed *them* to prepare the pizza, as well as *they* have non-physical capabilities that facilitate the pizza preparation, such as the knowledge and the experience on how to make a pizza. However, those capabilities are not relevant for the chef to perform other activities, such as "delivering the pizza". The context is important to define a resource, indeed an object can be considered a resource in one specific business process (model) and not in another [AIA+15, SBB+18]. Then, the chef is a resource when is assigned to the activity "making the pizza", on the contrary *they* are not a resource in the activity "delivering the pizza". However, the chef is always considered an agentive participant and its role is recognised only where exists a valid associated description [BF09, MVB+04].

Finally, note that we rely on a general notion of participant covering any object that takes part in a process. One may however restrict this notion only to "relevant" objects. In this sense, the relevant participants of a process are those that are directly related to the desired *goal*, which are typically common to multiple activities[7]. This seems indeed to be the idea behind the notion of *business artifacts* [CH09], which may be intended as process participants that are passed by from an activity to another, somehow keeping track of what happens as long as the process goes on.

In this Section an ontological analysis of business process participants has been explored in its complexity. This study contributed also to understand the participant concepts included in the *LB meta-model*, such as `actors` and their agentive role, non-agentive `artifacts` in terms of information objects and carriers, `roles` as dependent constructs, and finally `resources` in their multifaceted perspectives.

5.3 Flow relation between activities

As the comparative assessment described in Section 4.5 made explicit, common BPMLs always include a component to capture the sequence flow of business processes. However in the *LB meta-model* the connections among elements remained neglected. Instead of simply adding an entity for a sequence flow, which typically only addresses the temporal relationship between activities, we decided to provide an extensive ontological analysis of the kinds of relationships among business process activities.

We based our analysis on ontological dependences resulting in occurrence constraints involving

[7] An extensive analysis of goals can be found in Section 5.4.

activities that occur during the same process execution. Such constraints necessarily hold in a particular domain, independently of the way a business process is designed. For example, delivering a pizza necessarily presupposes that the pizza was baked. Similarly, no receive event can occur without a corresponding send event.

In formal ontology, ontological dependence is a fundamental relationship (or set of relationships) which can take many forms [Cor08, Fin94]. In general, an entity is dependent upon another when it is not ontologically *self-sufficient*, in the sense that it cannot exist alone. A basic form of dependence is the so-called *specific* (or *rigid*) *existential dependence*, which holds among two objects when the existence of one necessarily implies the existence of the other. For instance, we may say that a person is specifically existentially dependent on her brain. A weaker form is the so-called *generic existential dependence*, which holds when the existence of an object requires the existence of another *of a given kind*. For instance, a human being is generically dependent on a heart (under the assumption that the heart may be substituted). An even weaker form of dependence may hold between kinds, when the existence of an instance of one kind requires the existence of an instance of the other kind. This seems to be enough in our case, since in most business process models key elements (such as activities in a BPMN model or transitions in a Petri Net) are indeed understood as *kinds*, and we are interested in the relationships among them. However, since the instances of such kinds are temporal entities, we should talk about *occurrence* instead of *existence*, so that instead of *existential dependence relationships* we have to talk about *co-occurrence dependence relationships*. In the following, we shall introduce three forms of ontological relations that characterize the nature of such occurrence dependence relationships. The reason why we have chosen these specific forms of ontological dependences between activities is twofold: on the one hand they are grounded on important generic ontological dependences investigated in literature; on the other hand they seem to play a fundamental role in all the business processes (models).

In the following paragraphs we describe in detail the dependences. The process in Figure 5.2 will be used as an illustrative example. It describes a very simple pizza delivery process in whose control arcs specify that the execution of a pizza delivery process starts with the order, continues with the baking of the pizza, the addition of toppings, the delivery, and the payment. In addition to the relation between activities captured by the control arcs, most human beings would easily identify *further relationships* in this process. We will explain them below.

5.3.1 Activity Co-occurrence

In this Section we describe and illustrate three types of co-occurrence dependence relationships that are grounded in the notion of ontological dependence and which are relevant in the business processes examples introduced in this Section. These co-occurrence dependence relationships are: *historical dependence*, *causal dependence*, and *rationale-based co-occurrence*.

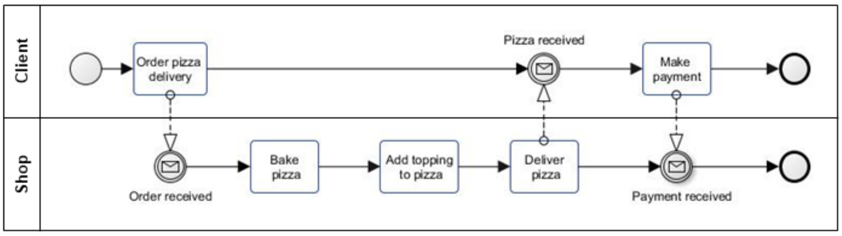


Figure 5.2: A simple pizza delivery process model

Historical dependence. A first type of occurrence dependence relationship is the *historical dependence*[8]. This dependence captures the situation where a certain activity occurrence presupposes that another activity occurred *in the past*. For example, an instance of `Deliver pizza` may occur only if an instance of `Bake pizza` occurred beforehand. We shall define historical dependence as follows:

> Let P_1 and P_2 be business process activities (that is, *kinds* of actions that have at least one occurrence in a business process). We shall say that P_1 is *historically dependent* on P_2 iff, necessarily, whenever an instance x of P_1 occurs at time t, there exists an instance y of P_2 that has occurred at a time $t' < t$.

Note that historical dependence is a relation holding *necessarily*, and has therefore an *ontological* nature. In contrast, a mere *temporal precedence* relation simply resulting from the fact that two activities precede one another in a *particular* business process model may have just a *prescriptive* nature, if no historical dependence holds between the same activities. For example, a certain model may say that an activity `Check contract` should always precede the activity `Sign contract`. Although these activities may be done in any order (since none of them causes or implies the existence of the other), there is a clear reason to have them in a specific temporal order, but this reason reflects a *business rule* and not an ontological constraint.

Causal dependence. A stronger type of occurrence dependence relationship is *causal dependence*. Causality is notoriously challenging to define [Gal12b], and its complete characterisation is beyond the purposes of this work. For our purposes, we assume the following definition, which characterizes causality in terms of *contribution to explanation*:

> A process activity P_1 is *causally dependent* on P_2 iff, necessarily, whenever an instance x of P_1 occurs, there exist an instance y of P_2 that occurs before x, whose occurrence *contributes to explain why x occurred*.

[8]For a generic account on dependence and, in particular, historical dependence see [Gal14].

This definition is admittedly naive, but it seems to be enough for practical cases. For example, an event of message receiving occurs because an event of message delivering occurred. Analogously, a pizza delivering activity occurs because an ordering event occurred in the past, and not because a particular pizza was baked. So, the relation between `Deliver pizza` and `Bake pizza` is a historical dependence, while that between `Deliver pizza` and `Order pizza delivery` is a causal dependence. Of course, a causal dependence implies a historical dependence.

Rationale-based co-occurrence. Finally, a third kind of occurrence dependence relationship is what we shall call *rationale-based co-occurrence*. The main rationales of business processes that we have identified are described in detail in the next Section (see Section 5.3.2): 'law of nature', goal, and norm.

> Let R be a rationale, typically associated to a certain business process. The process activities P_1 and P_2 are related by a *rationale-based co-occurrence* iff the occurrence of both P_1 and P_2 is necessary for the satisfaction of R.

Consider that no temporal constraint is imposed on P_1 and P_2, which may occur in whatever order. Focusing on the kind of rationale, while the goal and the norm are imposed by design, the 'law of nature' is a stronger constraint since it is imposed by nature. As consequence, the process has to comply to the "natural" constraints. Consider, for example, the activity `Deliver pizza` in Figure 5.2. Given the nature of our process' rationale, which may be stated as "Selling pizza", both `Deliver pizza` and `Make payment` (for the pizza) are necessary for the satisfaction of such rationale, and they are therefore co-occurrent with respect to such rationale. Assuming that no historical dependence holds necessarily between the two activities, a process re-factoring is possible, where the delivery occurs before the payment. What is necessary, however, is that the payment occurs sooner or later. Note that rationale-based co-occurrence is symmetric, differently from the previous two relations.

For the sake of simplicity, we are considering here only relationships between pairs of activities. Nonetheless the dependences introduced in this section could be generalised to multiple activities or to process patterns / sub-processes.

5.3.2 Rationales of occurrence dependence

After the investigation of dependences, we asked ourselves why these relationships occur. Dependence relationships between business process activities can be motivated by different aspects of the world a real process is embedded in. In this section we exemplify, by means of examples, the role that (i) genuine *ontological* constraints (hereafter 'laws of nature'), (ii) the *goal* of the process, and (iii) *norms* can play in determining historical dependence, causal dependence and rationale-based co-occurrence. While the categories considered here are not meant to be exhaustive, they are of fundamental importance for the representation of business processes. Genuine ontological dependence exists because of the way the real world is structured and cannot be circumvented by business processes. Dependences related to the goal often refer, in our opinion, to the very nature of the process. They may be circumvented, but their violations may have dramatic effects on the meaningfulness of the process. Finally, laws and regulations often define a social world as important as the physical one for business processes. Also in this case, dependences may be violated but their violations have strong effects on the compliance of the process w.r.t. the normative world that regulates them (see e.g., [GR10]).

Rationales in historical dependence Historical dependence seems to play an important role in business process models and may come in different forms. A first example is provided by pairs of activities that pertain to the "switch" between two complementary states such as turning on and off, entering and exiting and so on. A paradigmatic example in business process models is constituted by the activities `Login` and `Logout` from a web page in a session. While it is possible the login occurs without a logout, the opposite can not occur. If a logout does occur, then the login must have occurred before. This is a particular case of historical dependence and is due to a 'law of nature' that can be generalised, as we said, to all changes between complementary and mutually exclusive binary states. Different examples still due to 'laws of nature' are the ones of `Bake pizza` and `Deliver pizza` discussed in previous sections, or the one of an administrative procedure of applying for a PhD position in which an applicant submits the PhD request (application form) to the PhD office, which is then checked for compliance to the submission rules. `Submit PhD application` and `Check PhD application` are connected together by a historical dependence as the PhD office can not check something that has not been submitted. By generalisation, the two forms of historical dependence mentioned here depend upon a 'law of nature' that determines that one can perform an activity on an artefact only if this artefact exists and is available.

An example of historical dependence related to the goal of the process is the one involving two activities `Make diagnosis` and `Propose treatment` activities in a healthcare process. While a diagnosis is not a genuine ontological constraint for the proposal of a treatment, the goal of the process of providing an effective (if not the best) cure to a patient triggers this historical dependence in a meaningful process.

A further example of historical dependence may be due to normative laws. For instance, in an on-line shopping purchase activity `Login` may be a normative necessary pre-requisite for the execution of activity `Purchase goods`, in order to certify the identity of the customer. Similarly to the example above, while a login is not ontologically needed for a customer in order to buy something, the social world determined by the norm imposes that a customer identification via `Login` is strictly necessary in order to accomplish an e-buy activity.

Rationales in causal dependence A first form of causal dependence, due to a sort of 'law of nature', is the one that holds between `Send` and `Receive` activities (events, in certain notations). Indeed the activity `Send message` not only is an existential requirement for `Receive message` to exist but it also causes the receipt of the message itself[9].

Further examples of causal dependence can be found if we focus on the goal of a business process. Consider again the pizza example. In this example `Order pizza delivery` causes several further activities in the process, and in particular `Deliver pizza`. Note that this is not due to a 'law of nature' but to the goal of the pizza shop, which is the one of making money by selling pizzas to customers and fulfilling their (customers) expectations. While a causal dependence is also a historical dependence the opposite does not hold as `Bake pizza` does not cause its delivery. Indeed a pizza (or any good) is not sold just because it is made but because someone asked for it.

Normative regulations can also refer to activities that are involved in a causal dependence. Consider for instance the activity `First use of software` and `Evaluate terms and conditions`. In this example, the first usage of a just installed software triggers the evaluation of terms and conditions and also motivates/explains why this activity occurs in a software installation process. Similarly to the above this is not due to a 'law of nature' but to normative requirements regulating the usage of artefacts (the software, in our case).

Rationales in rationale-based co-occurrence When it comes to the goal of the process, a typical example of rationale-based co-occurrence is the one involving the activities `Deliver good` and `Pay for good` in the context of an economically motivated selling-oriented business process, of which `Deliver pizza` and `Make payment` (for pizza) in Figure 5.2 is a specific example already illustrated in before. As a further example, consider the annual evaluation process of an employer in a given organisation. Whenever the goal is to ensure a transparent and fair evaluation, a rationale-based co-occurrence may involve two activities `Send evaluation to Human Resources` and `Send evaluation to employer` executed by the employer's boss. Indeed the provision of the evaluation to Human Resources is required to make the evaluation adopted by the organisation, while with the provision of the evaluation to the employer provides the possibility to highlight unfair treatments, and they are jointly required to achieve the overall goal.

The inquiry carried out in this Section exposed many types of relationships between activities going beyond their common temporal precedence. Since well known definitions of business process (see e.g., [Wes12b, JMPW93]) and most BPMLs stress the importance of the interconnection among activities (for instance to achieve a goal), we believe that both temporal relationships and co-occurrence dependences should be considered as business process elements. We will see in Chapter 6 how to include this analysis in the *LB meta-model*.

[9]Here we do not consider the situations in which the message has been sent but not received for whatever reason.

5.4 Business process goals

In this Section we take a step forward by investigating a central notion in the definition of business processes, that is, the notion of (business) process *goal*. As emerged from the work described in Chapter 4, the element `goal` is widely neglected and poorly interconnected with other business process elements both in the *LB meta-model* and in the notations of popular BPMLs considered in Section 4.5[10].

As a consequence, the link between goals and business processes remains often implicit, with the risk of slipping into a paradoxical situation: on the one hand, it is said to be central to the definition of business processes; on the other hand, it is treated somehow as external to the process itself. Thus, differently from what happens, e.g., in software development, where goal-oriented methodologies have heavily contributed to the development of the field of requirement engineering, goals rarely appear as first class citizens in business process modelling methodologies, while implicitly (and often heavily) influencing the way a process is designed.

The purpose of this Section is then to tackle the above paradox by offering an investigation of the notion (or the notions) of goal in the business process context, by providing a first classification of types of goals and their relationship with typical process participants. Differently from the previous Sections we do not provide here a careful ontological characterisation of the notion of goal, but primarily a first investigation and a classification. The reason we do this resides in the fact that this notion was so poorly understood in this context that we thought a preliminary study was first of all necessary in order to understand, at least in an intuitive manner, this notion. This classification and clarification will serve as a starting point for future ontological analysis that we decided to leave for future works.

Consider, for example, the generation process of the fiscal code for a newborn in an Italian hospital. Regardless of *how* the process is carried out, we can say that the overall *primary* process goal, or the *reason to exist*, of this process is the generation and association of a unique fiscal code to each newborn (and to no one else). Thus, the process is characterised by a well defined input (the presence of a newborn in a hospital) and a well defined output (the state of the world in which this newborn is associated to a fiscal code).

The diagram in Figure 5.3 shows the process model (represented in the BPMN 2.0 notation) describing (a simplified[11] version of) the generation of a newborn's fiscal code in an Italian hospital. The process starts with the obstetrician producing a (required) birth certificate, which is given to the parents who present it at the municipality. The municipality registers the request, optionally generates a proposed fiscal code, and then sends the request (possibly with the tentative fiscal code) to the (national) SAIA information system managed by a specific branch of the Home

[10]Exceptions can be found in some versions of EPC, the ARIS modelling language [Sch02a], and in the Guard-Stage Milestone (GSM) notation [HDF+11].

[11]We omit here several variants such as the registration directly at the hospital.

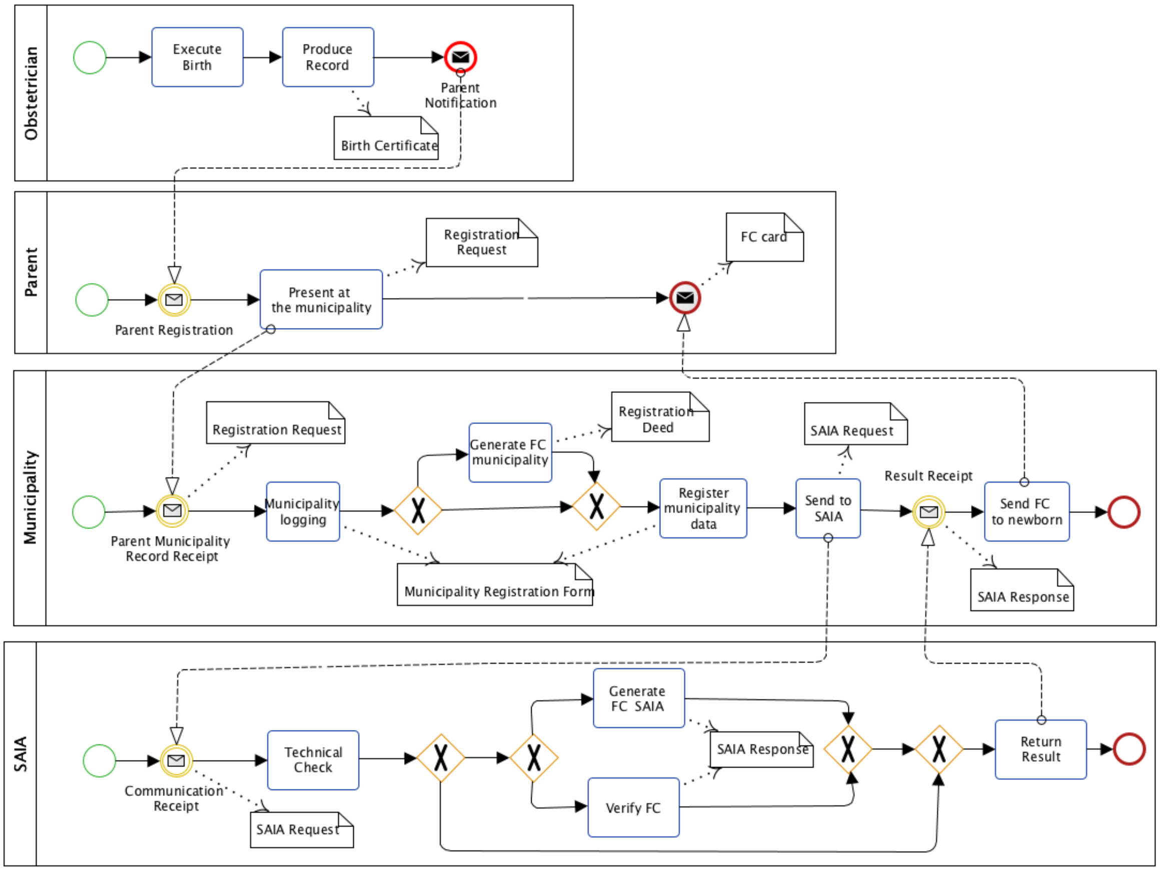


Figure 5.3: Birth management process

Office. SAIA checks the request and generates or validates the fiscal code before returning it to the municipality which then generates the card for the newborn.

The diagram in Figure 5.3 depicts a process that, given the expected initial state, leads to realise the goal expressed above. Indeed, it starts with a well defined input of an obstetrician delivering a newborn and describes how to bring about a state of the world in which this newborn is associated with a fiscal code. Nonetheless, the gap between the primary process goal and this (simplified, yet articulated) process representation is huge. Is the primary process goal depicted above the only motivation for the process to be organised in this way? Are there further factors (and therefore goals) that we need to explicitly take into account when we talk about the goals of a business process?

A first observation we can make concerns the relation / distinction between the primary process goal and the richer final state (output) of the process itself. For example, often business processes do not terminate with the achievement of the desired state of the world, but carry on additional steps. In the scenario of Figure 5.3, for example, the process terminates with the communication of the fiscal code to the newborn (parents). In this specific case this activity appears to be justified by other considerations which are not part of the process goal, and concern the participant data object handled by the process: one goal that the data object *carries* is to be recognised (having a social value) as fiscal code.

A second observation concerns the relation between the primary process goal and the specific goals of single activities that can be included in the business process. As already observed in Section 5.3 certain activities, or co-occurrences of activities, appear to be strongly related to the primary process goal of the process, and their change, e.g., removal, can modify the nature of the business process and even lead to question whether it should still be considered the "same" process, while others seem to be merely related to how steps are performed. As an example the removal of any 'generate fiscal code' in our scenario would dramatically change the process meaning. On the other hand the removal of 'generate fiscal code' at the municipality level alone would be considered just a process refactoring.

As this short informal discussion shows, characterising the goals of a business process is not a trivial activity, due to the multitude of aspects and features that may be considered.

5.4.1 On the definition of goal and its classifications

Since the notion of goal is not really well defined in the BPM field, then we methodologically decide to analyse the definitions of goals in other *quasi*-related areas of research.

In areas like multi-agent systems, philosophy, and psychology, goal is generally understood in terms of states that are desired by an agent. Rolf and Asada in [RA15] state that *the goal is a state of the world which satisfies some conditions posed by the agent (for whatever reason)*. There are different ways to understand this notion depending on whether the desired state is a setting of the world (a situation external to the agent) or is the agent's representation of it (e.g., an internal description like a list of values for state variables). The difference is that in the second case the goal indicates only the relevant features that the achieved state should satisfy. Practically, the goal corresponds to a class of world states.

The notion of goal plays also a crucial role in the area of planning systems. Indeed, as stated in [GNT16] "planning concerns the computational deliberation capabilities that allow an artificial agent to reason about its actions, choose them, organize them purposefully, and act deliberately to achieve an objective" often referred to as a *goal*. Goals are therefore typically meant to be states or conditions that have to be reached by the system in order to solve a problem represented in terms of initial condition (see e.g., [ML17]).

In software engineering, the notion of goal of a system has been investigated in the field of goal-based requirement engineering (GORE). Here goals are not defined in terms of states of the world but in terms of objectives: Van Lamsweerde defines a goal as *an objective the system under consideration should achieve. [...]*[VL01], while Anton states that goals are *high level objectives of the business, organization or system. They capture the reasons why a system is needed and guide decisions at various levels within the enterprise* [Ant96]. Within this field several classifications of goals were developed, for instance the distinction between *functional* and *non-functional* goals [VL01]. The first ones denote the services that the system must provide; the second ones refer to quality attributes and *constraints* of the system, such as security, usability, and reliability.[12] Another way to classify goals is related to their temporal characteristics [VL01]: *achieve* goals specify the behaviour required by a system sometimes in the future, while *maintain* goals regulate the behaviour of a system in all possible states. Finally, an *optimize* goal is used to compare behaviours to select those which better meet some (soft) property. A further classification of goals is among *hard goals* and *soft goals* [VL01]. Hard goals are related to functional requirements and are well defined and measurable, while soft goals are defined as imprecise with a no clear cut sense, and they lay the basis for the non-functional requirements [CdPL09].

5.4.2 Business processes and their goals

We present here a first investigation and categorisation of the notion(s) of goal(s) that can be found in business processes. We ground our investigation on the notion of *participant* (see Section 5.2) so as to keep our analysis independent from the specific modelling approach or modelling language that can be used to represent business process models.

We have identified five categories of goals: (i) *primary goal* (reason to exist), (ii) *transaction goal*, (iii) *data and organization oriented goal* (actors and objects), (iv) *instantiation goal*, (v) *quality goal*. Some of these goals are linked with the analysis of the literature provided above in Section 5.4.1. The primary goal is inspired by the definition of goals given in multi-agent systems (i.e., [RA15]) and quality goals are inspired by research in goal-based requirement engineering.

The primary goal (reason to exist). The first, and possibly most important perspective upon which to explore the notion of goal in business processes, is tied up to the process' "reason to exist". From an intuitive point of view most people would answer the question "why does the process in Figure 5.3 exist?" with the answer "to generate a fiscal code for a newborn". Or to the question "why does a loan process exist?" with the answer "to handle requests and issue loan offers." Formulating this intuition in a precise definition is not easy. If we take seriously the investigation of the reason to exist of a business process, several other elements may need to be

[12] Functional and non-functional goals are linked with the notions of functional and non-functional requirements (NFR) [CdPL09]. Despite the overlaps / similarities between the terms *goal* and *requirement*, they should be treated separately: indeed goals are used to capture *why* (the motivation for which) the system needs to behave in a certain way, while requirements underlie *how* the goal must be achieved [Ant96].

addressed. One may say that a loan process exists because banks exist and have the goal of making money, or because people are willing to borrow from banks in order to satisfy their personal goals. To narrow the investigation, recall that business processes need to have a well defined input, which constraints the state of the word in which the process starts, and also organisational boundaries, which informally demarcate the actors for which the goal should have value.

Thus, since the goal appears to be connected to an evolution of states of the world (or a fragment of it) for some actors / organisations, we can start from the definition of goal for an agent as expressed in [RA15] (see Section 5.4.1) and modify it as follows:

> *the goal of a business process is the realisation of a state of the world, starting from an initial condition, which is of value to one or more organisational participants (for whatever reason).*

That is, the goal of a process is to bring about a state of the world, starting from some initial conditions, which is of interest to at least one organisational participant. Usually, one or more of these participants is regarded as the process *owner*. For instance, the goal of the process in Figure 5.3 is to generate a fiscal code for each newborn, and this is the goal of the municipality and of SAIA.

Transaction goals. While the primary goal gives a high level perspective, it does not aim to explain why, at the end of the modelling process, the model layout is in this or that way. This organisational aspect is related to transaction goals (and sub-goals), that is, all those goals which are roughly represented and observable in the behavioural model of a business process, where the procedural aspects are explicitly defined. If we take this perspective, a business process is conceived as a processable workflow (model) system composed of: (i) a set of activities, (ii) their transactions and relationships (control flow), (iii) the participants that perform the activities, as well as the data flow.

The elements characterised by the transaction goals, which are mostly present in the behavioural view of a business process (model) are: (i) the final state reached after the last transaction (e.g., the token in an *end* state in a Petri-net.); and (ii) the output (effects) of each activity / sub-process. The behavioural perspective focuses on the cumulative effects' of activities which participate in the process, and the effect of the final activity is assumed to be the final desired state of the process. Thus, from this perspective the goal of the process is given by the accumulation of activities' (desired) effects conceived as partial or intermediate goals. The accumulation leads to a final comprehensive effect taken as the desired goal of the process itself.

Compared to the primary goal, transaction goals represent a richer descriptions. A problem in focusing only on this perspective is the fact that not all activities which participate to the behavioural dimension are essential to achieve the primary goal of the process (think of a verification check which is not necessary to the process) neither to characterise the identity of the process itself. Also, it may be the case that accumulations of activities' effects already realise a state of the world that correspond to the primary goal even before the process' end. Thus an investigation of primary and transaction goals may be useful in order to isolate *representative* activities that are relevant to the identity of the process.

Data and organization oriented goals. Although the specific relations between actors and goals, as well as, data objects and goals are likely to be different, we consider them together because we analyse the relations between business process participants and goals. Among the different process participants, actors playing roles in organisations and objects in the data flow appear to be particularly important when describing process goals. Both participants are explicitly represented in certain modelling languages (e.g., BPMN or EPCs) together with their intuitive relation with the behavioural component. For instance, in BPMN 2.0 organisational actors and roles are captured by modelling elements such as pools and lanes, whose intuitive meaning is to specify who, within the organisation, is in charge of executing a specific set of tasks. Similarly data objects are often depicted together with their relations with activities, and they can serve as a prerequisite of an activity or be something produced / updated by an activity.

Organisational actors and data objects can have specific goals which do not necessarily coincide with those of the process. Some of the goals of actors / data objects appear to be close to the overall goal of the process, while others may differ, or even be conflicting. Another important characteristic of participants is that often they act as carriers of the primary goal. This is what happens to the fiscal code in our example. This object, travelling along the data flow of the process changes its state such as into registered, requested, generated, checked and so on. An object can also have goals attributed to it such as, for the fiscal code, being permanently stored somewhere or being revealed to the person it corresponds to. Besides these specific aspects, this object participates in a fundamental manner to the overall process goal.

Instantiation goals. Although business processes are traditionally conceived as *types* at the diagram level, they assume a significance only because they are executable. The execution level concerns the *instantiation* of the process in so-called execution traces, or cases. A case, thus, assumes the form of a sequence of events (thought of as the executions of the activities at the diagram level), each of them paired with its execution time and, possibly, additional attributes concerning performers, data objects and so on. For example, the instantiation of the fiscal code process concerns the generation of a specific code x concerning a newborn y with parents z, in a specific municipality, with each activity happening at a specific time.

The instantiation dimension can be another lens through which to observe business process goals. A first class of meta-goal that concerns all business processes is related to properties that are usually investigated in formal methods and verification under the umbrella of soundness properties [vHH+10]. Indeed processes have the goal of being sound, with no livelocks, deadlocks, and other anomalies which relate to the fact that they can be executed from start to end in any (or relevant) circumstances. Further goals, which are implicit and always valid at the instantiation level, are related to execution repeatability. The generation of the fiscal code must be executed (and in the same way) not only once, or twice, or ten times, but for all newborns until the goal of generating a fiscal code per newborns remains valid. Similarly, it has to allow the concurrent execution of several instances, a property that may be unwanted in other scenarios. While these goals may be rarely visible at an abstract representation level, such as the one of Figure 5.3, they become determinant when refining the representation at a level that is closer to the technological one.

Quality goals. Another orthogonal dimension in discussing goals of a business process is provided by the categories of *hard* and *soft* goals typical of requirement engineering. In this perspective, if the hard goals appear to be related to the primary goal of the process, the notion of soft goal appears to be related to all the organisational, decisional, and strategic assumptions that are expressed in term of business functions having an impact on the enterprise choices.

Consider, for instance, the process of *purchasing raw material to sell a product*. This process involves many functions and departments, such as acquisition, quality, marketing, and sale. All of them have activities to perform and goals to be achieved, and often the strategic and decision oriented dimensions of an organisation are captured by qualities the process must satisfy rather than procedures the process must perform (see [CAGG11]). These qualities of a process are rather close to the notion of soft goals proper characteristics of non-functional requirements. Typical examples that pertain to business processes are *performance*, *security*, *multidimensionality*, and *user-friendliness* goals with all their subgoals. For instance, security may be expanded in accuracy, traceability, availability, and so on. Quality goals are indeed present in our example: fiscal codes should be generated within a certain timeframe and stored in a reliable data store, just to mention two of them.

This identification of business process goals provided an initial exploration useful to improve how this notion should be understood in the BPM community. Moreover this study will contribute to an expansion of the element `goal` included in the *LB meta-model*.

5.5 Ontological elements in the five business process modelling languages

The purpose of this Section is to contextualise the analysis provided in this Chapter in light of the five business process modelling languages introduced in Section 4.5 (i.e., BPMN 2.0, UML-AD, EPC, CMMN, and DECLARE). We propose the following discussions: (i) a reflection on the representation of enodogenous and exogenous activities, preconditions, and event *à*-la EPC in the five languages; (ii) an investigation about the possibility of representing participants'

ELEMENTS	BPMN	UML-AD	EPC	CMMN	DECLARE
ENDOGENOUS ACT. VS EXOGENOUS ACT.	Somehow	Yes	Somehow	No	No
EVENT-EPC VS PRECONDITION	Somehow	Somehow	Yes	Somehow	No
AGENTIVE VS NON AGENTIVE	Somehow	No	Somehow	No	No
INFORMATION VS CARRIER	No	No	No	No	No
OBJECT VS ROLE	Somehow	Somehow	Somehow	No	No
OBJECT VS RESOURCE	Somehow	Somehow	Somehow	No	No
DIFFERENT TYPES OF RELATIONS BETWEEN ACTIVITIES	No	No	No	No	Somehow
GOAL	No	No	Somehow	Somehow	No

Table 5.1: Ontological elements in the notations

characteristics in the modelling languages; (iii) an analysis of the languages looking at their capability to express occurrence dependences and their rationales; and (iv) an analysis of the notations to understand if and how their provide the possibility to represent goals[13].

The presence of `event-BPMN` and `event-EPC`. While the behavioural components of business processes are well represented in the considered languages, there are still some notions that are not so well-specified. For example, the distinction between *endogenous* and *exogenous* activities is often implicit or missing. As we can observe in Table 5.1, both DECLARE and CMMN do not represent this difference. Instead in BPMN and UML-AD endogenous and exogenous activities are somehow represented. In BPMN a task is an endogenous activity and event is an exogenous activity. In UML-AD this distinction is event more clear; indeed the language includes not only endogenous activities as actions and exogenous activities as events, UML-AD but also specifies explicitly "external" partitions which include exogenous activities. The situation is more confused for EPC, where functions (i.e., activities) are meant to be endogenous; yet the notation does not make explicit whether exogenous activities exist or not. For instance, the element event[14] in EPC could be exogenous (as well as endogenous), but this aspect is not fully clarified.

Concerning *event à-la EPC* and *preconditions*, this distinction is more subtle. In fact an `event-EPC` is composed of a state and a trigger. Since preconditions are states, preconditions can therefore be part of an `event-EPC`. Without considering the EPC language which, of course, includes the `event-EPC`, the languages BPMN, UML-AD, and CMMN comprise preconditions (e.g., guards and sentry) as well as "activators", such as activities and events. However this exact combination of a state plus trigger which characterises `event-EPC` is not explicit in these languages. DECLARE does not allow to represent this distinction at all. These points are all summarised in Table 5.1.

[13]Due to the lack of a deeper characterisation of the goals in BPMLs, this point is not dissimilar from the results provided in 4.5.1.

[14]An event in EPC is considered as sort of state with activator power (see discussion in Section 4.4).

Representation of participants' characteristics. The representation of participants in the five BPMLs differs greatly as represented in Table 5.1. Indeed many characteristics of business process participants are still hidden. CMMN and DECLARE do not offer any support to the modelling of entities that participate into the activities. It is therefore ignored in the remaining of the discussion. Focussing on the agentive\non-agentive participants, the specification of activity owners in EPCs seems to suggest that they have the *ability to act*. Also, pools in BPMN are understood as participants in collaboration, and therefore exhibiting the *capability to collaborate*. In UML-AD, activity partitions may be used for grouping activities with different purposes, which encompass the one indicating the activity performer; however, when used for this purpose, also the UML-AD notation seems to suggest the representation of an *ability of the performer to act*.

No actors appear in CMMN and neither BPMN nor UML-AD specify whether the actor (e.g., customer) explicitly refers to a single individual (e.g., Nina) or to an organisation. In both cases, it reasonably stands for the *role* of a participant. This consideration reveals, besides the lack of graphical constructs for specifying actors in declarative languages, also the underspecification of both BPMN and UML-AD with respect to our analysis, since pools and activity partitions can be used to refer to different types of participants, but also to their roles.[15] On the other hand, the distinction between single actors and organisations can be explicitly conveyed in EPC, although the difference between participants and their roles is blurred.

Also the distinction between objects and *resources* for the achievement of the process and activities is not clear. For instance, EPC characterises the graphical elements for resources that are allocated to activities, however the language does not permit to distinguish between role as a resource. Similarly, BPMN, UML-AD and CMMN define the data-objects for an activity, yet without discerning between objects and resource.

Considering the status of data objects, BPMN (and in part UML-AD) offers the possibility to model it (e.g., *Ticket paid*, *Loan approved*, *Claim issued*). On the other hand, in EPC and CMMN this cannot be explicitly modelled, although it can be inferred by looking at the changes of the world. From a more general perspective, BPMN and EPC separate the data from the control flow (they have explicit different graphical notations for the two flows). In contrast, in UML-AD and CMMN, data objects are represented in a unique flow with activities and control flow elements, so that the process execution cannot proceed unless the data objects are processed/available. In this sense, data object participants play a fundamental role within the overall process, and it becomes necessary to properly identify which data objects the process manipulates. As well as it is important to distinguish between information and its carries.

[15]Although some support is given in the meta-models of the different languages, what we aim at emphasising here is the lack of support provided by the graphical notations of the different languages.

Representation of temporal and occurrence dependence and rationale. Focusing on the relationships between activities, the five BPMLs capture only the temporal aspect of the connections among them (i.e., the temporal sequence flow). The only language that specifies other types of relations is DECLARE (see Table 5.1). While it would be incorrect to say that DECLARE patterns have the aim of specifying the kind of relation existing between different activities, it is also true that some (temporal) patterns may be better suited to model causal vs. temporal vs. dependent relations. Thus we may say that, from an ontological perspective, DECLARE somehow guides the modellers to think about the type of relation existing between activities, besides the simple sequencing.

This parallelism between occurrence dependences and DECLARE patterns has been developed and presented in detail in [ABF+18b]. The general idea is based on the fact that since dependence expressions have effects on finite execution traces, a way to characterise (some of) their effects on process executions is to describe them using Linear-time Temporal Logic (LTL_f) with $f$inite execution semantics [DDM14]. Then we can translate co-occurrence dependence as the LTL_f to the formula $\Diamond A \leftrightarrow \Diamond B$ which corresponds to the *co-existence* DECLARE template. Historical dependence can be interpreted in LTL_f as $\neg B \mathcal{W} A$ which corresponds to the *precedence* DECLARE template. Finally, causal dependence corresponds in LTL_f to the formula $\neg B \mathcal{W} A \wedge \Box(A \rightarrow \Diamond B)$ and *succession* is the DECLARE template counterpart. Given this interpretation of dependence expressions, we can note that a causal dependence enforces also a rationale-based co-occurrence and an historical dependence.

Representation of goals Finally, moving to the specification of the kinds of goals that a business process realises, as Table 5.1 points out, none of the modelling languages force the modeller to make them explicit. The only language that explicitly contains a general *goal* construct is (one of the variants of) EPC. While the milestones of CMMN can be conceived as goals, yet there is no clear distinction between milestone as a goal and as a state.

To conclude, in this Chapter we dug into the ontological status of several business process components, ranging from the usage of the label "event" to the roles of participants in business processes and business process models. We also investigated deep into the kinds of ontological relations among activities proposing possible classes of motivations which can explain these relations. Finally, we defined types of business process goals that pertain to several aspects of the process itself.

This last Section made explicit how some of the aspects that emerged from our investigation are actually included in the available notations. We are convinced that the analysis carried out in this Chapter can help the BPM community to better understand important components of business processes. Furthermore, this analysis will be used in the next two Chapters to accomplish two different tasks: in Chapter 6 it will be useful to revise some aspects of the *LB meta-model* proposed in Chapter 4 and to solve some of the critical issues identified there; in Chapter 7 we will illustrate how the investigation on the notions of dependence relationships and rationale supported a refinement of the BPMN notation and how we evaluated the usability and usefulness of this extended notation in an empirical manner.

5.6 Contributions and limitations of the Chapter

In this Chapter we analysed from an ontological perspective four elements (event, participant, relationship among activities, and goal), which were identified as missing or problematic in the literature and in the *LB meta-model*.

The limitations of this study regard mostly the approach we decided to adopt. Indeed, ontological analysis presents some limitations and the ones that concern the thesis are: (i) the selection of the elements to investigate, and (ii) the identification of the "most suitable" ontological approach for the analysis.

The first limitation was mitigated by deciding to perform the ontological analysis on business process elements which are relevant in the BPM literature. Relevance for the field was evaluated using the *LB meta-model* which was extracted from works in the field, several definitions of business process, and by comparing the *LB meta-model* with five business process modelling languages.

The second limitation was mitigated by evaluating and choosing the most suitable ontological view for the analysis of each element without being tied to a single specific ontological view. In this case the appropriateness of each ontological strategy was evaluated on the basis of the business process modelling element to be investigated.

Chapter 6

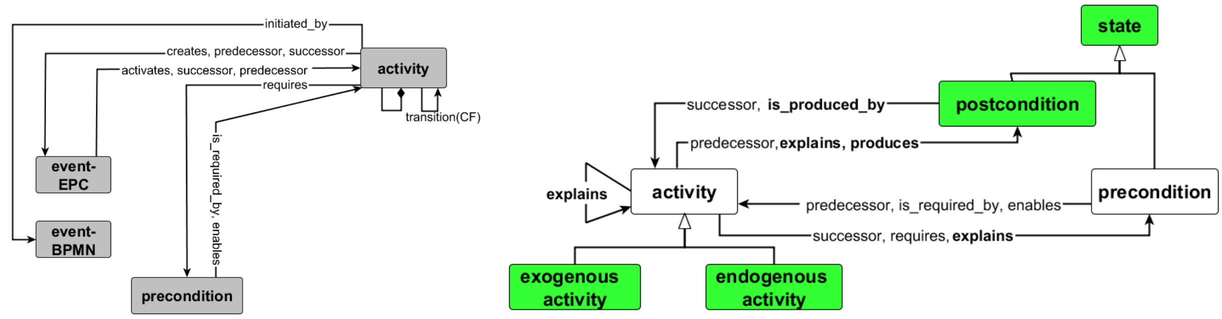
Revising the *LB meta-model*

Chapter 4 and Chapter 5 addressed the main challenges of this thesis that is, to develop a business process meta-model starting from the literature and perform an analysis of some of its components using ontological analysis. The content of those Chapters contributed to the achievement of the two main goals of this thesis, that is, **GOAL 1** and **GOAL 2** as described in Chapter 1.2. This Chapter presents the realisation of ***GOAL 3.1:*** which shows how we can apply ontological analysis in the field of BPM to enrich the *LB meta-model* presented in Chapter 4 with the results obtained in Chapter 5. In this Chapter we perform the methodology which pertains to ***TASK 3***.

Before presenting the content, we would like to stress the fact that this Chapter presents a still preliminary effort to improve the *LB meta-model*. We consider this study preliminary since in the time-frame of the thesis we were not able to implement all the results of the ontological analysis in the *LB meta-model*. For instance, the *rationales* explored in Section 5.3 are not integrated in the refactoring of the meta-model. Nevertheless we decided to include this work in the thesis for two reasons: (i) although preliminary, we believe that the proposal we make in this Chapter can contribute to clarify the meaning of some problematic entities of business processes; (ii) the Chapter represents an important application of ontological analysis in the field of BPM. Indeed, the results of the ontological analysis can support the BPM community to have a better understanding of their domain of investigation, and to create more robust business process meta-models and models.

In this Chapter we enrich the *LB meta-model* presented in Section 4.3 in four different ways:

- The first enrichment concerns the notions of `event-BPMN` and `event-EPC` and their relations with the notions of activity and state.
- The second re-elaboration of the meta-model is focused on the analysis of business process participants, with a particular emphasis on resources and roles.



(a) Snippet of the original *LB meta-model*.

(b) The new proposal.

Figure 6.1: Re-factoring of the event, activity and state component.

- The third part is centred on the integration of the connection flows and the ontological occurrence dependences.
- Finally, the fourth study presents a re-factoring of the meta-model to incorporate several notions of goal.

These enrichments aim at solving some issues of the *LB meta-model* discussed in Sections 4.4, 4.5.1 and 5.5, yet maintaining as much as possible unaltered the original *LB meta-model*. For this reason, we chose to leave in the revised meta-model all the relations collected in the *LB meta-model* (including the inverse relations).

This Chapter is organised as follows: the integration of the ontological analysis of `event-BPMN` and `event-EPC` is described in Section 6.1; the extension of the *LB meta-model* with participants is explained in Section 6.2; the addition of the connection flow and occurrence dependences is addressed in Section 6.3; the insertion of goals is provided in Section 6.4; Section 6.5 discuss some issues concerning the enrichment of the *LB meta-model* using ontological analysis; finally in Section 6.6 we present the contributions and the limitations of this Chapter.

6.1 event-BPMN and event-EPC in the *LB meta-model*

In this Section we propose to integrate in the *LB meta-model* the results of the analysis of `event-BPMN` and `event-EPC` described in Section 5.1.

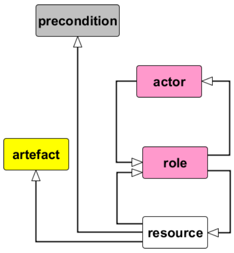
In the original *LB meta-model* (see Section 4.3 and Figure 6.1a where a snippet of the *LB meta-model* concerning the event is reported), there were two kinds of events: event à-la BPMN and event à-la EPC, with two associated different intuitive semantics. The `event-BPMN` is described in [Mod11] as "something that happens during the course of a process". The `event-EPC` is conceived in [Men08] as "[...] preconditions and postconditions of functions" and also as a trigger\activator in the specification of ARIS EPC[1]. To solve these ambiguities, in Section 5.1 we relied on previous investigations on the notions of event and activity and, in particular, we adopted the view of events as tokens and activities as types.

Starting from these observations we decided to remove the label "event" from the meta-model (as it pertains the token level that we do not consider) and we propose to: (i) consider `event-BPMN` as an exogenous activity; (ii) consider `event-EPC` as a state, to take into account its view as pre-postconditions; and (iii) to leave for further work the trigger aspect of `event-EPC`. According to these analysis we proposed the changes described in the following.

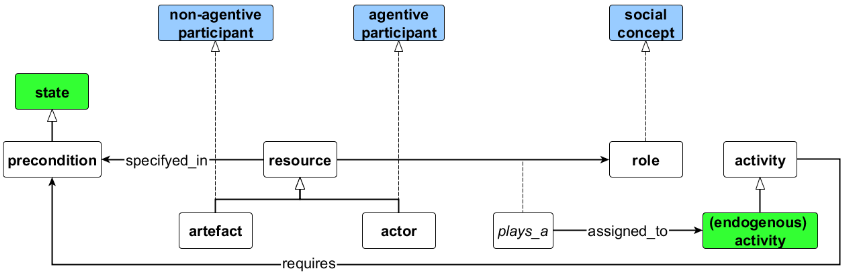
- `event-BPMN`: We suggest to replace the entity `event-BPMN` with the entity `exogenous activity`, the label "activity" with `endogenous activity`, and to consider both subtypes of the entity `activity`;
- `event-EPC`: Re-factoring the model to take into account the double facets of `event-EPC` as a state and as a trigger is more complicated. By looking at the *LB meta-model* in Section 4.3 and Figure 6.1a, we can notice that states are represented only by precondition and the `event-EPC` as trigger can be found in the *LB meta-model* when `event-EPC` *`activates`* `activity` is specified. Yet, if we consider the `event-EPC` mostly as a state, as we discussed in Section 5.1, it cannot cause anything by itself [Gal12b]. In this respect, the relation `precondition` *`enables`* `activity` found in the *LB meta-model*[2] appears to be more appropriate as a relation between a state and an activity. Inspired by the analyses in [ABF+18b] and [Gal12b], we propose to solve the ambiguities concerning the status of `event-EPC` by viewing it as a specific pre- or postcondition (i.e., a state), and thus removing it together with its *`activates`* relation from the diagram and adding the explicit entities of `state` and `postcondition`. We also delete the relation *`initiated_by`* between `event-EPC` and `activity`. Nonetheless, we strongly believe that this causal notion involving activities should be further investigated. Indeed, this double view of the notion of `event-EPC`, together with the higher occurrence frequency of the notion of precondition (see Table 4.7 for the frequency of occurrence of `precondition` in the analysed meta-models), seem to suggest a need to incorporate some notion of "trigger" (distinct from the notion of state) that can explain (cause) the activation of activities within a business process. Instead, when discussing causal relations we can note that, although activities cannot cause directly anything (e.g., *`create`*) at type level, they have a sort of causal power, as they can *explain* why a certain activity type can cause something else, such as a state or other activities. Thus we incorporate a relation *`explain`* between activities.

[1]See ARIS Community: https://www.ariscommunity.com/system/files/EPC-Cheat-Sheet_Final_2019.pdf

[2]Although the label "enable" seems to be more suitable at token level, in this paper we retain it in the meta-model to represent the relation between precondition and activity.



(a) Snippet of the original *LB meta-model* (taxonomy).



(b) The new proposal.

Figure 6.2: Re-factoring of the ORGANISATIONAL/DATA part.

Figure 6.1b summarises the re-factoring of the two notions of `event-BPMN` and `event-EPC` explained above. Filled boxes represent newly added entities, and boldface has been used to denote newly added relations. This notation is used through the entire Chapter. Note, that we have included also postconditions into the diagram, and the relations that pertain to this entity. The two relations *`is_produced_by`* and *`produces`* have been re-extracted from the original study of meta-model elements and relations. More specifically, these relations belong to the meta-model proposed by [HLBB13]. Also, we have transferred the relations between `event-EPC` and `activity` to the appropriate relations between `pre-postconditions` and `activity`. In this re-elaboration of the *LB meta-model*, pre-postconditions are states.

6.2 Participants in the *LB meta-model*

Section 5.2 widely explained the notion of business process participants. In this Section we integrate some of those findings in the *LB meta-model*. As we have seen in Section 4.3, the meta-model does not clarify enough the ORGANISATIONAL/DATA parts; indeed it represents several "is_a" loops concerning the entities `artefacts`, `resource`, `actor`, and `role`.

In the analysis of Section 5.2 participants were classified as physical, such as a customer, and non-physical, such as an informational content that is usually supported by a physical entity. Another important distinction was made between agentive and non-agentive participants and the fact that these participants can play roles and be resources in the context of business processes.

In Figure 6.2a a snippet of the original *LB meta-model* involving the ORGANISATIONAL/DATA part is provided, and in Figure 6.2b an enrichment of the ORGANISATIONAL/DATA component based on the analysis of business process participants is depicted. For the sake of clarity, in Figure 6.2b the blue boxes denote the upper level concepts introduced in Section 5.2 of this thesis. In this diagram a business process `resource` *`plays_a`* `role` when it is *`assigned_to`* `(endogenous)` activities[3]. Note that we used association classes to reify the *plays_a* relation, to denote that the object representing a resource playing a role is assigned to an activity. An actor is an agentive business process participant and an artefact is a non-agentive participant, and both can have *physical* and/or *non-physical* characteristics. For example, two or more copies of the same physical document are different carriers of the same piece of (non-physical) information included in those documents. Note that the association between the resource and the role occurs within the boundaries of activity, which somehow plays here the role of context in the definition of something as a resource.

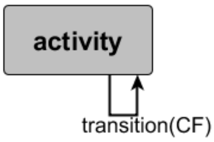
A final comment is devoted to the resource *is_a* precondition relation found in the *LB meta-model*. While this relation must be deemed wrong, as a resource is not *usually* seen as a state, it is nonetheless true that the existence of resources with certain characteristics and capabilities can act as precondition to the execution of certain activities. In the re-evaluation of the *LB meta-model*, resources are not preconditions (i.e., states), but rather resources can be *specified_in* preconditions, which are states. As we have seen before, often activities *require* specific states, a.k.a. preconditions, to be performed and then without those preconditions the activity is incomplete. However, sometimes a precondition could be the mere existence of a resource. For example, "the ID card is available" is the precondition of the activity "storing the ID card in the system". Here, "being available" means that the ID card exists. Although treating the existence as a state of an object is philosophically controversial, within the context of business process (modelling) is less. Indeed the creation, modification, and deletion of an object are usually considered states of the object, as they are seen as part of the lifecycle of the object itself.

6.3 Connection flow and occurrence dependences in the *LB meta-model*

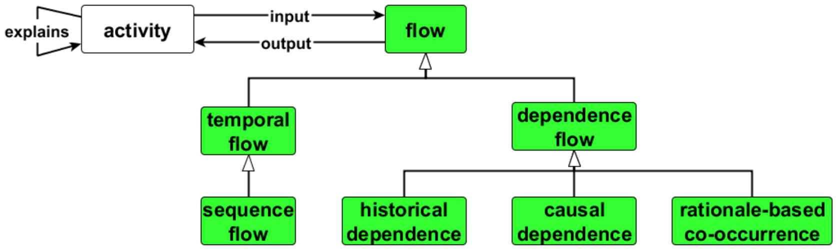
In this Section we propose to include in the *LB meta-model* the flow components. This proposal takes into account the results emerged from Section 5.3.

The enrichment of the *LB meta-model* concerning the relationships among activities is not so trivial. Indeed, the meta-model as it emerged from the SLR is completely lacking of any sequence flow components. Yet, there is one activity relations which could provide a starting point for this expansion: the relation from an activity to an activity *transition(CF)* (see Section 4.2.3, Tables 4.8 and 4.9, as well as Figure 6.3a). However this relation is very general and does not specify any constrains apart from denoting the generic control flow relation between activities. In Section 6.1 we also introduced the relation *explains* among activities which aims to capture a sort of "causal" connection. In this Section we further expand this analysis of relations among activities by introducing an important business process element that is missing, i.e., the flow.

[3] Here we focus on resources that are assigned to activities within the process owner boundaries.



(a) Snippet of the original *LB meta-model*.



(b) The new proposal.

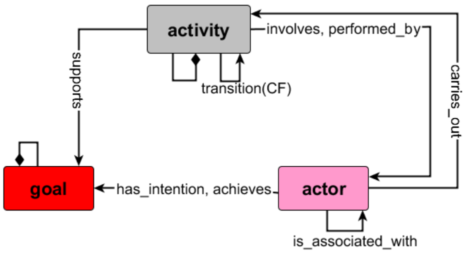
Figure 6.3: Re-factoring of the flow element.

Figure 6.3b depicts our proposal for including flow elements in the *LB meta-model*. The `flow` component defines generic activities' connections, both temporal and ontological. The flow takes in *`input`* activities and released in *`output`* activities. The flow entity replaces the *`transition(CF)`* of the original *LB meta-model*. The connections flows among activities can be temporal (i.e., `temporal flow`) and ontological (i.e., `dependence flow`). The former defines the temporal sequential order of the activities, the latter specifies the occurrence constraints identified in Section 5.3. The `temporal flow` is decomposed in a `sequence flow`, which is often represented in business process modelling languages as precedence arrows between activities, while the `dependence flow` has three sub-classes, `historical dependence`, `causal dependence` and `rationale-based co-occurrence` which have been widely explained in Section 5.3.

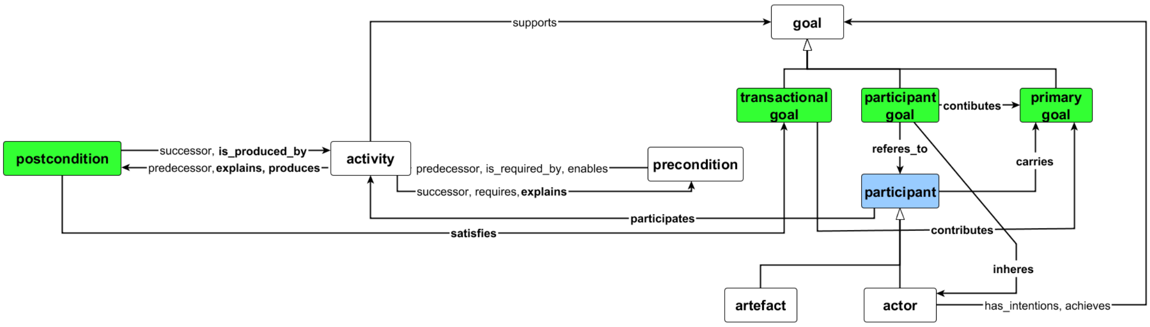
6.4 Goals in the *LB meta-model*

Goals have been studied in Section 5.4, in which a classification of business process related goals has been proposed. The goals we propose are: *primary goal*, *transaction goal*, *data and organisation oriented goal*, and two meta-level goals divided in: *instantiation* and *quality*. While the first three types of goals are directly related to the business process model diagram, the meta-level goals are more abstract. In this Chapter we focus only on the diagram-related goals, that is, the first three.

While Figure 6.4a depicts the snippet of the original *LB meta-model* in its part concerning the `goal` element and its relations, Figure 6.4b represents the extension of the *LB meta-model*, which takes into account the analysis of goals that has been carried out in Section 5.4. The meta-model is enriched by adding three sub-classes of goals, `primary goal`, `transactional goal` and `participant goal`. The `postcondition` of the activity *`satisfies`* the `transactional goal`. The `participant goal` *`refers_to`* `participants`, actors and artefacts, which *`participate`* in the activities. In particular, this kind of goals *`inheres`* in the `actor` participant. In this sense



(a) Snippet of the original *LB meta-model*.



(b) The new proposal.

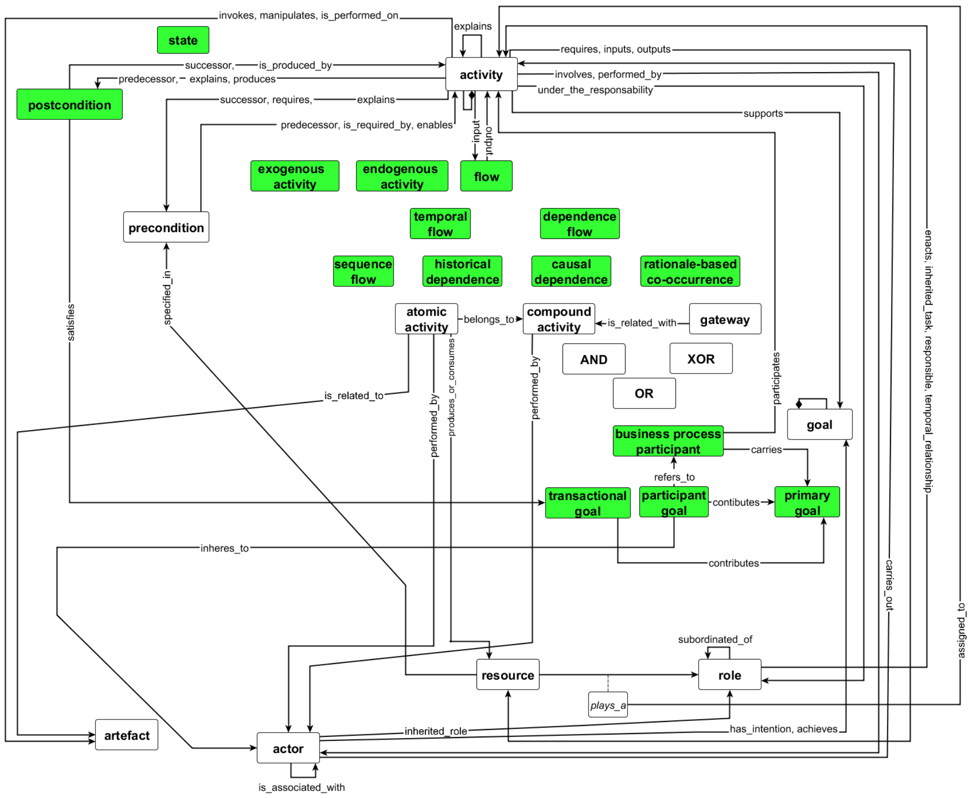
Figure 6.4: Re-factoring of the goal element.

actors have *intentions* and the content of these intentions can be goals [GdAFG08]. Both `transactional goal` and `participant goal` *`contribute`* to the `primary goal` which is the realisation of a (desired) state of the world which is relevant for at least one participant of the process. Note that activity *`supports`* `goal`, and the latter is the super-class of the three more specific goals. This means that activities bear all three sub-goals. Similarly `actor` has (intention) goals and aims at achieving goals.

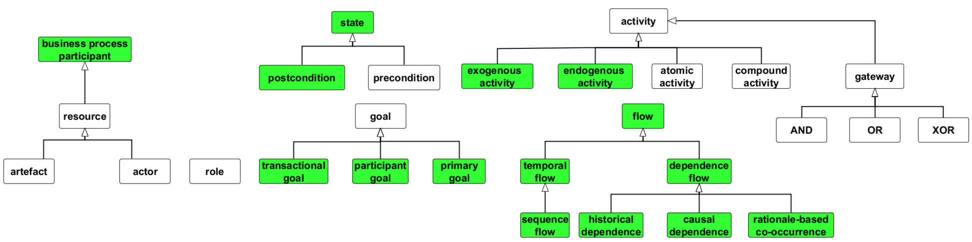
6.5 The revised meta-model

In the previous Sections we proposed some changes to the *LB meta-model* to overcome problems outlined in Chapter 4, and more specifically in Sections 4.4 and 4.5. These changes have been embedded in the *LB meta-model* enriching it with the results emerged from Chapter 5.

The changes we propose for the meta-model, described in Figures 6.1b–6.4b include several new entities and relations. Tables 6.5a, 6.1b, and 6.1c report all newly introduced and deleted entities and relations. Figures 6.5a and 6.5b depict the new version of the *LB meta-model* (without taxonomical relations and taxonomy only, respectively) that includes all the changes proposed in Figures 6.1b–6.4b. The white entities are the ones that were already included in the original *LB*



(a) The new entities and relations.



(b) The new taxonomic relations.

Figure 6.5: The new meta-model.

Table 6.1: New and deleted entities.

(a) New and deleted entities.

New entity	Deleted entity
exogenous activity	event-BPMN
endogenous activity	event-EPC
state	
postcondition	
flow	
temporal flow	
dependence flow	
historical dependence	
causal dependence	
rationale-based co-occurrence	
participant goal	
transactional goal	
primary goal	
business process participant	

(b) Deleted relations.

Relation	Domain	Codomain
is_produced_by	postcondition	activity
activates	event-EPC	activity
predecessor	event-EPC	activity
successor	event-EPC	activity
creates	activity	event-EPC
predecessor	activity	event-EPC
successor	activity	event-EPC
initiated_by	activity	event-BPMN
transition(CF)	activity	activity
is_a	resource	precondition
is_a	actor	role
is_a	resource	role
*is_*	role	resource
is_a	resource	artefact

(c) New relations.

Relation	Domain	Codomain
is_produced_by	postcondition	activity
is_a	postcondition	state
explains	activity	postcondition
produces	activity	postcondition
explains	activity	precondition
is_a	precondition	state
explains	activity	activity
is_a	exogenous activity	activity
is_a	endogeneous activity	activity
is_a	artefact	resource
is_a	actor	resource
plays_a	resource	role
specified_in	resource	precondition
assigned_to	resource	endogenous activity
input	activity	flow
output	flow	activity
is_a	temporal flow	flow
is_a	dependence flow	flow
is_a	sequence flow	temporal flow
is_a	historical dependence	dependence flow
is_a	causal dependence	dependence flow
is_a	rationale-based co-occurrence	dependence flow
is_a	transactional goal	goal
is_a	participant goal	goal
is_a	primary goal	goal
participates	participants	activity
contributes	transactional goal	primary goal
contributes	participant goal	primary goal
carries	participant	primary goal
inheres	participant goal	participant

meta-model, while the green coloured boxes are the new added components. Note that Figures 6.5a and 6.5b do not include all the upper ontology elements that were depicted in blue in diagrams 6.1b–6.4b. Indeed although those concepts were helpful for clarifying the ontological status of some business process meta-model components, these foundational elements do not directly belong to the business process meta-model. An exception was made for the `participant` entity (and its relations) which we renamed as `business process participant` in this specific domain. This decision is based on the fact that the notion of business process participant appears to be meaningful in this context.

To sum up, here is the list of the main changes. We have deleted some entities, for instance `event-EPC` and `event-BPMN`, which have been included in the notions of activity and state. The entity `event-EPC` has been divided in `precondition` and `postcondition`, while the entity `event-BPMN` has been renamed as `exogenous activity`, which is an extra-organisational activity. `endogenous activity` has been introduced to complement the exogenous one and refers to activities internal to the organisation. The entity `state` has been introduced in order to clarify the ontological status of pre-postconditions and also make visible that resources are not preconditions. Another important point is related with the unravelling of the subsumption relations of the entity `resource`. In this refactory of the meta-model, actors and artefacts are resources and not vice-versa, moreover the relation between resource and role is not an is_a, but rather a *`plays_a`* in the context of an activity assignment. We also enrich the meta-model by adding the flow-related entities and creating two sub-classes of flow, temporal and (ontological) dependence which are further divided into other more specific connecting objects. Rationales (see Section 5.3) were not included in the meta-model as they do not directly belong to the business process graphical components. Finally, we made an attempt to provide some dignity to the entity `goal` in the meta-model, specifying its sub-types its relations with other entities.

Overall, these 18 new entities and 35 relations complement the existing knowledge of business process and business process modelling. Yet, the main aim of this study is not to provide a complete theory on business process, indeed our idea is to advance some initial developments and be open to discuss these with the different communities which are interested in this topic.

6.6 Contributions and limitations of the Chapter

In this Chapter we provided a revision of the *LB meta-model* that incorporates the analysis of the four business process elements investigated in the previous Chapter. This contribution goes into the direction of producing a reference meta-model of what constitutes a business process.

The main limitation of this Chapter lies in the fact that we were able to investigate and revise only few elements. This limitation concerns both elements that are present in the original *LB meta-model* (e.g., the entity `gateway`) and elements that were not present in the original *LB meta-model* but should be added to it (e.g., *value*).

We mitigated this limitation by identifying elements that were clearly challenging or missing in the original *LB meta-model* and we are willing to continue this study also on the elements that remained excluded from this thesis.

Chapter 7

Applying ontological analysis results in practice: the case of occurrence dependences and rationales

While the previous Chapter (see Chapter 6) provided a possible use of the ontological analysis outcomes towards the construction of a business process meta-model by enriching the *LB meta-model*, in this Chapter the focus is on the application of the ontological analysis results in the context of business process modelling and analysis. More specifically, we propose a notation to graphically annotate BPMN process models with information on occurrence dependences and their rationales. Moreover, we provide: (i) a demonstration of the use of these dependence and rationale annotations for business process *documentation* and *redesign* purposes through two application scenarios, and (ii) an evaluation of the effectiveness of the dependence and rationale annotations for supporting business process modellers and analysts through an *empirical user study*. ***GOAL 3.2*** motivates the research conduced in this Chapter and ***TASK 4*** guides the methodological steps we performed to reach that goal.

The research carried out in this Chapter shows how ontological analysis studies can have an impact in practice. More in detail, the investigations carried out show how ontological analysis outcomes could facilitate and support business process modellers and analysts in their modelling tasks.

The Chapter is divided in four parts: Section 7.1 introduces a possible way to represent occurrence dependences and rationales in BPMN diagrams, i.e., the dependence and rationale annotations used in the application scenarios and the user study; Section 7.2 outlines occurrence dependences and their rationales applied to business process documentation and redesign; Section 7.3 deals with the design and execution of the empirical study aiming at evaluating the effectiveness of activity dependences and rationales for process modellers and analysts; in Section 7.4 we

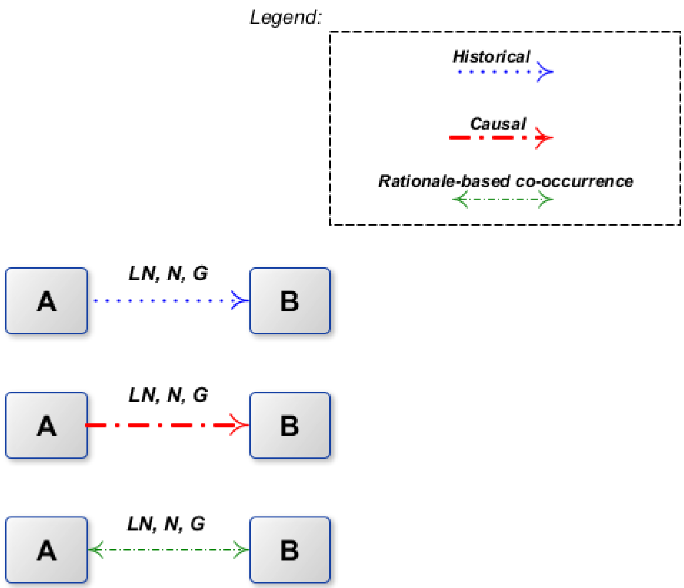


Figure 7.1: Annotations for dependences and rationales.

summarise few discussion points concerning the usefulness of ontological analysis results in practice. Finally, at the end of this Chapter, we identify the contributions and the limitations, i.e., the threats to validity of the study (see Section 7.5).

7.1 Annotations for dependences and rationales

In Section 5.3 we described three types of dependences between activities (historical, causal and rationale-based co-occurrence) and three types of rationales that motivate their existence ('law of nature', goal and norm). These relationships can be represented in the diagrams by enriching the models with annotations. In this Section we describe a possible way to enrich BPMN business process models with dependence and rationale annotations.

Dependences between activities can be depicted in a process model as the temporal relationships are represented, i.e., as arrows between pairs of activities. As shown in Figure 7.1, we extended the BPMN notation by introducing special arrows for representing historical, causal and rationale-based co-occurrence dependences. Different types of lines and different colours are used for distinguishing the arrows representing the three types of dependences. The blue dotted line represents the historical dependence, the red dash-dotted line is used to represent the causal dependence, while the green dash-dotted line represents the rationale-based co-occurrence dependence. The three rationales associated to the dependence arrows, i.e., 'law of nature',

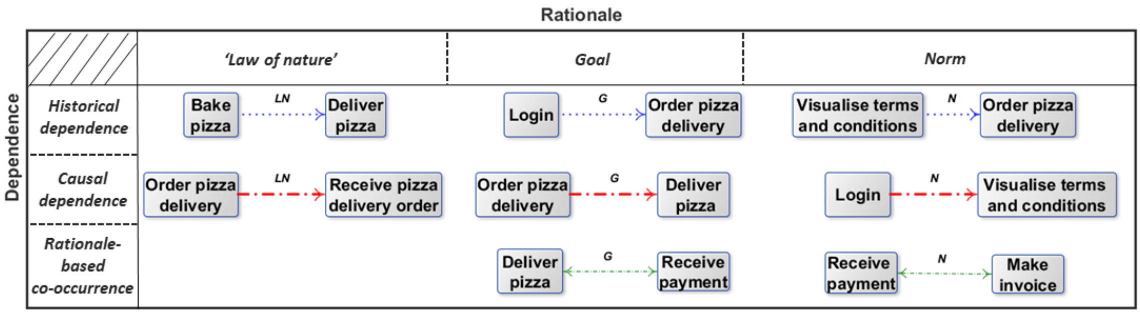


Figure 7.2: Annotation example.

norm, or goal, can instead be annotated on top of the arrows with the acronyms *LN*, *N* and *G*, respectively.

In Figure 7.2, we provide, for each type of dependence, i.e., historical, causal and rationale-based co-occurrence, an example for each of the three rationales starting from the process model in Figure 5.2, except for the 'law of nature' rationale-based co-occurrence dependence, for which we were unable to find an instantiation on this process model. For instance, activity `Deliver pizza` is historically dependent on activity `Bake pizza`, due to a 'law of nature'. This relationship is represented through a blue dotted arrow annotated with the label *LN*. Another example is related to the authentication procedure in an online service, where a causal dependence exists between activities `Login` and `Visualise terms and conditions` because of a normative regulation. The relationship is depicted in the figure as a red dash-dotted arrow annotated with the *N* label. The rationale-based co-occurrence between the two activities `Deliver pizza` and `Receive payment` because of the goal of the process is instead graphically captured by the green dash-dotted arrow. Since the dependence is motivated by the goal of the process, the corresponding rationale-based co-occurrence arrow is annotated with label *G*.

7.2 Application scenarios: documentation and redesign

In this Section we describe two application scenarios that could benefit of the analysis carried out in Section 5.3 on occurrence dependence and rationales: business process *documentation* and business process *redesign*.

Business process documentation. Business process models are often used by organizations as a means for documenting the procedures carried out. However, the information contained in the model sometimes is not enough in order to make clear the reasons why some parts of the process model have been designed in a certain way.

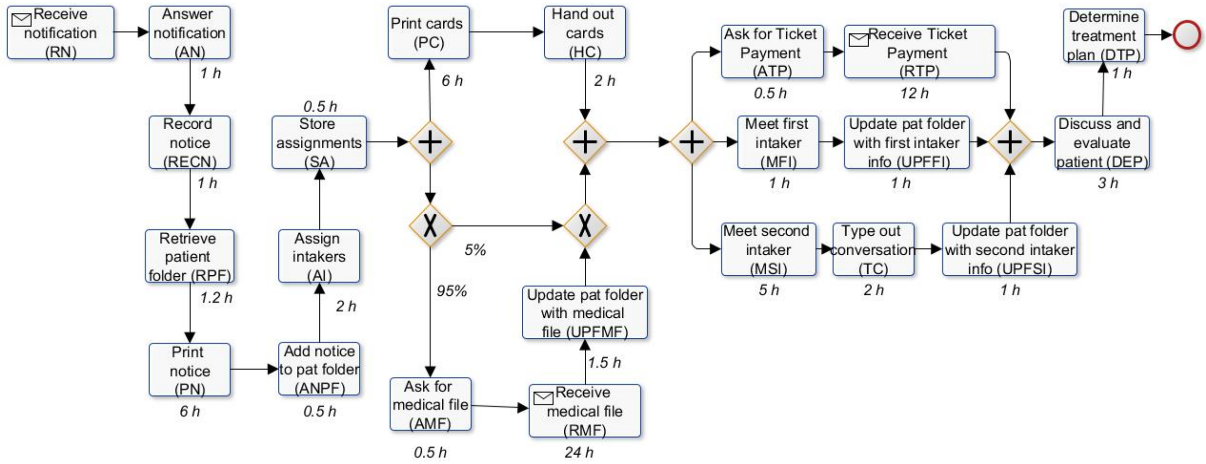


Figure 7.3: *Intake* process of a healthcare institute.

Let us consider a realistic scenario of an *Intake process for elderly patients with mental problems*, inspired by the procedure reported in [DRMR13] that describes the process carried out in a healthcare institution of the Eindhoven region. The *Intake* process starts when the institute receives a notice by the family doctor of the person who needs the treatment. The notice is answered, recorded and printed. The patient's folder is retrieved, if it already exists, or it is created, if the patient has never been registered in the healthcare information system, and the notice added to the patient's folder. Two intakers (a social-medical worker and a physician) are then assigned to the patient and the assignments stored in the system. Two cards containing information about the patient, one per intaker, are printed and handed out. Meanwhile, if needed, the medical file of the patient is requested to the patient's doctor and, whenever it is received, the document is added to the patient's folder. Once the medical file is available for the appointment, the patient can meet the intakers and is asked to pay the ticket. At the end of each of the two meetings, the patient's folder is enriched with the new information acquired by the intakers. When the documentation by each of the two intakers has been collected, it is evaluated and a treatment for the patient decided.

Figure 7.3 reports the *Intake* process described in BPMN and annotated with some hypothetical activity cycle time[1] as well as with the probability distribution of the alternative branches.

Let us assume that a new director has been appointed, and she\he\they has\have been provided with the institute business process models in order to get familiar with the procedures carried out in the institute. When looking at the *Intake* process model in Figure 7.3 (in which data objects are not reported to ease the readability, and activity labels, as often happens, are not

[1]The cycle time of an activity (process) is the average time it takes between the moment the activity (process) starts and the moment in which the activity (process) completes. The cycle time hence includes both the processing and the waiting time of an activity (process).

extremely informative), she\he\they is\are only able to grasp the execution ordering of the activities currently carried on in the institute, while missing other types of dependences among them. This lack of information could result in possible misunderstandings of the process model as well as of what it represents. By only looking at the model, she\he\they may ask the reason why in the model activity `Assign intakers` occurs before activity `Update pat`(ient) `file with first intaker information`.

Table 7.4 reports the occurrence dependences identified among the activities of the *Intake* process by using the notation introduced in Section 7.1. Some of the dependences are real-world ones, i.e., they depend on *'laws of nature'*, others relate to the *business goal* of the process, while others pertain to *norms*. The dependence expressions are grouped accordingly in Table 7.4.

Among the *law-of-nature* dependences, a historical dependence can be identified between activities `Record notice` and `Print notice`. Intuitively, printing a notice demands for a state of the world in which the notice is in an electronic format, i.e., it requires that it has been (electronically) recorded. Similarly, a historical dependence exists between `Retrieve patient folder` and all the activities that demand for the existence of the folder in order to be executed (i.e., `Add notice to patient folder`, `Update pat. folder with medical file`, `Update pat. folder with first intaker info`, `Update pat. folder with second intaker info`). A historical dependence also exists between activities `Print cards` and `Hand out cards`, as handing out cards demands for a state of the world in which the cards have been printed out. Few causal dependences can also be identified, as for instance between activities `Receive notice` and `Answer notice` (the notice answer is caused or explained by the notice receipt), between activities `Ask for medical file` and `Receive medical file` (the receipt of the medical file is caused by the request for the file to the doctor) and between activities `Ask for ticket payment` and `Receive ticket payment` (the payment reception is caused by the payment request).

Among the *business goal* dependences, a rationale-based co-occurrence can be identified between activities `Receive ticket payment` and `Determine treatment plan`. Indeed, due to the business nature of the *Intake* process, in order to get the process accomplished, both determining the treatment plan for the patient and getting the ticket paid for the service are necessary activities. Removing the occurrence of one of the two activities would change the process into a different one. However, the two activities are not bound by any temporal constraint. Similarly, for the rationale-based co-occurrence between activities `Receive ticket payment` and `Discuss and evaluate patient info`. Moreover, a historical dependence can be identified between activities `Discuss and evaluate patient` and `Determine treatment plan`. Indeed, in an *Intake* process, a decision on the treatment plan of a patient cannot be taken, unless the patient's information has been carefully evaluated. Last but not least, a causal dependence relationship holds between activity `Receive notice` and activity `Discuss and evaluate patient`. The discussion and evaluation of the patient is indeed triggered (in an *Intake* process) by the request to start an intake procedure. Similarly for the causal dependence between activities `Receive` `notification` and activity `Determine treatment plan`.

Finally, among the norm-based occurrence dependence, two historical dependences can be identified (between the pair `Assign intakers` and `Update pat. folder with first intaker information` and between the pair `Assign intakers` and `Update pat. folder with second intaker information`). Indeed, an intaker is allowed to report information in the patient folder only if she\he\they has\have been appointed to do it, i.e., a historical dependence relationship holds between the two activities (and, hence, the latter cannot occur before the former).

The additional information that the occurrence dependence is able to provide, makes it clear to the new director that a dependence relationship holds between activities `Assign intakers` and `Update pat. folder with first intaker information`, as well as the reason why they have to occur in that specific order. Hence, making explicit these dependences helps the new director to understand why the procedure has been designed as it is.

Business Process Redesign It is often the case that business process models need to be redesigned. This can be due to different reasons e.g., because the world, the organization or the procedure they describe changes, or for optimization reasons. Several approaches and techniques have been investigated in the BPM community in order to support business analysts in business process redesign (see e.g., [DRMR13, RM05]).

Let us assume, that the new director of the healthcare institute, in order to better understand the efficiency of her institute, has appointed a business analyst to analyse the processes carried out in the institute. By analysing the process under the perspective of evaluating its cycle time, the business analyst notices that the process presents some bottlenecks. Indeed, activities `Print notice`, `Receive Payment Ticket` and `Receive medical file` have a high average duration time (6, 12 and 24 hours, respectively). In the first case, the high duration time is due to the fact that only one printer is available in the institute, while in the second and in the third case this is due to the response time required by patients and medical doctors to pay the ticket and to provide the medical file, respectively. Moreover, although in the last case the request for the file from the doctor is optional, it is needed in 95% of the cases. This causes a high process cycle time[2] ($= 53.4$h). In order to solve the issue, the institute director, at the suggestion of the

[2]The computation of the process cycle time is based on flow analysis [DRMR13] and depends on the structure of the process. In this case, the average time required for a process execution is given by the average time required by: (i) the sum of the time required by the activities in sequence before the first split AND gateway, which is, in turn, given by the sum of the average times of the activities in sequence ($(1 + 1 + 1.2 + 6 + 0.5 + 2 + 0.5)h= 12.2$h); (ii) the sum of the times required by the most costly branches of the two AND blocks, i.e., the one dealing with the optional request to the doctor of the medical file and the one related to the ticket payment receipt. The former is computed as the weighted (with the corresponding probabilities) average of the two alternative branches between the XOR split and the XOR join, (i.e., $((0.95 * (0.5 + 24 + 1.5)) + (0 * 0.05))h= 24.7$h), while the second is the sum of the average cycle time of the activities `Ask for ticket payment` and `Receive ticket payment`, (i.e., $(0.5 + 12)$h=12.5h), respectively; and (iii) the time required by the last two activities (i.e., $(3 + 1)$h=4h). The average cycle time is hence $(12.2 + 24.7 + 12.5 + 4)$h$= 53.4$h.

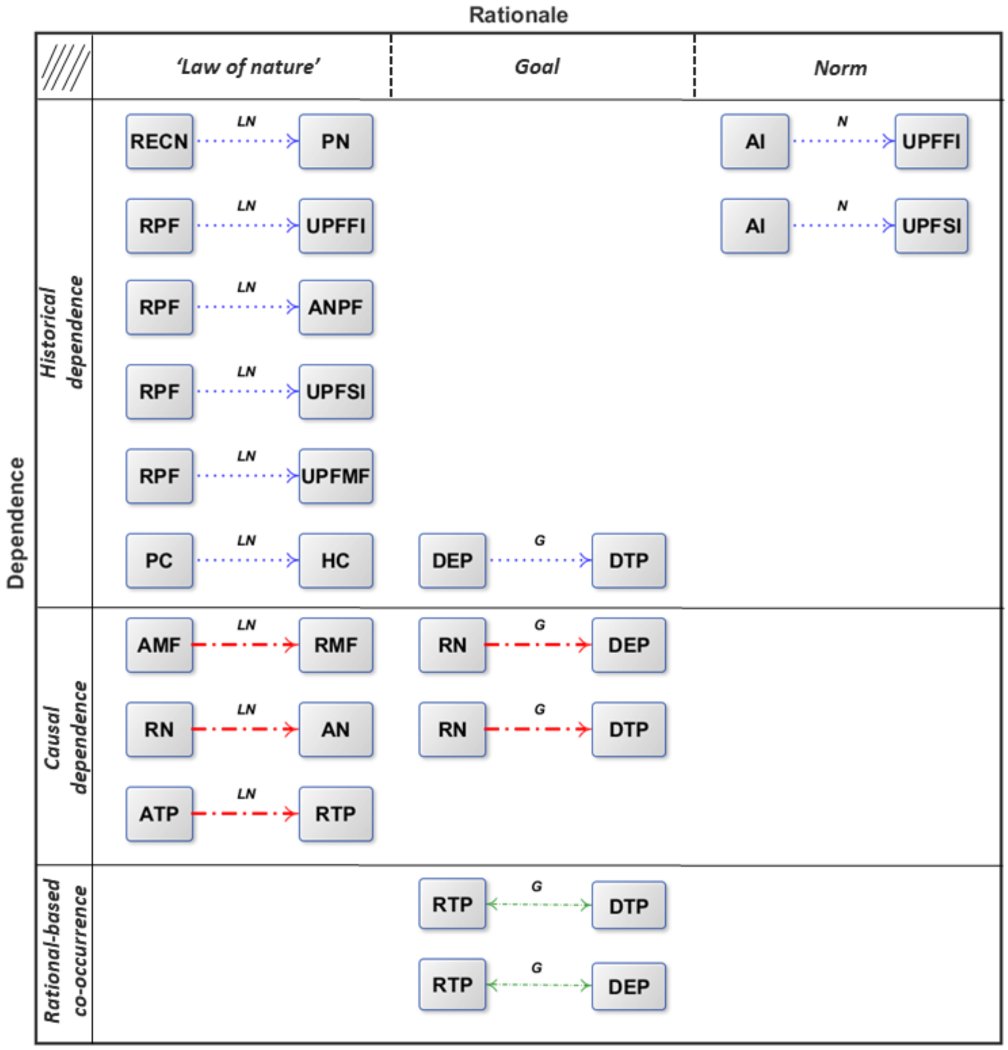


Figure 7.4: Dependence expressions characterising the *Intake* process.

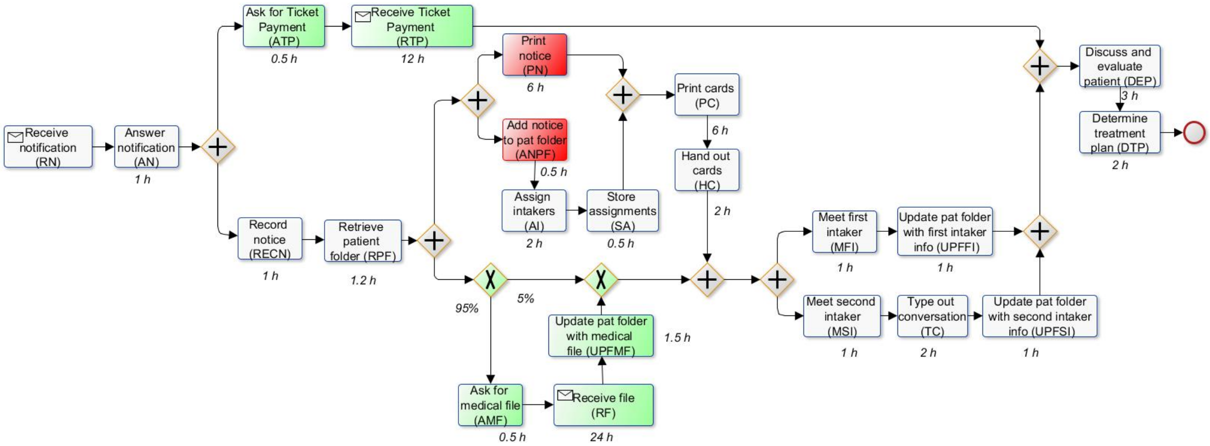


Figure 7.5: *Intake* process redesigned according to the analyst's suggestions.

business analyst, decides to redesign the process.

In order to reduce the overall cycle time of the procedure, the business analyst suggests to apply two business process behaviour heuristics: *parallelism* and *resequencing* [DRMR13]. While the first heuristic consists of evaluating what "can be executed in parallel", the second one consists of "moving the activities to more convenient places" [DRMR13] (see Section 2.4.2). According to the process re-design heuristics, the business analyst suggests to (i) parallelise the printing of the notice and the enrichment of the patient file up to the storing of the intaker assignments; (ii) anticipate the request for the payment to the patients and the request for the medical file to the doctor. Figure 7.5 shows the redesigned model. Such a redesign allows the healthcare institute to save about 16.5 hours of cycle time by reducing the cycle time from 53.4 to 36.9 hours - as most of the flow related to the notice management and to the intaker assignment is actually executed in parallel with the long time required for waiting for the medical file.

However, by looking at the dependence expressions reported in Table 7.4, the business analyst can easily notice that, while anticipating the request for the medical file to the doctor and for the ticket payment to the patient (depicted in green in the diagram) does not violate any of the identified dependences, this is not the case for the parallelisation of the printing of the notice and the enrichment of the patient folder (marked in red). Indeed a historical dependence relationship holds between activity `Add notice to the patient folder` and activity `Print notice`, so that swapping them would result in an incorrect model.

7.3 Empirical evaluation of dependence and rationale annotations

As explained in the previous Section, occurrence dependence and rationale annotations can be used to: (i) enhance business process models understanding, and (ii) support the activity of business process model redesign. In this Section we are interested in evaluating the impact of and the effort required when using dependence and rationale annotations in business process models have for business process modellers and analysts. To this aim, we conducted an empirical study with human subjects evaluating the effectiveness (in terms of benefits and costs) of occurrence dependence and rationale annotations on business process model *comprehension* and *redesign*. Besides the effectiveness of leveraging dependence and rationale annotations for business process model comprehension and redesign, we also tried to understand the effort required for enriching business process models with these annotations. To this aim, we conducted a more qualitative investigation involving users on the effort required for annotating business process models with dependence and rationale annotations.

In this Section we provide in detail: (i) the description of the experimental design of the empirical user study (Section 7.3.1), (ii) the results of the evaluation (Section 7.3.2); and (iii) the investigation on the effect required for annotating process models with dependences and corresponding rationales (Section 7.3.3).

7.3.1 Experimental design

This Section focuses on the description of the experimental design that has been used to evaluate the support provided by dependences and rationales between business process activities presented in Section 7.1. Specifically, the empirical study with human subjects aims at evaluating the impact of dependence and rationale annotations in business process models on *comprehension* and *redesign* tasks. The study is conducted and reported according to the methodology proposed by Wohlin [WRH+12] for the evaluation of software engineering experimentations.

7.3.1.1 Goal of the study

The **goal** of the study is to analyse two approaches (leveraging business process models *with* and *without* activity dependence and rationale annotations) with the purpose of evaluating their effectiveness in supporting analysts and modellers in the process model *comprehension* and *redesign* in the context of business process analysis and maintenance operations. The **quality focus** of the study is related to (i) the quality of the results obtained (both actual and perceived) and (ii) the effort required (in terms of perceived effort) for process model comprehension and redesign tasks. The **perspective** considered is of both modellers and business analysts interested in investigating the benefits of using annotations to clarify the nature of dependences between activities and the rationale of these dependences for supporting business process comprehension and redesign. The **context** of the study consists of (i) two objects (two process models and their descriptions) and (ii) a group of master students enrolled in the BPM course at the University of Tartu, Estonia as subjects.

The **objective** of the study is twofold: (i) investigating the support offered by dependence and rationale annotations in BPMN process models (in terms of actual and perceived quality of the results, as well as perceived effort) in comprehension tasks with respect to traditional BPMN process models; (ii) investigating the support offered by dependence and rationale annotations in BPMN process models (in terms of actual and perceived quality of the results, as well as time spent and perceived effort) in redesign tasks with respect to BPMN process models without dependence annotations. To this aim, we asked the subjects to accomplish two assignments: the *Process Comprehension* and the *Process Redesign* task. The Process Comprehension task, aimed at comparing the comprehension of process models without (WOA) and with (WA) dependence and rationale annotations, consists in answering a process comprehension question. The Process Redesign task, aimed at comparing the redesign of process models without (WOA) and with (WA) dependence and rationale annotations, consists in redesigning a process model in order to improve the overall process cycle time[3].

7.3.1.2 Research questions

The assumptions of this empirical study are based on the idea that dependence and rationale annotations can support modellers and analysts: (i) in the comprehension of business process models and (ii) in the redesign of business process models. These assumptions provide us with a direction for the research questions we aim to investigate in this empirical study:

RQ1. Does dependence and rationale annotation support in business process models improve process comprehension, i.e., the quality of process comprehension outcome, without increasing the (perceived) effort it requires?

RQ2. Does dependence and rationale annotation support in business process models improve process redesign, i.e., the quality of the process redesign outcome, without increasing the effort it requires?

RQ1 is related to the comprehension of business process models enriched with dependence and rationale annotations. The hypotheses related to this research question are the following ones:

[3]We recall that the process cycle time, which is the average time it takes between the moment a process starts and the moment it completes, is based on flow analysis and depends on the structure of the process [DRMR13].

- ($H1_0$) Dependence and rationale annotation support in business process models does not improve the process comprehension;
- ($H1_a$) Dependence and rationale annotation support in business process models improves the process comprehension.

RQ1 is explored by considering three factors: (i) the *objective quality* of the outcome of the comprehension task; (ii) the *perceived quality* of the outcome of the comprehension task; (iii) the *perceived effort* of the comprehension task.

$H1_a$ can hence be divided in three sub-hypothesis concerning both objective ($H1A_a$) and perceived aspects ($H1B_a$, $H1C_a$):

- ($H1A_a$) Dependence and rationale annotation support improves the quality of the comprehension task outcome;
- ($H1B_a$) Dependence and rationale annotation support improves the perceived quality of the comprehension task outcome;
- ($H1C_a$) There is difference between the effort perceived when accomplishing comprehension tasks with process models with and without dependence and rationale annotations.

RQ2 is focused on the impact of dependence and rationale annotations on the redesign task. The hypotheses identified for this research question are:

- ($H2_0$) Dependence and rationale annotation support does not improve the process redesign task;
- ($H2_a$) Dependence and rationale annotation support improves the process redesign task.

Also **RQ2** has been analysed by evaluating different factors. Specifically, the investigated factors are: (i) the *objective quality* of the outcome of the redesign task; (ii) *objective time* required for the redesign task[4]; (iii) the *perceived quality* of the outcome of the redesign task; (iv) the *perceived effort* required for carrying out the redesigned task.

The alternative hypothesis $H2_a$ of **RQ2** is hence decomposed in four sub-hypothesis concerning both objective ($H2A_a$ and $H2B_a$) and perceived aspects ($H2C_a$, $H2D_a$) :

- ($H2A_a$) dependence and rationale annotation support improves the quality of the outcome of the redesign task;

[4]Note that we did not investigate the time required for the comprehension task as we considered it negligible.

- ($H2B_a$) there is no difference between the time required for accomplishing the redesign task on process models with dependence and rationale annotations and the time required for accomplishing the redesign task on process models without dependence and rationale annotations;
- ($H2C_a$) dependence and rationale annotation support improves the perceived quality of the outcome of the redesign task;
- ($H2D_a$) there is no difference between the effort perceived when accomplishing the redesign task on process models with dependence and rationale annotations and the effort perceived when accomplishing the redesign task on process models without dependence and rationale annotations.

7.3.1.3 Context

The study is designed considering two objects: the *Intake Process* (IP) and the *Order Fulfillment* process (OF). The *Intake Process* for elderly patients with mental problems describes the process carried out in a healthcare institution of the Eindhoven region already described in Section 7.2 (the process model is inspired by a process model reported in [DRMR13]). The *Intake Process* model with dependence and rationale annotations is depicted in Figure 7.6.

The *Order Fulfillment* process has been inspired by a process model reported in [DRMR13]. It starts when a purchase order is received from a customer. If the product requested is in stock, it is retrieved from the warehouse before the order can be confirmed. If the product is not in stock, it needs to be manufactured before the order handling can continue. To manufacture a product, the required raw materials need to be ordered. Two preferred suppliers provide different types of raw materials. Depending on the product to be manufactured, raw materials may be ordered from Supplier 1 or Supplier 2, or from both. Once the raw materials are available, the product can be manufactured, and the order can be confirmed. According to an internal policy, once the order has been confirmed, the product can be delivered to the customer (once the shipping address has been requested received) and the invoice emitted (once in the cases in which the invoicing address is different from the shipping one, the invoicing address has been asked and received). Once the product is shipped and the payment received, the order is archived, and the process completes. The *Order Fulfillment* process model with dependence and rationale annotations is reported in Figure 7.7.

Both IP and OF process models are designed in BPMN 2.0. The first process model includes 22 activities, 4 parallel gateways, 2 exclusive gateways and one end event. The annotated IP model contains 16 dependences and corresponding rationales. The second process model is composed of 18 activities, 2 inclusive and 4 exclusive gateways and one end event. The annotated OF model includes 18 dependences and corresponding rationales.

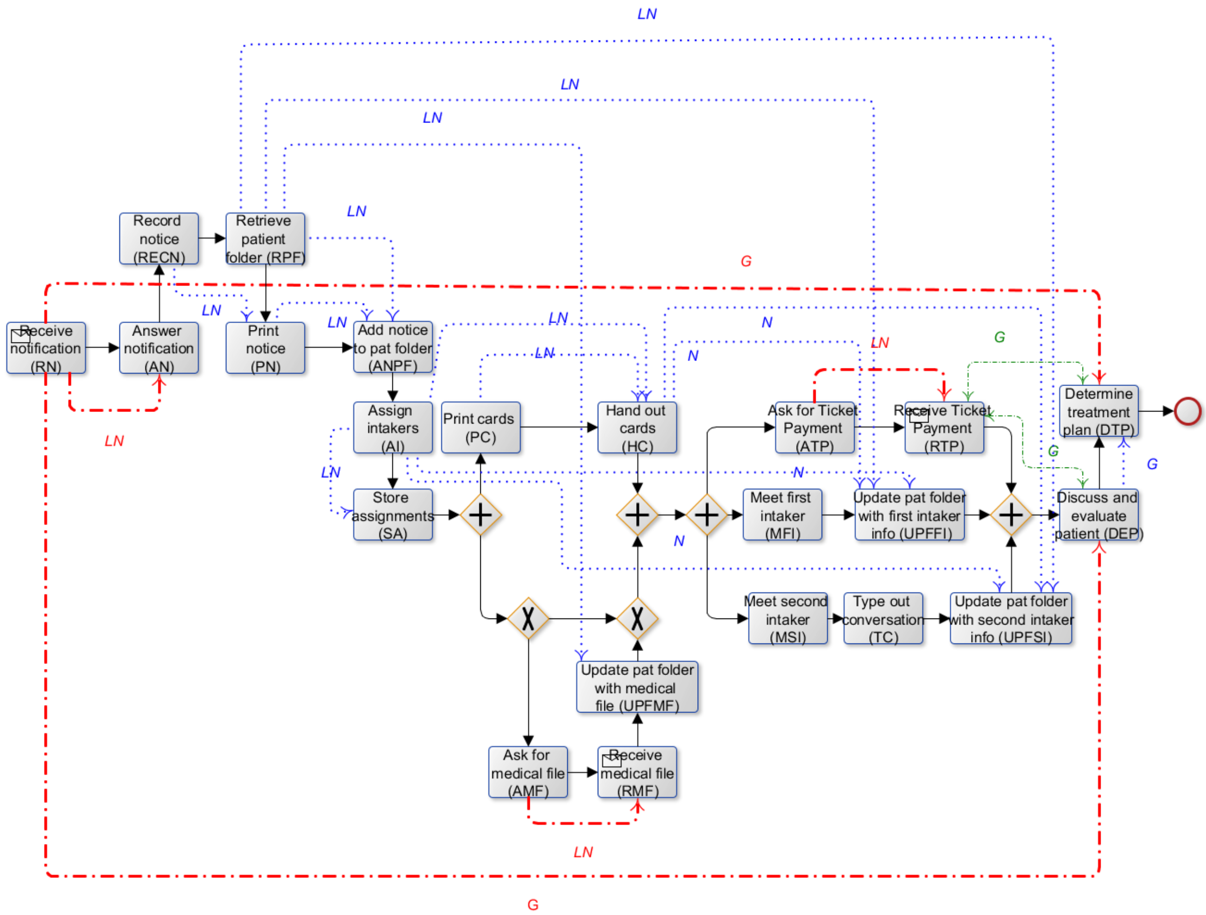


Figure 7.6: Intake process with dependence and rationale annotations.

The subjects involved in the study were 37 Master students enrolled on a BPM course at the University of Tartu, Estonia. Almost all of them were at the year 4 - except one student at the year 5 - of the Master Programme in Computer Science. Figure 7.8a provides an overview of the master specialisation of the students. Figure 7.8b summarises instead the main topics characterising the background of the subjects. Almost all of them declared to have knowedlge in *Computer science* and many of them in *Business management*.

7.3.1.4 Design, material and procedure of the study

The design adopted in the study is a *balanced design* [WRH+12]. The human subjects are divided in four *balanced* groups (G1, G2, G3, G4) and the evaluation test is organised in two sessions (S1, S2). In each session (S1 and S2), subjects are asked to carry out both a Process Comprehension

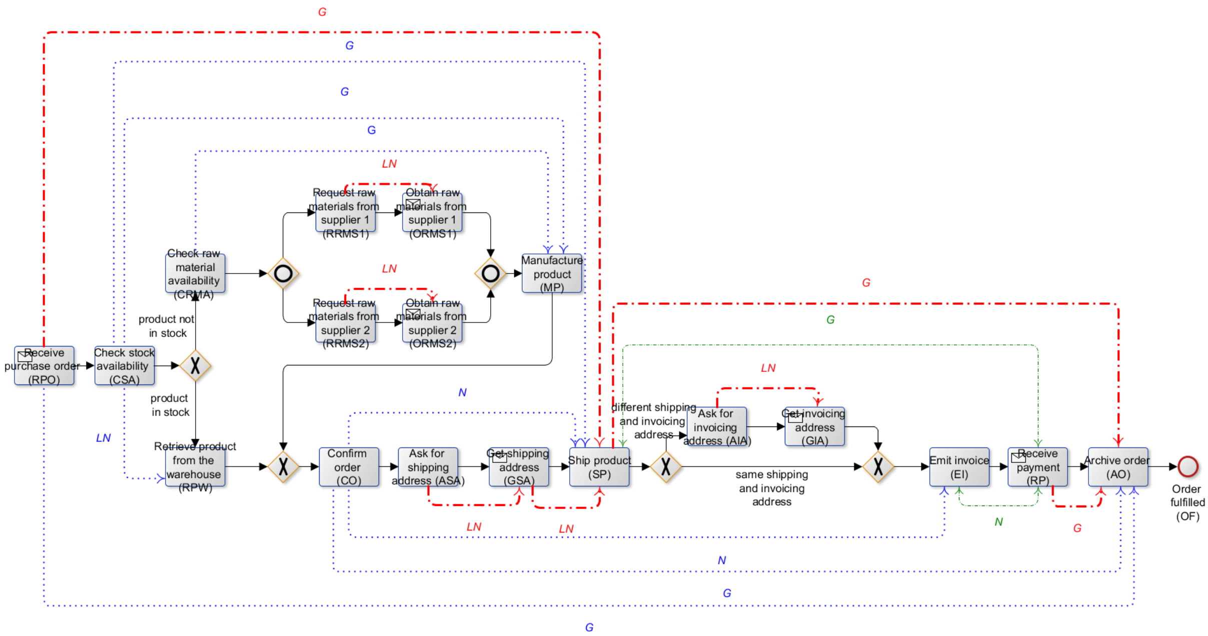


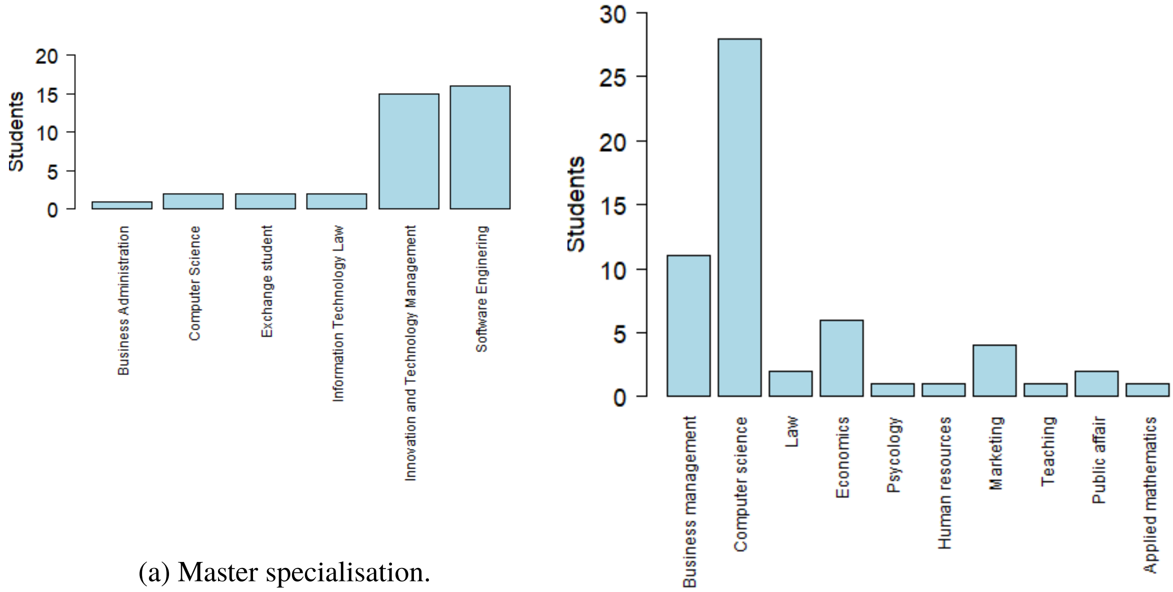
Figure 7.7: Order fulfillment process with dependence and rationale annotations.

and a Process Redesign task on one of the two objects (*Intake Process* and *Order Fulfillment* models) with one of the two treatments (WOA and WA). Each subject was asked to carry out the Process Comprehension and a Process Redesign task both without and with dependence and rationale annotations, i.e., with both the treatments: the WOA treatment has been used for performing both tasks on one of the two process models in one laboratory session and the WA treatment has been used (for performing both tasks) on the other process model in the other laboratory session. Table 7.1 reports the object and the treatment for each group. For instance, the subjects in group G1 were asked to perform both the Process Comprehension and a Process Redesign tasks on the *Intake Process* model without dependence and rationale annotations (WOA) in session S1 and on the *Order Fulfillment* model with dependence and rationale annotations (WA) in session S2.

		G1	G2	G3	G4
S1	WOA	IP		OF	
	WA		IP		OF
S2	WOA		OF		IP
	WA	OF		IP	

Table 7.1: Balanced design adopted in the study.

Subjects were initially provided with a pre-questionnaire (see Appendix D) collecting information



(a) Master specialisation.

(b) Background topics.

Figure 7.8: Subject background.

on their background.[5] Then, at each session, they were provided with the following material:

- a process model description;
- a process model in BPMN without or with dependence and rationale annotations according to whether they have to accomplish the Process Comprehension and Process Redesign tasks with treatment WOA or WA, respectively;
- in case of treatment WA, a handbook summarizing the dependence annotations;
- a comprehension task specification;
- a redesign task specification;
- a post-questionnaire collecting a subjective assessment about the perceived quality of the outcome of the tasks and the effort required for carrying out the tasks (see Appendix E).

Before the experiment, subjects attended a 25-minutes tutorial on occurrence dependences and rationales. After the training phase, the subjects were asked to fill the pre-questionnaire. After a

[5]The whole material provided to subjects is available at https://drive.google.com/drive/folders/1bZqu-CYaKT1b122TkwDbLSAc-GpTZ_GN.

break, the two sessions were carried out, according to the design reported in Table 7.1. Each session (S1 and S2) was planned to last approximately 1 hour, organised in: comprehension question (approximately 10 minutes); redesign task (approximately 30 minutes), post-questionnaire (approximately 10 minutes). Subjects were asked to mark the starting time, before starting the tasks, and the end time, once the tasks were completed. The Process Comprehension task is a comprehension question on the process model, while the Process Redesign task consists in redesigning the process model with the purpose of reducing the overall process cycle time [DRMR13], by increasing the process activity parallelisation. One of the techniques to reduce the process cycle time, indeed, assuming to have enough resources, consists in parallelising the activities that can be parallelised (see activity parallelisation in Section 2.4.2).

7.3.1.5 Variables

In the study, a unique *independent* variable has been considered, i.e., the treatment. The treatment in this experiment can assume only two values WOA (business process models *without* dependence and rationale annotations) and WA (business process models *with* dependence and rationale annotations).

Since for each research question, and corresponding hypothesis, we investigated both objective and subjective factors, we have several *dependent* variables. Table 7.2 reports for each hypothesis (*H1* and *H2*), the objective (obj) and subjective (subj) aspects investigated and the corresponding sub-hypothesis described in Section 7.3.1.2. For each sub-hypothesis, the related variable, its range or unit of measure, as well as its description are reported in the last three columns of the table.

Hp	Analysis type	Sub-hp	Variable	Range/Unit of measure	Description
H1	obj	*H1A*	QC	[0:3]	Quality of the outcome of the Process Comprehension task
	subj	*H1B*	PQC	[1:5]	Perceived quality of the outcome of the Process Comprehension task
		H1C	PEC	[1:5]	Perceived effort required for the Process Comprehension task
H2	obj	*H2A*	QR	[0:6]	Quality of the outcome of the Process Redesign task
		H2B	TR	min.	Time spent for the Process Redesign task
	subj	*H2C*	PQR	[1:5]	Perceived quality of the outcome of the Process Redesign task
		H2D	PER	[1:5]	Perceived effort required for the Process Redesign task

Table 7.2: Dependent variables.

In detail, in order to evaluate the objective quality of the Process Comprehension task, the answers provided by the subjects to the Process Comprehension question are classified according to 4 categories: (0) wrong answer; (1) wrong answer but correct logical flow; (2) correct answer; (3) perfect answer. The quality of the redesigned models produced as output of the Process Redesign task, instead, are evaluated according to 7 categories ranging from low quality (0) to very high quality (7) by taking into account whether: (i) the process was optimized; (ii) activity dependences were violated; (iii) modelling errors were introduced. In detail, the quality of the process optimisation is measured in terms of activity parallelisations applied in order to reduce the average cycle time. A number of activity parallelisations, not violating the activity dependences, and aiming at reducing the process cycle time, were identified independently by two of the researchers carrying on this research and used as a gold standard to evaluate the redesign carried out by the subjects. The time required for the Process Redesign task is measured by asking the subjects to mark the task start and end time. Finally, the subjective metrics are computed by collecting the answers of the subjects contained in the post-questionnaire. Each subject was asked to express her evaluation on a 5-point Likert scale (from 1 to 5, where 1 is very low and 5 is very high) about the perceived output quality and the effort spent in the Process Comprehension (PQC and PEC, respectively) and in the Process Redesign (PQR and PER, respectively) tasks.

Table 7.2 shows that for the sub-hypothesis *H1A* of *H1*, the variable QC measures the objective quality of the output of the Process Comprehension task, while PQC and PEC measure the (subjective) perceived quality of the outcome of the Process Comprehension task (*H1B*) and the perceived effort required for the Process Comprehension task (*H1C*), respectively. Concerning *H2*, the variables QR and TR measure the objective quality of the outcome (*H2A*) and the time required (*H2B*) for the Process Redesign task, respectively. The subjective aspects of the Process Redesign task are instead evaluated through the PQR and the PER variables, which measure the perceived quality of the output (*H2C*) and the perceived effort (*H2D*) of the Process Redesign task.

7.3.2 Results of the study

In this Section we report the results of the data analysis carried out. The statistical analysis of the data has been performed considering two aspects: (i) the influence of the *main factor*, i.e., the treatment, and (ii) the presence of possible *cofactors* that influence the results.

For the analysis of the main factor, due to the violation of the preconditions of parametric tests (small number of data points and non-normal distribution) and due to the fact that each subject performed the assignments with both treatments, we leveraged a non-parametric paired test, the *Wilcoxon* test. We also used the *Cohen's d* formula to calculate the effect-size of the statistical significance of the results.[6] As for the analysis of the main factor, also for the cofactor analysis we used a non-parametric test, i.e., the *Kruskal-Wallis* test [Dod08].

All the analyses are performed with a level of confidence of 95% (p-value < 0.05), i.e., there is only a 5% of probability that the results are obtained by chance.

[6]The effect size is considered small for $0.2 \leq d < 0.5$, medium for $0.5 \leq d < 0.8$ and large for $d \geq 0.8$.

7.3.2.1 Data Analysis

The results of the analysis are organised so as to answer each of the two research questions, by looking at the results related to each of its sub-hypothesis.

Research Question 1. In order to answer **RQ1**, which focuses on the Process Comprehension task, we separately investigated each of the objective and the subjective aspects (and corresponding sub-hypothesis and variables) reported in Table 7.2.

Figure 7.9 and Table 7.3 report the descriptive statistics and the statistical significance of the variable QC, which measures the objective quality of the outcome of the Process Comprehension task ($H1A$) in the WOA and WA scenarios. The plot clearly shows that the quality of the answers given by the subjects when using the WA treatment is more variable than the quality of the answers given by the subjects when using the WOA treatment. This suggests that the quality of the answer to the comprehension question for WA depends on the subjects more than in case of WOA. The plot and the data also reveal that the quality of the provided answers is higher when models are enriched with dependence and rationale annotations. The result is statistically significant with a *medium* effect-size ($|$effect-size$| = 0.507$), thus allowing us to reject $H1A_0$ and assess that the quality of the outcome of the Process Comprehension task with the WA treatment is higher than the quality of the outcome of the same task with the WOA treatment.

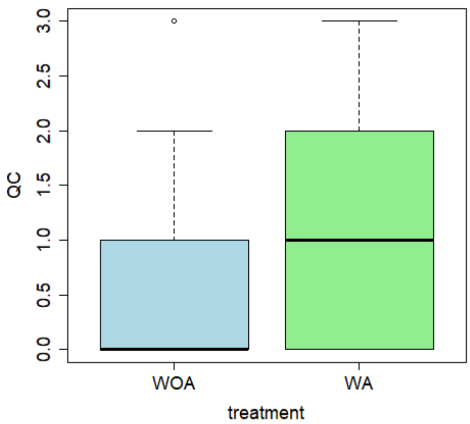


Figure 7.9: $H1A$: QC boxplots.

	WOA	WA
mean	0.65	1.14
median	0	1
standard deviation	0.92	1
p-value	**0.01**	
| effect size |	**0.507**	

Table 7.3: $H1A$: QC analysis.

Differently from the results obtained by looking at the objective quality of the outcome of the Process Comprehension task, the involved subjects did not perceive differences between the quality of the outcome of the task without or with dependence and rationale annotations. This is clearly shown in Figure 7.10 and Table 7.4, which also reveal that the distribution of the variable measuring the perceived quality for the comprehension task (PQC) is almost the same for the two treatments and that no statistically significant difference exists between them. We can hypothesize that this discrepancy between the reality and the perception of the reality is due to the initial *cognitive burden* caused on the subjects by the introduction of the dependence and the rationale annotations. The results do not allow us to reject $H1B_0$ and assess that dependence and rationale annotations improve the perceived quality of the Process Comprehension task outcome.

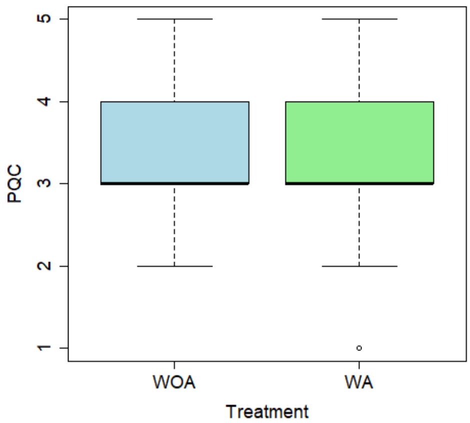


Figure 7.10: $H1B$: PQC boxplots.

	WOA	WA
mean	3.29	3.03
median	3	3
standard deviation	0.97	0.98
p-value	0.325	

Table 7.4: $H1B$: PQC analysis.

Finally, Figure 7.11 and Table 7.5 report the results of the perceived effort required for the Process Comprehension task. By looking at the boxplots and at the descriptive statistics, we can observe that there is almost no difference for the PEC variable between the two treatments. The statistical analysis also confirms that the difference in terms of perceived effort between the two treatments is not statistically significant. We cannot assess $H1C_0$, that is cannot assess that there is a difference between the effort perceived by subjects with the WOA and WA treatments.

Overall, although the subjects seem to be not aware of it, the support of dependence and rationale annotations in business process models improves the process model comprehension, without increasing the (perceived) effort required to accomplish the comprehension task (**RQ1**).

Research Question 2. The focus of **RQ2** is on the Process Redesign task. Also in this case, we separately investigated each of the objective and the subjective factors (and corresponding sub-hypothesis and variables) identified for **RQ2** in Subsection 7.3.1 and summarised in Table 7.2.

Figure 7.12 and Table 7.6 report the results related to the (objective) quality of the outcome of the Process Redesign task (QR). Both the boxplots and the descriptive statistics show that the quality of the outcome of the Process Redesign task with the WOA treatment is more variable (QR has a higher variance) than the quality of the Process Redesign outcomes obtained with

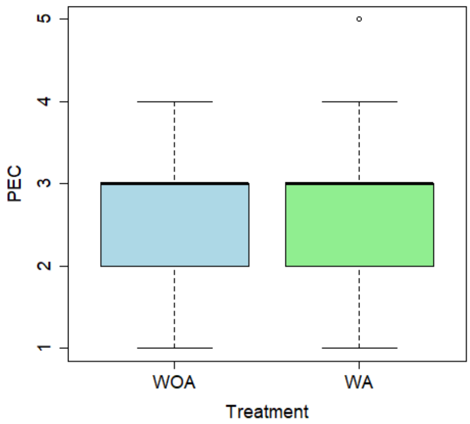


Figure 7.11: $H1C$: PEC boxplots.

	WOA	WA
mean	2.7	2.97
median	3	3
standard deviation	0.81	0.96
p-value	0.186	

Table 7.5: $H1C$: PEC analysis.

the WA treatment. This suggests us that, in the case of WOA, the quality of the outcome of the task depends upon the subject who has carried out the task more than in the WA case. Besides being more homogeneous across subjects, the quality of the Process Redesign task outcome with dependence and rationale annotations is also overall better than the quality obtained without this information. This result is also statistically significant, with a *small effect-size* (see Table 7.6).

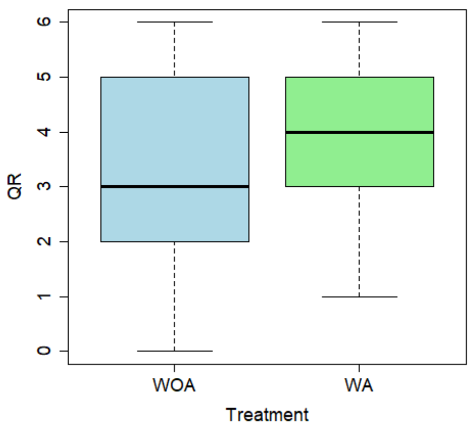


Figure 7.12: $H2A$: QR boxplots.

	WOA	WA
mean	3.39	4.05
median	3	4
standard deviation	1.61	1.43
p-value	**0.008**	
| effect size |	**0.43**	

Table 7.6: $H2A$: QR analysis.

In order to better understand the motivations behind the improved quality of the redesign outcome with WOA, we inspected the QR variable by looking at the three components (and corresponding sub-variables) determining its value (see Section 7.3.1.5): (i)the number of possible activity parallelisation not introduced in order to reduce the process cycle time, i.e., the number of missing parallelisation (MP); (ii) the number of violations of activity dependence relationships (DV); (iii) the number of other errors introduced in the redesigned model (E). Table 7.7 reports the descriptive statistics and the statistical analysis results carried out independently for each of the three sub-variables.

	Missing activity parallelisations (MP)		**Dependence violations (DV)**		**Errors (E)**	
	WOA	WA	WOA	WA	WOA	WA
mean	1.39	1.42	0.84	0.37	0.37	0.16
median	1	1	0	0	0	0
standard deviation	1.26	1.27	1.35	0.79	0.67	0.36
p-value	1		**0.024**		0.059	
|effect size|			0.43			

Table 7.7: Process Redesign outcome detailed analysis.

By looking at the table we can observe that there is no difference between the number of missing activity parallelisations in the outcome of the Process Redesign task when using treatments WOA and WA. Instead, the difference between treatments WOA and WA outcome models is due to the number of errors and especially of violated dependence relationships between activities. Indeed, the number of violated dependences and errors in the models produced as outcome for the Process Redesign task with the WOA treatment is higher than the number of violated dependences and errors in the models produced as outcome for the Process Redesign task when leveraging dependence and rationale annotations. The result is statistically significant with a *small* effect-size for dependence violations and almost statistically significant for the errors. This analysis brings us to conclude that the difference in terms of outcome quality in the Process Redesign task between WOA and WA treatment is mainly due to the different number of violations of activity dependences in the redesigned process models.

The analysis carried out allows us to reject the null hypothesis $H2A_0$ and to assess that the support provided by dependence and rationale annotations improves the quality of the outcome of the Process Redesign task ($H2A_a$).

The results related to the (objective) time required for carrying out the Process Redesign task are reported in Figure 7.13 and Table 7.8. The data reveals that carrying out the Process Redesign task with dependence and rationale annotations takes slightly more time than executing the same task without dependence and rationale annotations. However, such a difference is not statistically significant. Hence, we cannot reject $H2B_0$, that is, we cannot assess that there is a difference in the time required for carrying out the Process Redesign task without or with dependence and rationale annotations.

Moving to the subjective analysis, the data reveals an opposite situation with respect to the one observed for the objective variables. Differently from the actual quality of the Process Redesign task outcome, indeed, Figure 7.14 and Table 7.9 show that the perceived quality of the Process

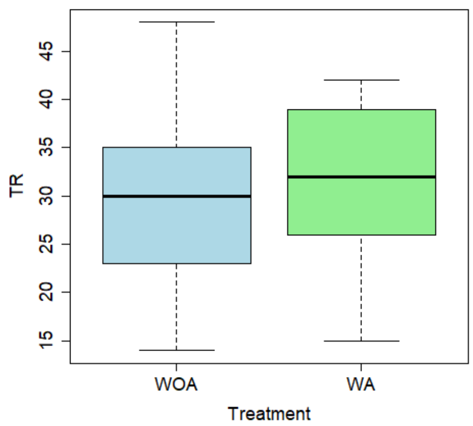


Figure 7.13: $H2B$: TR boxplots.

	WOA	WA
mean	29.24	31.58
median	30	32
standard deviation	8.36	7.89
p-value	0.3674	

Table 7.8: $H2B$: TR analysis.

Redesign task outcome in WA scenarios is slightly lower than the perceived quality of the Process Redesign outcome in WA scenarios. This difference between the actual and the perceived quality can again be due to the initial *cognitive burden* caused by the introduction of the dependence and rationale annotations in BPMN process models. Yet, the difference is not statistically significant, thus preventing us to reject the null hypothesis $H1C_0$, as well as to state that the perceived quality of the Process Redesign outcome by leveraging dependence and rationale annotations is different from the perceived quality of the Process Redesign outcome without leveraging dependence annotations.

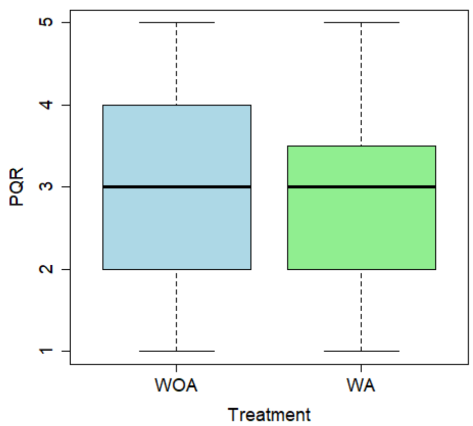


Figure 7.14: $H2C$: PQR boxplots.

	WOA	WA
mean	3.09	2.77
median	3	3
standard deviation	1.1	1.14
p-value	0.1668	

Table 7.9: $H2C$: PQR analysis.

The cognitive burden seems to have a role also in the subject perception of the required effort.

Indeed, the effort perceived by subjects for carrying on the Process Redesign task is slightly higher for the WA scenario than for the WOA setting, as shown in Figure 7.15 and Table 7.10. The result, however, is not statistically significant. Therefore we cannot reject $H2D_0$ and we cannot assess that the perceived effort for the redesign task without and with dependence and rationale annotations are different.

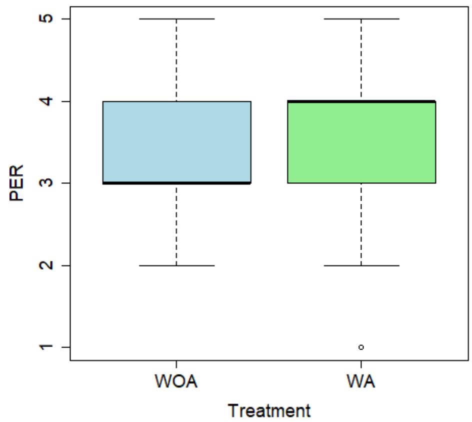


Figure 7.15: $H2D$: PER boxplots.

	WOA	WA
mean	3.22	3.54
median	3	4
standard deviation	0.79	0.9
p-value	0.092	

Table 7.10: $H2D$: PER analysis.

Summing up, although the subjects seem to have a different perception, the support of the dependence and rationale annotations in process models improves the quality of the output of the Process Redesign task - mainly because of a reduction of dependence violations and errors - without increasing the time required to accomplish the task (**RQ2**).

7.3.2.2 Co-factor analysis

Together with the main factors we also investigated the impact of possible cofactors on the obtained results. In detail, we investigated the following cofactors:

- the laboratory session in which the task has been performed (S1 or S2);
- the process model that has been used as object (IP or OF);
- the declared experience of the subjects in designing models and in designing and redesigning business process models, as well as the declared knowledge of the subjects in the Business Process Management field and of the BPMN language, collected in the pre-questionnaire;
- the declared clarity of dependence and rationale annotations, collected in the pre-questionnaire;

- the declared clarity of the process descriptions and clarity of the task descriptions, collected in the post-questionnaire.

The statistical analysis carried out reveals that in most of the cases the cofactors do not have any impact on the dependent variables. For instance, neither the laboratory session, nor on the objective quality and the required time of the redesign model (QC and QR respectively). In contrast, the models seem to have an impact on the perceived effort of both the comprehension (p-value = 0.02) and the redesign task (p-value = 0.008), as well as on the perceived quality of the redesign task (p-value = 0.019). By looking at the data, it comes out that the perceived effort required for both the Process Comprehension and Process Redesign tasks on the *Order Fulfillment* model is lower than the perceived effort required by the same tasks on the *Intake Process* model. Similarly, the perceived quality of the Process Redesign outcome is higher for the *Order Fulfillment* model than for the *Intake Process* one. The laboratory session in which the task has been carried out seems also to have an impact on the perceived effort (p-value = 0.013) and the perceived quality (p-value = 0.016) of the comprehension task. The perceived effort is lower and the perceived task outcome quality is higher when the Process Comprehension task is carried out in the second laboratory session, which is not very surprising. On the contrary, the laboratory session does not make any impact on the perceived quality and effort of theProcess Redesign task.

Concerning students' expertise and clarity of object and treatment descriptions, Table 7.11 summarises, for each of the factors, the mean, median and standard deviation of the declared expertise/knowledge and perceived clarity on a 5-point Likert scale (where 1 indicates a low expertise/knowledge and a low clarity, while 5 indicates a high expertise/knowledge and clarity). Overall, subjects have a medium or good expertise in the design area and good knowledge of the Business Process Management and BPMN field, while they have a low experience in process model redesign. Moreover, dependence and rationale annotations were overall clear to all of them, as the descriptions of the process models and of the two tasks. However, while all of them seem to have the same level of confidence on dependence and rationale annotations, the perception on the clarity of process model descriptions and tasks was less homogeneous.

By inspecting potential co-factor reported in Table 7.11, we find that only the business process model design expertise has an impact on the perceived effort (p-value = 0.039) and on the perceived quality of the redesign task (p-value = 0.047). While this expertise of the subjects seem to have a positive correlation with the perceived required effort, it also seems to have a negative correlation with the perceived quality of the redesign task: subjects with higher experience have, on the one hand, perception of lower required effort, but, on the other hand, are less satisfied on the quality of the redesigned models. Finally, we found that the perceived clarity of the dependence annotations has an impact on the quality of the outcome of the redesign task (p-value = 0.021): when the dependence annotations are perceived as clearer, the quality of the redesign task outcome is also higher.

Factor	mean	median	standard deviation
Experience in designing	2.87	3	0.81
Knowledge in the Business Process Management field	3.55	4	0.68
Knowledge of BPMN	2.79	3	0.66
Experience in business process design	2.82	3	0.86
Experience in business process redesign	2.47	2	0.79
Clarity of dependence annotations	4.1	4	0.6
Clarity of rationale annotations	3.81	4	0.51
Clarity of process model descriptions	3.75	4	0.99
Clarity of Process Comprehension task	3.92	4	1
Clarity of Process Redesign task	3.77	4	1

Table 7.11: Descriptive statistics of subjects' expertise and clarity of object and treatment descriptions.

7.3.3 Enriching models with dependence and rationale annotations

Besides evaluating the benefits that leveraging dependence and rationale process annotations can bring to modellers and analysts, we also investigated the effort required for annotating business process models. To this aim, we asked the same subjects who carried out the Process Comprehension and Process Redesign task, to perform also a Process Annotation task. Specifically, the subjects were provided with a business process model and its description, and were asked to enrich the model with dependences and rationale annotations.

Figure 7.16 reports the Process Annotation task model - the *Loan Application* process model - which describes the procedure carried out by a bank when receiving a loan application request, and is inspired by the process model described in [DRMR13]. The loan application process starts when a loan application is received from an applicant. According to the internal regulation of the bank, a loan application is assessed as eligible if it passes two checks: (i) the applicant's loan risk assessment, and (ii) the appraisal of the property for which the loan has been asked. The risk assessment requires, by law, a credit history check on the applicant. Once both the loan risk assessment and the property appraisal have been performed, the applicant's eligibility can hence be assessed. If the applicant is not eligible, the application is rejected, otherwise an acceptance pack (including a repayment schedule) is prepared and sent to the customer. The customer needs to agree upon the repayment schedule by sending the signed documents back to the loan provider. According to the procedure the latter has to then verify the repayment agreement: if the applicant disagreed with the repayment schedule, the loan provider cancels the application; if the applicant agreed, the loan provider approves the application. In both cases, according to the law, the loan provider has to then notify the applicant of the application status.

Before asking the subjects to perform the experiment, the Process Annotation task was performed independently by two of the researchers carrying on this research and the results discussed with a

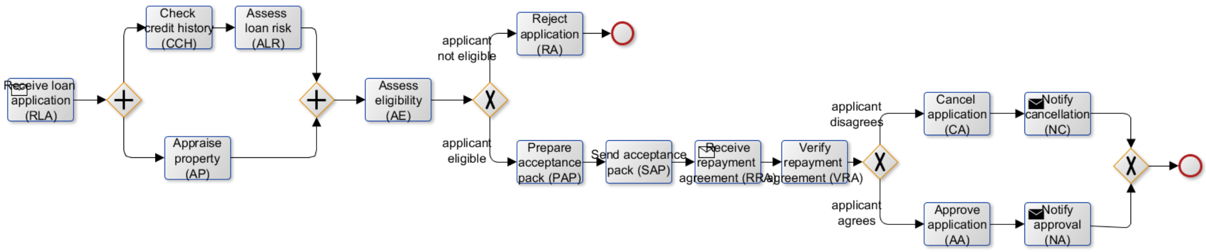


Figure 7.16: *Loan Application* for the Process Annotation task.

third one, with the aim of identifying a gold standard set of dependence and rationale annotations for this process model. The final gold standard set contains 20 activity pair dependences - and corresponding rationales. We used the gold standard set in order to quantitatively evaluate dependences and rationales identified by subjects. Specifically, we computed:

- the number of correct dependence/rationale annotations (C_d/C_r);
- the number of incorrect dependence/rationale annotations (I_d/I_r);
- the number of missing (w.r.t. the gold standard set) dependence/rationale annotations (M_d/M_r).

We used this information also to compute an accuracy measure of the annotation activity carried out for dependences and rationales. By considering the number of correct dependence/rationale annotations as *true positive*, the number of incorrect dependence/rationale annotations as *false positive* and the number of missing dependence/rationale annotations as *false negative*, we were able to compute *precision* ($prec_d/prec_r$), *recall* (rec_d/rec_r) and *F-measure* (fm_d/fm_r) metrics for the annotation task carried out by each subject.

Moreover, we also asked subjects (i) to mark the start and end time, so as to be able to compute the time required for performing the Process Annotation task (T); and (ii) to fill a post-questionnaire (see Appendix F), in order to collect their perception about the effort and time required for annotating process models with dependences (PE_d and PT_d) and rationales (PE_r and PT_r), respectively, as well as the overall satisfaction (S) with the Process Annotation task. Most of the post-questionnaire questions were 5-point Likert scale (from 1 to 5 where 1 is very low and 5 is very high) closed questions. The post-questionnaire, however, also included few open questions collecting subjects' suggestions on possible further types of activity dependences and rationales. Table 7.12 summarises, for each objective (obj) and subjective (subj) variable related to the Process Annotation task, its range/unit of measure and its description.

Figure 7.17 reports a plot related to the distribution of correct, incorrect and missing dependence and rationale annotations. The plot shows that while the number of correct and incorrect dependence and rationale annotations is commonly in the range of $2-6$ annotations, many of the

Analysis Type	Variable	Range/Unit of measure	Description
obj	C_d	int	Number of correct dependence annotations
	C_r	int	Number of correct rationale annotations
	I_d	int	Number of incorrect dependence annotations
	I_r	int	Number of incorrect rationale annotations
	M_d	int	Number of missing dependence annotations
	M_r	int	Number of missing rationale annotations
	$prec_d$	[0,1]	Precision related to dependence annotations
	$prec_r$	[0,1]	Precision related to rationale annotations
	rec_d	[0,1]	Recall related to dependence annotations
	rec_r	[0,1]	Recall related to rationale annotations
	fm_d	[0,1]	F-measure related to dependence annotations
	fm_r	[0,1]	F-measure related to rationale annotations
	T	minutes	Time required for the Process Annotation task
subj	PE_d	[0,5]	Perceived effort for dependence annotations
	PE_r	[0,5]	Perceived effort for rationale annotations
	PT_d	[0,5]	Perceived time required for dependence annotations
	PT_r	[0,5]	Perceived time required for rationale annotations
	S	[0,5]	Perceived satisfaction with the Process Annotation task

Table 7.12: Variables related to the Process Annotation task.

dependence and rationale annotations in the predefined gold standard - usually a number from 14 to 18 annotations - are missing. Moreover, by looking at the plot, we can also notice that while there is no difference between dependences and rationales in the distribution of correct and missing annotations, the number of incorrect dependences is overall higher than the number of incorrect rationales. This suggests that overall identifying the correct type of dependence is more tricky than identifying the correct rationale.

Similar observations can be done by looking at the corresponding plot in Figure 7.18, reporting the values of precision, recall and F-measure related to the dependence and rationale annotations. Overall, while precision is reasonably high, with an average around 0.5, recall and F-Measure are not very high due to the high number of missing annotations. Moreover, due to the difference between dependences and rationales in the number of incorrect annotations, precision for rationale annotations is overall higher than for dependence annotations, while recall and F-measure are quite close.

Figure 7.19 depicts the distribution of the time required to complete the Process Annotation task, by showing that most of the subjects spent less than 15 minutes to complete the task, with an average of around 13 minutes.

Finally, moving to the subjective analysis, Figure 7.20 shows the distribution of the answers on a 5-point Likert scale (from 1 to 5 where 1 is very low and 5 is very high) given by the subjects on the perceived effort and time required for annotating a process model with dependences and rationales, as well as the overall subject satisfaction. The plot shows that, on average, subjects

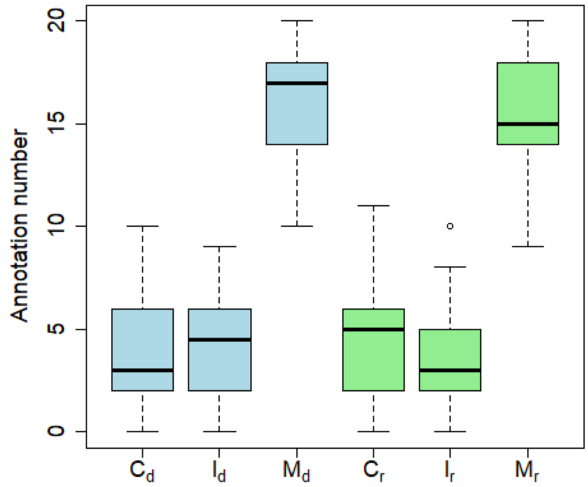


Figure 7.17: Correct, incorrect and missing dependence and rationale annotations

perceived that a medium effort and time are required for carrying out the task. It also reveals that, while the perception about the required time is almost similar for dependence and rationale annotations, subjects perceive that enriching process models with dependences requires less effort than enriching it with rationale annotations. Also the overall satisfaction level is on average on a medium level.

7.4 Discussion

From the analysis carried out in Section 7.3.2 we found out that dependence and rationale annotations support analysts and modellers in business process comprehension and redesign. Indeed, while the actual quality of the outcome of the Process Comprehension and the Process Redesign tasks carried out with models enriched with dependence and rationale annotations is higher than the outcome quality of the same tasks performed with models without annotations (with a medium and small size, respectively), the time required for the Process Redesign task with annotations is not (statistically significantly) higher than the time required without annotations.

Contrarily to the objective results on the effectiveness of dependence and rationale annotations for Process Comprehension and Process Redesign tasks, the involved subjects perceived as overall equal or lower the quality of the outcome of the tasks. This could be related to the higher expectations that the modellers have towards their comprehension of the models and towards the redesigned models. Indeed, this can be due to the fact that the annotations make the modellers

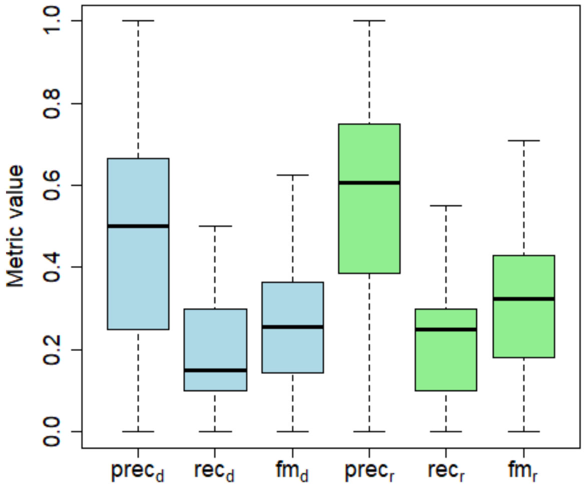


Figure 7.18: Precision, recall and F-measure related to dependence and rationale annotations in the Process Annotation task.

aware of the process model criticalities. Moreover, as mentioned in Section 7.3.2, another reason behind this situation could be related to the cognitive burden introduced with the dependence and rationale annotations. Indeed, although the subjects were trained on the usage of the dependence and rationale annotations and declared that the annotations were clear to them, the amount of new information was possibly enough to overload their working memory. Similarly, the cognitive burden could have impacted also their effort perception: they perceived a slightly lower effort in carrying out the redesign task without dependence and rationale annotations than with annotations. Nevertheless, the qualitative answers (to the open questions) about the encountered difficulties provided by the subjects in the post-questionnaires reveal that most of them found annotations very useful for deciding how to correctly redesign the model, and the task performed with annotations easier than the same task performed without annotations. Only few subjects claimed that the notation chosen for representing occurrence dependences and rationales is overly complex with respect to the advantages of the annotations.

The subjects were also overall satisfied with the typologies of dependence and rationale annotations, although some of them suggested to reduce the different dependence typologies to lower down the complexity of the annotated models. In particular, many of them suggested to merge the historical and causal dependences and some of them to keep only the causal dependence. This is possibly due to the focus of the subjects on the specific redesign task being carried out. In the redesign task, indeed, they only had to avoid violating activity dependences. For this purpose the difference between historical and causal dependences is not relevant. Finally, the subjects

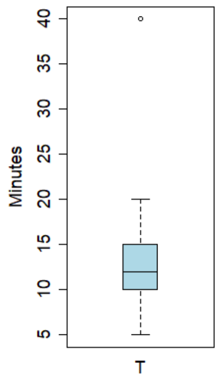


Figure 7.19: Annotation time.

provided few suggestions for improving the notation conveying the dependence and rationale information (e.g., trying to make the label of the annotation closer to the arrow), which will be taken into account for future works.

Together with the effectiveness of dependence and rationale annotations in business process modelling and analysis tasks, the analysis carried out in Section 7.3.3 shows that the effort - in terms of amount of time - required to modellers for enriching business process models with some of the dependence and rationale annotations (overall the subjects added to the model only a subset of the dependences identified by the experts in the gold standard) is reasonable (around 10 - 15 minutes). The reason behind the inability of subjects to identify all the existing dependences could be mainly related to their lack of experience in this type of task or to the amount of time they had. Indeed, although the subjects were trained on the usage of the dependence and rationale annotations, they actually never tried to discover these dependences by themselves.

As for the annotation effectiveness, also in this case, the objective results are not completely confirmed by the subjective ones. Indeed, apart from few exceptions, the difficulty and the time required for the model enrichment with dependence and rationale annotations was judged between medium and high by the subjects. Similarly, the perceived quality of the outcome of the annotation task was mainly between below average and on average. Also in this case the reason can be due to the cognitive burden that the introduction of the new notation could have caused in the subjects, as well as to the lack of experience. This is also confirmed by the qualitative results. Indeed, most of the subjects stated that the proposed types of dependences and rationales are enough; some of them event stated that the proposed types of dependences and rationales are too many; many of them pointed out the lack of experience as the main difficulty encountered in carrying out the task; some of them stated that they were confused in the selection of the correct dependence annotation - some of the answers mentioned the difficulty to identify the difference between the historical and causal dependence.

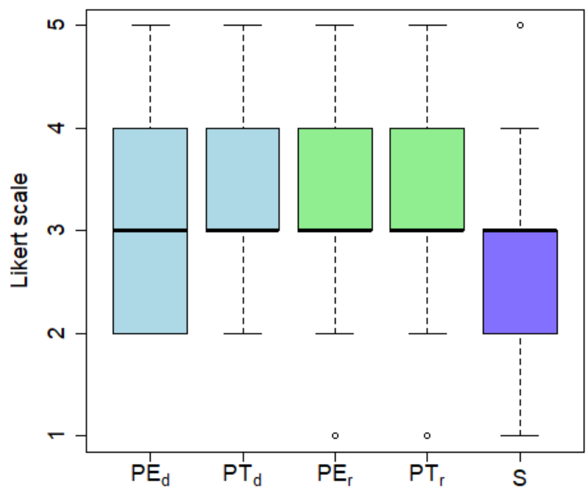


Figure 7.20: Process Annotation difficulty and time perception.

Summing up, the cognitive burden due to the introduction of dependence and rationale annotations in business process models does not heavily affect the analysis and redesign tasks, where analysts and modellers only need to read and use annotations. However, when modellers need to enrich models with annotations, the cognitive burden and the lack of experience could have a strong impact, due to the difficulty of modellers to exhaustively identify dependences and rationales in business process models.

7.5 Contributions and threats to validity (a.k.a. limitations) of the study

The main contributions of this Chapter are: (i) the proposal of a new notation that enriches BPMN process models with occurrence dependences and rationales and (ii) the empirical evaluation of the proposed notation.

The limitations of the work described in this Chapter are mainly related to the *threats* affecting the validity of the study. These are grouped according to the categories defined in [WRH+12].

Conclusion validity concerns the relation between the treatment and the outcome. In order to ensure such a validity, since not all the preconditions required by parametric statistical tests held in our study, we used non parametric tests - the Wilcoxon and the Kruskall Wallis tests - for the analysis of the main factor and of the cofactors, respectively.

Internal validity threats deal with external factors that could affect the dependent variables. In order to ensure such a validity, we measured the impact of possible cofactors on the dependent variables (Section 7.3.2.2). We found that: (i) the objects impacted on the perceived effort of both the Process Comprehension and the Process Redesign tasks, as well as the perceived quality of the Process Redesign task; (ii) the laboratory sessions had an impact on the perceived effort and the perceived quality of the comprehension task. We tried to mitigate these threats by using two different objects and adopting a balanced design that allowed us to limit biases.

Construct validity is related to the relationship between theory and observation. In order to limit the construct validity threats, we conducted a controlled experiment (i.e., laboratory sessions were performed under our supervision) and we carefully measured the analysed data. The outcomes of the Process Comprehension and the Process Redesign tasks were qualitatively and quantitatively evaluated: the provided feedback was used by students as a preparation for the final exam. Time was measured by asking subjects to report start and end task time and subjective judgements were measured by means of standard scales.

External validity concerns the generalization of the findings. The subjects involved in the evaluation were students belonging to the same class rather than real business process modellers or analysts. However, the number of involved subjects was relatively high and they all had experience in Business process modelling and analysis. Moreover, they had competencies not homogeneously distributed, thus providing a good sample of the population. Finally the choice of the specific representation of activity dependences and their rationales also limits the generalisability of the results. However, we needed a way to convey the dependence representation.

Chapter 8

Related work

In this PhD thesis we grouped the relevant related works in three classes: (i) *business process modelling and languages*, described in Section 8.1, (ii) *ontological analysis in business process modelling*, described in Section 8.2, and (iii) *empirical evaluation in business process modelling* described in Section 8.3. In this Chapter we summarise each related work belonging to the above classes and we commented the works belonging to each group on the basis of the research proposed in this PhD thesis.

8.1 Business process modelling and languages

In this Section we describe the related works dealing with business processes and business process modelling (see Section 8.1.1), including papers focused on specific modelling languages (see Section 8.1.2).

8.1.1 Business processes modelling

Some research in the literature focuses on the analysis and comparison of the approaches and techniques proposed in business process modelling. Aguilar-Saven and Ruth Sara in [As04] provide a general review and a classification of the main business process modelling techniques. First, the paper provides a review of several business process modelling techniques and tools (e.g. flow chart techniques, workflow techniques, and so forth). Second, they propose a framework in which the presented techniques are classified in order to guide practitioners and academics to choose the most suitable technique among the ones analysed. The framework includes the descriptions of the techniques, together with their attributes and characteristics. Finally, a discussion on strengths and weaknesses of each technique from the point of view of users and modellers is provided.

In [MP00], Melão and Pidd present a conceptual analysis that clarifies the nature of business processes and their models discussing the different approaches in business process modelling. The paper starts with a discussion about business process re-engineering (BPR) focusing on its paradoxes and evolution towards the process management. The work proceeds by analysing the facets of business process modelling that emerged from BPR (e.g., feedbacks from practitioners as well as theoretical advances in the field). The core of the paper is centred on the conceptual framework that aims at defining business processes according to different perspectives. For instance, business processes are seen as deterministic machines, as complex dynamic systems, as social constructs.

Giaglis in [Gia01] also provides a description of business process modelling techniques (and also Information Systems Modelling techniques) together with a taxonomy and an evaluation framework. The techniques taken in consideration range from flowcharting to Role Activity Diagrams.

The work of Becker et al. [BRvU00] introduces the *Guidelines of Modeling* (GoM) framework. The framework aims at increasing and improving the *quality* of the models and of the modelling activity. The GoM framework consists of six quality aspects: correctness, relevance, economic efficiency, clarity, comparability, and systematic design. In the paper several aspects related to the business process modelling, such as the workflow management, the activity view (functional), the data and organisational views, control, and simulation are considered and analysed.

8.1.2 Business processes modelling languages

Some of the papers in the literature have as focal point the comparison of business process modelling languages and their components[1].

The work of List and Korherr in [LK06] proposes a conceptual framework aiming at evaluating several notations. To fulfill this purpose a general meta-model to evaluate the business process modelling languages is developed. The meta-model is composed of four important aspects that pertain to business processes: functional, organisational, behavioural, and informational. After the illustration of the meta-model, the authors describe several business process modelling languages (e.g., UML-AD 2.0, BPMN, IDEF3) to finally evaluate those languages according to the expressivity of the general meta-model.

In Söderström et al. (see [SAJ+02]) a framework to translate business process models from a process modelling language into another (and compare business process modelling languages) is presented. Also in this case the authors developed a general meta-model and compare three

[1]Some of these works are also included in the primary studies selected for the Systematic Literature Review (see Chapter 4).

modelling languages using it. In the work of Heidari et al. [HLBB13], a general meta-model is proposed starting from the elements of seven business process modelling languages. The language independent meta-model is finally compared and analysed with an ontology.

In the work of Lin et al. [LYP02] generic and common elements of business processes are extracted considering the main constructs involved in process models. First the authors propose a review of the literature on business process modelling languages focusing on their components, representations, features, and procedures. The elements and concepts of the modelling strategies are then extracted and placed into some sub-classes (i.e., functional, behavioural, informational, and organisational perspectives) to compare the modelling strategies also considering the verification\validation and the modelling procedures.

The paper proposed by Mili et al. [MTJ+10b] includes in the analysis a comprehensive investigation of many business process modelling languages, such as the IDEF family, Petri-net, EPC, UML, BPEL, BPMN and many others. In addition, the authors compared the languages on the basis of four views: informational, functional, dynamic, and organizational.

Considering specific notations, Dijkman, Dumas, and Ouyang in [DDO08] enriched the semantics of the BPMN 2.0 language by mapping its constructs with the formal semantics of Petri-nets. Then, the authors proposed a tool that transforms the BPMN 2.0 models into Petri-nets. Another mapping is the one provided by Báo [Bao10], in which elements of BPMN are translated into UML-AD elements.

Positioning the PhD thesis. These works aim either at: (i) providing a classification of business process modelling techniques and quality guidelines (the works in Section 8.1.1); or (ii) comparing and clarifying the business process notations' components and sometimes proposing conceptual frameworks for business processes (the papers illustrated in Section 8.1.2).

Despite these works share with this thesis the focus on the analysis of business process modelling and notations, none of them provides a systematic and well-founded analysis of business process elements.

8.2 Ontological analysis in business process modelling

This Section provides a description of the main works in the research field of ontological analysis in business process modelling and closely related fields. The first group of related works (see Section 8.2.1) includes the research focused on the Bunge Wand and Weber ontology and its application in business process modelling and conceptual modelling. The second group (see Section 8.2.2) is composed of papers that performed an ontological analysis in the same two fields while using other kinds of ontologies. In the third group we include further research in ontological analysis (see Section 8.2.3). Finally, we discuss these related works on the basis of this thesis.

8.2.1 The impact of Bunge Wand and Weber ontology

Many works at the intersection between the two fields of ontologies and business process modelling rely on the *Bunge Wand and Weber* ontology (BWW)[2] [WW90b] for analysing business process models and notations. This ontology is developed from the thesis of the "Representation Theory" proposed by Wand and Weber and inspired by the colossal work of Mario Bunge (see for instance [Bun77a, Bun77b, Bun12]) concerning an ontological treatise. From the beginning, the BWW was used to evaluate and compare notations and components belonging to the cognate field of business process modelling, that is conceptual modelling.

For instance in the work of Wand, Storey, and Weber [WSW99] an investigation of the relationships used in conceptual modelling leveraging the ontological guidelines of the BWW is reported. In 2002 Opdahl and Henderson-Sellers evaluated one of the most popular languages used in conceptual modelling, UML, with the BWW ontology [OHS02]. The authors also considered the four *ontological discrepancies*[3] underlined by Wand and Weber [WR08]: construct overload, construct redundancy, construct excess, and finally construct deficit. Later in a work proposed by Evermann [Eve08] a UML and OWL representation of the ontology of Bunge are presented. The author translates the Bunge's ontology into the UML language and aftewards the UML version of the Bunge ontology is translated into OWL (e.g., class-class, multeplicity-cardinality).

In the work of Green and Rosemann [GR00], the BWW ontology is adopted to evaluate the grammar of the ARIS framework [Sch02b]. The authors decided to analyse ARIS as an integrating approach for business processes (see Section 2.1.2). As a result of the analysis ARIS seems to have some ontological lacks. According to the author, this could be due to an "over-engineered" ([GR00] pg. 82) of the BWW ontology that lacks aspects specific for process modelling.

More recently, Recker et al. [RRIG09] compared 12 business process modelling techniques and languages using the Bunge Wand and Weber ontology as a reference framework. In this work construct lack, redundancy, excess, and overload are identified by mapping the business process modelling languages elements with the BWW ontology.

Other similar works evaluate particular languages using the BWW ontology. For instance in [RRK07] the BPMN language is evaluated in light of: the BWW representation capability and the workflow patterns [RvdAtHE05][4]. Another study [RI07] proposed by Recker and Indulska

[2]For a general overview and critiques see also: http://users.tpg.com.au/suetagg/roger/RelatedEssays/OntologyBungeWandWeber.htm.

[3]The ontological discrepancies are parameters to evaluate the clarity of the UML notation. One example is to determine when a language construct has too many ontological meanings.

[4]Workflow patterns website: http://www.workflowpatterns.com/.

focuses on the evaluation of Petri-nets through the BWW ontology. Also in this case the authors mapped the entities of the BWW with the components of the Petri-nets and in the final discussion some considerations are summarised. For instance, the Petri-nets are not able to capture many aspects of the *real-world*. Also in [zMIK07] the authors proposed an evaluation of some Business Rules Modelling Languages (e.g., SRML and SBVR) by comparing the language elements with the BWW ontology.

In a more general setting Davies et al. [DGMR03] use meta-models to compare ontologies. In this work the authors extract the meta-models of the BWW ontology and the Chisholm's ontology [Chi96] to finally compare them. Although this work is not strictly situated in the BPM field, it constitutes a general and alternative approach to use ontologies and meta-models.

8.2.2 Ontologies and ontological analysis

Besides the works relying on the BWW, other works in the literature propose an ontology-based analysis of business process models and related fields. For instance Cherfi et al. in [CAC13] deal with the quality aspects of business processes using ontologies to exploit business process domain knowledge. After identifying the business process meta-model, the authors create an ontology meta-model to semantically map and improve the semantics of business process models.

Considering specific modelling languages, in [SAG10] Santos Jr. et al. presented an ontological analysis of ARIS EPCs using the UFO ontology for the semantic interpretation of the elements. In particular the authors focus on the analysis of *function*, *event*, and *rule*. Two extended versions of this work are proposed in [JAG10, JAG13], in which the focus on the organisational aspects of ARIS is emphasised. Instead, Cardoso et al. [CSJA+10] aim at integrating the ARIS framework with the TROPOS goal modelling [BPG+04] and at suggesting an ontological interpretation for both approaches using the UFO ontology [GW10b]. In the context of an enterprise, an ontological approach of goals and other related elements is provided in Cardoso et al. [CAG12].

In another work [GW11a] Guizzardi and Wagner centred their research on BPMN simulation modelling dealing with its “real-world semantics". They analyse BPMN in light of several ontologies, such as Agent-Based Discrete Event Simulation Ontology (ABDESO) [GW11b], the Discrete Event Simulation Ontology (DESO) [GW10a], and the Unified Foundational Ontology (UFO) [GW10b]. On the other hand, in the work of Sanfilippo, Borgo, and Masolo [SBM14] an ontological analysis of *event* and *activity* in BPMN, relying on the DOLCE ontology [MBG+03] is proposed.

In [NLM07] De Nicola, Lezoche, and Missikoff propose a new language, the *Business Process Abstract Language* (BPAL), which includes some ontological notions of business processes. After an analysis of the literature on approaches and modelling languages, the paper describes the BPMN constructs from which the main modelling constructs of BPAL are derived. Finally, the authors compare BPAL with BPMN and PSL, which is a formal language for representing processes [BG05].

In [GGA16], instead, the dichotomy between object-based and event-based approaches in conceptual modelling and business process modelling is investigated. Specifically, the authors provide a rich analysis of endurants and perdurants in conceptual modelling and business process modelling touching some important challenges, such as the identity of the objects over time and the change of the events. Also in [GWdAF+13], a general ontological analysis of the events is provided. The analysis is performed considering the UFO ontology and, although the paper is not committed to the specific representation of events in business process modelling, it mentions that this research is a building block for building a reference framework also in business process modelling.

Focusing on the ontologies as artefacts, in [DSSK07] the Business Process Modelling Ontology (BPMO) is introduced. The ontology is meant to be general and comprehensive including the most used techniques, e.g., considering both block-oriented and graph-oriented approaches. Focussing on specific languages, instead, Rospocher, Ghidini, and Serafini in [RGS14] propose a BPMN 1.0 ontology that specifies elements, attributes, and properties in OWL-DL (the Description Logics fragment of OWL). With the new version of BPMN, another ontology is proposed in [Nat11]. In [GD06] a Petri-net ontology is discussed. It is developed starting from its meta-model and is expressed using RDFS and RDF. As the authors outlined, the ontology captures only Time Petri Nets and is not automatically translatable into other popular ontology languages, such as OWL.

8.2.3 Further related research in ontological analysis

Besides the work focussing on the application of ontology-based approaches to business process models and related fields, other works provide ontological analysis of organisational aspects that can be related to business processes.

An interesting contribution is the one provided by Bottazzi and Ferrario in [BF09] where the DOLCE ontology is adopted to perform an ontological analysis of organisational aspects. The paper provides formal and informal definitions of many relevant entities included in the organisation, such as roles, agents, and norms. A comprehensive work on *collectives* (also in organisational terms) from an ontological perspective can be found in [BCGL06].

Yet considering the human-aspects, [MVB+04] includes an ontological analysis of social *roles* from many points of views, for instance as properties\anti-rigid properties and dynamic aspects. After the first understanding of roles, the authors propose a formal characterisation of social roles integrating the axioms into the DOLCE ontology. Another work on roles is provided in [MGKK15] by Mizoguchi et al., in which an occurrent-dependent view of roles is proposed. This work is not specifically targeted on business process modelling, however many organisational and process aspects are considered.

Positioning the PhD thesis. The works described in the previous Sections are mostly focused either on ontological analysis of specific elements, or on the development of ontologies as artefacts. Differently from most of the works described in the previous Sections, the ontological analysis performed in this thesis does not commit to any specific reference ontology. Moreover, the majority of the business process modelling elements that we analysed were never investigated from the ontological point of view. Finally, we decided not to develop an ontology on the basis of our ontological analysis. This decision was driven by the fact that there are already several ontologies in literature and then we chose to provide a solid foundation for business process modelling elements which was missing.

8.3 Empirical evaluation in business process modelling

This Section includes the related works concerning evaluations and empirical analysis in the business process modelling field. We grouped the related works on empirical studies in the field of business process modelling in two clusters: the first one is related to the business process model redesign, and the second one is related to the business process model understandability. These works are described in Section 8.3.1 and Section 8.3.2. In the final paragraph we provide few comments that compare these works with the one carried out in this thesis.

8.3.1 Empirical evaluations in business process redesign

In the work of Mansar et Reijers [MR05] a framework for business process redesign is identified in order to describe its best practices and guide the methodological principles of redesign. In the paper this framework has been validated by providing a survey to practitioners to evaluate the impact and usage of each best practice. In the study of Goksoy et al. [GOV12], a wide study of business process reengineering and organisational changes within the Simens company, has been reported. In detail, the employees' ideas on business process reengineering are collected through questions and analysed.

Kock et al. [KVDD09] conduct an empirical study on the relationships between business process modelling decisions and business process redesign. These relationships involve: the communication flow orientation of business process models, the quality of business process models, and the process redesign success. For the authors the explicit communication flow of the model is related with the quality model (e.g., ease of generation, ease of understanding, completeness, and accuracy) and this one is related with the success of the redesign. For instance, easier and clearer models facilitate the redesign. However, from the study emerged that the completeness of the model does not impact positively on the redesign.

8.3.2 Empirical evaluations in business process understandability

Several papers propose empirical evaluations of business process understandability. Houy et al. in [HFL14] provide an extensive analysis of the literature of the theories that ground business process understandability. Also in the work of Dikici et al. [DTD18] a systematic analysis of the literature is performed. In this case the authors focus on the indicator factors that impact the process understandability[5].

The paper by Mendling et al. [MRC07] explores the process understandability as a quality factor. In the paper six factors that could impact the understandability are identified. These factors are: *personal factors*, *model characteristics*, *modelling purpose*, *knowledge of the domain*, *use of several languages for the same model*, and *visual and graphical characteristics*. From the research emerged that the personal factors (especially the theoretical knowledge) influence the understandability. The second important finding regards the model characteristics; indeed, the size of the model influences the process of understandability. The authors validated the study by conducting interviews with process modellers.

In the work of Reijer and Mendling [RM11] the personal factors and the model characteristics influencing the understandability are investigated with the support of questionnaires. Focusing on the personal factors, theoretical knowledge, practical experience, and educational background are the variables considered. Concerning the models characteristics, there are many: the number of elements (in particular *arcs*, *tasks*, *connectors*, and *gateways*), the size of the model, the number of splits, the complexity of the control flow, the density of the connections, the connectors heterogeneity.

In Soffer et al. [SKW11] the authors focused on the *Process of Process Modeling*, with an emphasis on the quality of the models (see [BRvU00]). The Process of Process Modeling regards the cognitive process(es) of the model development. This theory is hence devoted to explain the "problem solving" in shaping and creating models which includes two steps: *comprehension*, and *modelling*[6].

In the work of Di Francescomarino et al. [DFRGV14], a user study to evaluate the impact of semantic annotations in (collaborative) business process modelling is proposed. Here, the authors prove that the semantic annotations improve the design and revision of the model, as well as the quality of the model itself.

Considering specific languages, in [RD07] the authors study the activity of teaching and learning business process modelling languages. The aim of the study is to examine whether there are differences in the process of understanding of two popular languages, BPMN and EPC. As result

[5]Some of the papers describe in this Section were found in the mentioned SLR [HFL14, DTD18], while other papers were found in our study and knowledge of the literature.

[6]In another development of the Process of Process Modeling (see [PZW+11]) the phases of building a process are three: *comprehension*, *modelling*, and finally *reconciliation*.

it emerged for instance that there is no much difference in the understandability assumption underlying BPMN and EPC.

Positioning the PhD thesis. All these papers focus on the evaluation of different aspects of business process model design, redesign, and comprehension. Indeed, some of these works analyse the impact of the redesign and the factors that influence it, while others study the factors that influence the model comprehension\understandability and quality, such as certain models' characteristics (e.g., the control flow). Differently from these works, in this thesis we provide an empirical analysis that aims at evaluating the effectiveness of the support provided by dependence and rationale annotations to business process modellers and analysts in comprehension and redesign activities.

Chapter 9

Conclusions and future works

In this Chapter I summarise the achievements of this PhD thesis and the future works I would like to address. I also make an attempt to describe them as my journey during these three years. Therefore I will use a more personal style and the “I” pronoun.

My journey started by realising that the literature is one of the biggest source of knowledge for research: it reports experiences and reflections, and it also reveals what is missing. Starting from that observation, I initiated an inquiry into the state of the art of business process meta-models: I provided an overview of the elements in the world of business process entities by merging the available meta-models from the literature and creating the first contribution of this thesis, which is the *literature-based meta-model* (*LB meta-model*). This study enables to understand how business processes are conceived in the BPM community and, at the same time, it makes evident the meta-models' potentialities and criticalities. The *LB meta-model* can be seen as a snapshot of the state of the art in business process meta-models and it contains most of the fundamental elements of business processes according to the literature. The comparative assessment of the *LB meta-model* with five popular business process modelling languages contributes to highlight strengths and weaknesses of the *LB meta-model*.

The main limitations of this contribution are mostly related to the literature reviews and include possible flaws in the selection of the papers, imprecisions introduced in the extraction of data from the selected works, and potential inaccuracies due to the subjectivity of the analysis carried out. However, I mitigate these threats by following the guidelines reported in [KC07, Kit04].

After the definition of the *LB meta-model*, my journey continued by investigating some of the elements of the *LB meta-model* identified as problematic or missing, from an ontological perspective. Here, I provided a clarification of four of these elements: event, participant, activities' relationship, and goal. Although I was not able to provide an ontological analysis of all the *LB meta-model* components, the reported analysis represents a first step towards a better understanding of what characterises a business process.

Aiming at not only focussing on theoretical investigations based on ontological analysis but also at applying the results of the ontological analysis back to the practice and to the BPM community, I revised the *LB meta-model* with the results of ontological analysis. I believe that this revision and enrichment can contribute to (i) clarify the meaning of some problematic elements of business processes, and (ii) demonstrate an important application of ontological analysis in the field of BPM.

Although the ontological analysis presented in Section 5 is quite detailed, I was not able to investigate all the *LB meta-model*'s elements. Therefore, the revision of the *LB meta-model* is not yet complete, however I plan to analyse and revise further *LB meta-model* elements that remained outside of this work.

As a further application of the ontological analysis to the BPM field I worked for (i) the development of a new ontologically grounded notation to express ontological constraints between business process activities going beyond the temporal flow, and (ii) its evaluation. This work has been proposed in order to show the value of ontological analysis results for business process modellers and analysts. I evaluated the impact of the new notation in the tasks of business process model redesign and comprehension, and I further explored the drawbacks of this notation for the modelling activity. These results demonstrate a possible way to apply ontological analysis outcomes to "real world" applications.

The limitations of this part of the thesis are related to the *threats* affecting its validity. One of the main threats concerns the generalization of the findings. Indeed the subjects involved in the evaluation were students belonging to the same class rather than real business process modellers or analysts. However, the number of subjects involved was relatively high and they all had experience in business process modelling and analysis. Moreover, they had not homogeneously distributed competencies, thus providing a good sample of the population of modellers and analysts.

Concerning the future works, I believe that the *LB meta-model* provides a clear picture of the state of the art of business process meta-models. Nevertheless, integrations may be possible with other works from the literature. What I find more stimulating is to expand the second and the third contributions of the thesis by analysing from the ontological perspective other *LB meta-model* elements that remained unexplored and by integrating them in the meta-model. An example of element to investigate is `gateway`. I would also like to consider as an object of investigation those elements that are mentioned as important in the most modern business process definitions, but that are not widely considered in the notations and in the meta-models. A pertinent example is *value* and its relations with other business process elements, such as resources and goals. Focussing on the last part of the thesis, I am planning to repeat the experiment with business process modellers and analysts. Moreover, I would like to improve the notation with the suggestions received during the empirical study. I would also explore how to incorporate and evaluate further ontological constraints between activities and other elements, and to consider other redesign dimensions beyond time.

As a further, somehow related and new work, I would like to think bigger and investigate the notion of business process and its elements in terms of *sustainability* [Har03]. In particular, I would like to explore the notions of value, resource, and goal in a business process also according to environmental, social, and economical sustainability [SBK17, dPJ15, SRvB12] as a contribution to model and implement more sustainable business processes.

Appendix A

Further results from the SRL

In conducting the review to address **GOAL 1**, we went further, in particular we answered to other research questions, these are:

RQ1. What types of business process meta-models are being proposed in literature and how can we characterise and categorise them?

RQ2. What is the role of a business process meta-model?

RQ3. Are the proposed business process meta-models evaluated? How?

RQ1 focuses on the differences among BPML meta-models and aims at investigating them. It also aims at identifying which are the relevant characteristics that meta-models share or in which they differ. RQ2 is devoted to the identification and classification of the purpose for which the meta-models were introduced / used in the investigated works. Finally, RQ4 aims at investigating the way the proposed meta-models are evaluated. This question lies on two different motivations. The first, obvious one is to map how meta-models of business processes are evaluated; the second is to assess the importance provided to the evaluation of meta-models in different studies and to identify suggestions for possible evaluation methodologies. Indeed in literature there is a lack of guidelines and evaluation criteria for the development of meta-models in the area of business process models and this can hamper their perceived usefulness and (practical) adoption.

In this Appendix the answer to these RQs are summarised as follows: in Section A.0.1 a classification of the meta-models is advanced; Section A.1 is centered on the purposes why the meta-models are developed; finally in Section A.2 the evaluation of the primary studies' meta-models is presented.

A.0.1 Kinds of meta-models proposed in literature

When we started to analyse the business process meta-models literature, one of the first question that raised was specifically related to the typologies of meta-models that have been proposed. For this purpose we developed the *RQ1.1* which focuses on the differences among BPML meta-models and aims at investigating them. It also aims at identifying which are the relevant characteristics that meta-models share or in which they differ. *RQ1.1* could have several answers, depending on the perspective exploited to look at the meta-models. In this paper we answer *RQ1.1* in two different steps.

The first characterisation we did observe in looking at the papers is based on their relationship with specific modeling languages or paradigms. Indeed, by looking at the meta-models of the 36 primary studies, we can observe that they can be divided in two mutually exclusive categories: the first one, hereafter called **BPM**, contains meta-models whose primary aim is to describe business processes; the second one, called **NoBPM**, contains instead meta-models that describe business processes but whose primary aim is to describe something different from a business process (e.g., a service, an enterprise model and so on). These two categories, in turn, contain two different sub-categories: the first one, called **Ind**, which contains general meta-models of business processes that are not related to any concrete business process modelling language; the second, hereafter named **Dep**, which contains meta-models of concrete business process modelling languages. In turn, **Dep** can be divided in two (sub-)sub-categories: the first one, called **Exist**, contains meta-models of an existing well-established business process modelling language, while the second one, hereafter called **New**, contains meta-models of new modelling language proposed in the very same paper, or by the same author in closely related papers.

Category	Primary studies
BPM	
Ind	[SAJ+02, HLBB13, LK06, KYY14, HLK11, BTG16, MZ15, BG11, WJA+06, AKR07, PM03] [RvdAtHE05, HZS10, CAC13, TIM05, RRF08, BA13]
Dep	
New	[MS04, DMPS10, WW11]
Exist	[ACRD16, BTG17, DS17, Nat11, KL07, KZM+16, SAG10, LDtH+08, SV15, DHV13, FSB07] [SM11, RCE+14]
NoBPM	
Ind	[GCSP05]
Dep	
New	[MB13]
Exist	[HTZD08]

Table A.1: A first characterisation of meta-models.

Table A.1 provides the list of these categories (where indentation is used to indicate subclasses), together with a classification of the primary studies w.r.t. the categories just introduced. In short, 18 papers present meta-models that are independent from any specific modelling language, while 18 papers belong to the language specific class **Dep**. Of the latter, the biggest group is the one describing meta-models of existing business process modelling languages (14 papers). The remaining papers describe meta-models of newly proposed business process modelling languages (3 papers), meta-models of newly proposed languages that contain business process related aspects but that are not specific business process modelling languages (1 paper), and meta-models of existing modelling languages that are not specific to the business domain (1 paper).

By looking at the primary studies we did notice further characteristics the meta-models can have, ranging from the scope of the meta-model, to the type of language used to express it, to the tool support provided in the approach.[1] This second set of categories we did extract from the primary studies is:

- Formal (**FRM**): the meta-model is described by means of a formal language;
- Meta-models of models (**Mod**): the meta-model considers (only) the process model dimension;
- Meta-models of executions (**Exe**): the meta-model considers (only) the process execution dimension
- Meta-models of executions and models (**ModExe**): the meta-model considers both the process execution and the process model dimensions;
- Procedural (**Proc**): the meta-model adheres to a procedural view of business processes;
- Declarative (**Dec**): the meta-model adheres to a declarative view of business processes;
- Activity-centric (**Act**): the meta-model adheres to an activity-centric view of business processes;
- Artefact-centric (**Art**): the meta-model adheres to an artefact-centric view of business processes;
- Domain (**Dom**): The meta-model is domain dependent;
- Evaluation (**Eval**): The meta-model is (somehow) evaluated.

Table A.2 provides a description of the primary studies w.r.t. the classes introduced above. 9 primary studies provide a formal representation of the meta-model they describe. Hal of the primary studies (18) are focused on the model dimension only, 6 consider the execution dimension only, and 12 take into account both. Concerning the approach towards business process modelling, most primary studies adhere to the traditional procedural and activity-centric based view on business processes (28 and 32 papers respectively), with very few papers taking a declarative or artefact-centric view.[2]

Another aspect to be taken into account is the one related to the domain (in)dependency of the meta-model. In our study, only two papers focus on domain-specific business processes, while

[1]Note that, in answering *RQ1.1* we do not take into account the process model elements described by the meta-models (e.g., whether they enable to describe roles, goals, artefacts and so on). This is due to the fact that we have a specific research question (*RQ1.2*) devoted to investigate what is described by the meta-models.

[2]The work of [WJA+06] appears to provide an original, yet uncommon, "value centred" approach towards business process modelling that seems to share some characteristics of artefact-centric declarative approaches. Nonetheless, a classification under the **Dec** and **Art** categories was not possible, due to a lack of details.

Class	Primary studies
FRM	[ACRD16, Nat11, LDtH+08, SV15, DHV13, FSB07, SM11, DMPS10, MB13]
Mod	[HLBB13, LK06, BTG16, MZ15, RCE+14, WJA+06, PM03, HZS10, CAC13, RRF08] [ACRD16, BTG17, DS17, Nat11, KL07, SAG10, WW11, GCSP05]
Exe	[TIM05, SV15, DHV13, MS04, HTZD08, MB13]
ModExe	[SAJ+02, KYY14, HLK11, BG11, AKR07, RvdAtHE05, BA13, KZM+16, LDtH+08] [FSB07, SM11, DMPS10]
Proc	all, except [KYY14, BG11, DMPS10, ACRD16, DHV13, SV15, MB13, WJA+06]
Dec	[KYY14, BG11, DMPS10, ACRD16, DHV13, SV15, MB13]
Act	all, except [KYY14, DHV13, SV15, WJA+06]
Art	[KYY14, DHV13, SV15]
Dom	[WW11, DS17]
Eval	[BTG16, MB13, HLBB13, HZS10, CAC13, RRF08, BG11, WJA+06, PM03, ACRD16] [KL07, KZM+16, SM11, GCSP05, HLBB13, SAG10, DS17, WW11, Nat11]

Table A.2: A second characterisation of meta-models.

all the others are domain-dependent. The two domains are the financial sector [WW11] and a context-sensitive mobile domain [DS17]. Finally, slightly more than 50% of the meta-models are (somehow) evaluated (**Eval**), even if the level of evaluation differs greatly among the different papers. This aspect will be described in Appendix A.2. Please note that QA4 did concern with an evaluation/validation of the study which could encompass the meta-model while here we refer explicitly to the evaluation of the meta-model.

A.1 Meta-models purposes

Table A.3 provides a categorisation of the primary studies w.r.t. 17 different purposes we were able to extract from the studies themselves. While extracting the reason to introduce a meta-model is somehow complex, as meta-models can be exploited in several ways, in the table we report only the purposes that were actually substantiated and illustrated in the papers, and not, for instance, to the ones that were just mentioned or left for future work and generalisations.

As we can see, all meta-models in our primary studies aim at providing an illustration of what a business process is. The second most popular usage of a meta-model in our primary studies was the extension of the meta-model itself with a new concept (16 papers). [HLK11] extends it with quality metrics; [RRF08, DS17] with a notion of context; [BA13] with the notion of change and how change relates to business process elements; [BTG16, PM03, BTG17] with the notion of knowledge and knowedge-related concepts; [MZ15] introduces the relation between business processes and daily practices; [WJA+06] extends a business process meta-model with the notion of value; [RvdAtHE05, LDtH+08] with the notion of resource; [LDtH+08] introduces also a data dimension concerning artefacts and data objects; [ACRD16] with the notion of time; [SV15, KL07] extends it with the notion of goal, and [KL07] enriches it also with the notion of

Class	Primary studies
describe what a business process is	all
extend a meta-model with new concepts	[HLK11, RRF08, BA13, BTG16, MZ15, WJA+06, PM03, RvdAtHE05, ACRD16, BTG17, DS17, KL07, LDtH+08, SV15, SM11, RCE+14]
incorporate patterns in meta-model	[TIM05, KZM+16, SM11]
integrate process & domain ontology	[HZS10, CAC13]
support quality of models	[HLK11, HZS10, CAC13, TIM05]
compare modelling languages	[SAJ+02, HLBB13, LK06, KYY14]
map/integrate modelling languages	[HLBB13, GCSP05]
classify modelling languages	[SAJ+02]
evaluate modelling languages	[LK06, KYY14]
create language independent representation	[HLBB13, AKR07, BG11, HTZD08]
describe a modelling language	[DHV13, FSB07]
define a new modelling language	[MS04, MB13]
clarify semantics of modelling language	[SAG10]
formal representation	[Nat11, DMPS10]
exploit automated reasoning	[Nat11, DMPS10]
evaluate suitability of a ML for a domain	[WW11]
support extension of a ML to a new domain	[WW11]

Table A.3: Why introducing meta-models?

performance; finally, [SM11] extends it with RBAC related concepts (e.g., roles) and also RBAC related workflow patterns. Examples of extension of the meta-model are even more present if we consider also the two additional papers that incorporate workflow patterns in the meta-model and the two papers that extend business process meta-models with the ability to connect to domain ontologies.

Coming to the less frequent usages we can note that 7 papers exploit meta-models for comparing (integrating, classifying) different modelling languages and in some cases evaluate them; instead, 8 papers use meta-models for describing an existing modelling language, support the definition of a new one, or create from them a language independent representation. Another group of papers (3 in total) focuses on the creation of formal representations of meta-models in order to clarify the semantics of specific modelling languages or exploit automated reasoning techniques (e.g., to verify the well formedness of a business model specification). One paper exploits the business process meta-model of the Semantic BP Modeling Language (tipically used to model the public sector domain) to evaluate its adequacy to the banking sector, and to find out requirements for the modification of the language to the new domain.

A.2 Meta-models evaluations

As already reported in Table A.2 (see Section A.0.1), few primary studies present some forms of evaluation of the meta-models they describe. Table A.4 provides a categorisation of the forms of evaluation we were able to extract from the primary studies. Given that not many papers provide in depth evaluations, we have listed here also the studies in which use cases are mainly used as illustrative examples of how the meta-model (or the framework that includes the meta-model) can be applied.

Overall, only 7 papers present some form of evaluation, while 12 papers present illustrative examples. Illustrative examples are, thus, the most recurring method to show the applicability

Class	Primary studies
Extensive Case Studies	[BTG16, MB13]
Ontological Analysis	[HLBB13, SAG10]
Comparison with requirements	[DS17, WW11]
Formal properties	[Nat11]
Illustrative examples	[HLBB13, HZS10, CAC13, RRF08, BG11, WJA+06, PM03, ACRD16, KL07, KZM+16, SM11, GCSP05]

Table A.4: How are the meta-models evaluated?

of the approach. [HLBB13] provides a demonstration of applicability of the business process ontology it introduces to represent business process models by using a *Processing of automobile insurance claim* example. [HZS10] provides an illustration of how an online auction process is modelled using the approach presented in the paper. This illustration concerns also the meta-model as it shows how the ontology for the use case is built using the meta-model. [CAC13] exploits a use case to illustrate both the alignment between the domain ontology and the business process model and the fact that incorporating a domain ontology improves the quality of the resulting models. [RRF08] provides a case study which illustrates how the framework can be applied to model a ticket reservation and check-in process of a major Australian airline, and in particular to model the contextual dependent aspects of this process. [BG11] presents a use case in the medical domain to illustrate how the meta-model is used to model an actual workflow with respect to data and organisational aspects. [WJA+06] provides a use case taken from a scientific conference scenario to illustrate how the value object model presented in the paper can support the production of a Value Resource Model for the specific use case. [PM03] provides an illustration of how the modelling tool based on the theoretical meta-model proposed in the paper can be used to model the granting of full old age pension within the Greek Social Security Institute. In [ACRD16] a short illustration of how the motivating example is modelled using the proposed framework (based on the extended meta-model with time constraints) is presented. [KL07] demonstrates the practical applicability of the extension of the extended EPC and BPMN meta-models with an application to the *Processing of Automobile Claims* business process; [KZM+16] introduces an example to show how the modelling technique based on the extended metamodel of EPC to represent complex events can be used to represent an exemplary complex event pattern. [SM11] provides several real case examples to discuss how the newly introduced concept of Business Activity can be used to define process-related RBAC models. Finally, [GCSP05] presents a use case to validate the POP* meta-model as a common and standard language to exchange models among different Enterprise Modelling Tools.

The only two papers that provide real/extensive use cases and exploit them to support precise characteristics of the meta-model based framework are [BTG16] and [MB13]. The first presents a real use case taken from a medical domain. Here the aim is to go beyond a mere illustration and to evaluate how the concepts contained in the meta-model can support an understandable, adequate and expressive representation of Sensitive Business Processes. The latter provides an extensive validation of the Adore method (including the Adore meta-model) against two large use cases with the aim of showing that it can be used in a real-life context, and that it supports the capture of a real-life evolution process at the business process level.

A different form of evaluation of the characteristics and quality of the meta-models is provided in [HLBB13] and [SAG10]. These primary studies exploit an ontological analysis to show how the meta-meta model is successful in expressing concepts taken from upper level ontologies. In the first paper the upper level ontology used is the Bunge-Wand-Weber (BWW) upper level ontology [WW90a], while in the second it is the UFO upper-level ontology [GW04c].

[DS17] provides an evaluation of the extended meta-model by comparing it with the requirements for its development presented at the beginning of the paper. A similar evaluation is provided in [WW11].

Finally, [Nat11] provides an evaluation of the formal ontology in terms of its formal (logic-based) properties of consistency and correctness.

By looking at these results we can say that a rigorous evaluation of meta-models is often neglected in literature as it reduces, in the majority of cases, to mere illustrative examples. Three forms of evaluation stand out from this analysis and can provide the basis for guidelines and evaluation criteria for the development of meta-models in the area of business processes. First, an evaluation by means of real use cases: this can help the assessment of the elements contained in the meta-model to support the modeling of real scenarios. Second, an evaluation by means of a comparison with requirements: this can help the assessment of the meta-model w.r.t. needs or conditions that motivated its development. Third, an evaluation based on foundational ontologies: this can help assessing the meaning and properties of concepts present in the meta-model on the basis of well-known reference elements contained in foundational ontologies.

Appendix B

Meta-model entities

Entity	Reference
activity	All but [GCSP05, BTG17, FSB07, KL07, PM03, SV15, WW11] [BA13, WJA+06, RvdAtHE05]
atomic activity	[HLBB13, ACRD16, AKR07, LK06, FSB07, CAC13, TIM05, KZM+16, Nat11, BA13]
compound activity	[HLBB13, ACRD16, AKR07, LK06, FSB07, TIM05, DHV13, MS04, Nat11, BG11] [WW11, BA13]
activity instance	[FSB07, PM03, MS04]
manual activity	[HLBB13, TIM05]
automatic activity	[HLBB13, TIM05]
collaborative organisational activity	[BTG16, BTG17]
critical organizational activity	[BTG16, BTG17]
cancel activity	[FSB07, BG11, MB13]
event	[HLBB13, BTG16, HLK11, LK06, SAG10, NLM07, LDtH+08, CAC13] [KZM+16, Nat11, BA13, SAJ+02]
event sub-process	[HLBB13, KZM+16, Nat11]
throw event	[MB13, Nat11]
interrupting	[HLBB13, Nat11]
start event	[HLBB13, NLM07, KZM+16, SM11, SV15, BA13]
intermediate event	[HLBB13, NLM07, BA13]
end event	[HLBB13, NLM07, KZM+16, SM11, BA13, BTG16, DHV13, Nat11]
message event	[DHV13, Nat11]
event location	[KZM+16, SAJ+02]
state	[AKR07, BG11, SAJ+02]
precondition	[AKR07, RvB15, GCSP05, SV15, BG11, MB13, SAJ+02, DHV13]
postcondition	[AKR07, RvB15, GCSP05, SV15, BG11, MB13, SAJ+02]
data input	[HLBB13, BTG16, RvB15]
data output	[HLBB13, BTG16, RvB15]
conditional control flow	[HLBB13, BTG16, HZS10, Nat11]
sequence	[FSB07, TIM05, SAJ+02]
multimerge	[FSB07, BG11]
multi choice	[FSB07, TIM05]
syncronisation point	[FSB07, TIM05]
connecting object	[HLBB13, BTG16, HLK11, LDtH+08, CAC13, KZM+16, BA13]
sequence flow	[HLBB13, GCSP05, HZS10, FSB07, CAC13, TIM05, MS04, Nat11]
condition	[HLBB13, TIM05]
merge	[SM11, BG11]
join	[SM11, BG11]
fork	[SM11, BG11]
gateway	[HLBB13, BTG16, HLK11, LK06, SAG10, DMPS10, LDtH+08, GCSP05, CAC13] [KZM+16, Nat11, BG11, BA13]

`Complex` (gateway)	[HLBB13, Nat11]
`event-based gateway`	[HLBB13, Nat11]
`parallel gateway`	[HLBB13, LK06, SAG10, NLM07, FSB07, TIM05, KZM+16, MS04, Nat11, BG11]
`inclusive gateway`	[HLBB13, LK06, SAG10, NLM07, KZM+16, Nat11, BG11]
`exclusive gateway`	[HLBB13, LK06, SAG10, NLM07, TIM05, KZM+16, MS04, Nat11, BG11]
`flow operator`	[HLBB13, BTG16, Nat11, BG11]
`time point`	[MZ15, SAJ+02]
`cycle time duration`	[HLK11, KL07]
`temporal dependency`	[ACRD16, SAJ+02]
`message flow`	[HLBB13, BTG16, MZ15, CAC13, Nat11]
`data flow`	[LK06, HZS10, KZM+16, SM11, Nat11]
`association`	[HLBB13, KYY14, CAC13]
`conversational link`	[HLBB13, Nat11]
`knowledge flow`	[BTG16, BTG17]
`artifact`	[KYY14, LDtH+08, RvB15, CAC13, MS04, Nat11, WW11, BA13, WJA+06][1]
`physical artifact`	[BTG16, WW11]
`data object`	[LK06, CAC13, Nat11, BA13]
`message`	[HLBB13, BTG16, Nat11]
`conversation`	[HLBB13, BTG16, Nat11]
`call conversation`	[HLBB13, Nat11]
`information` (as data object)	[AKR07, BTG17, WW11]
`physical knowledge support`	[BTG16, BTG17]
`internal knowledge`	[BTG16, BTG17]
`tacit knowledge`	[BTG16, BTG17]
`external knowledge`	[BTG16, BTG17]
`explicit knowledge`	[BTG16, BTG17]
`procedural knowledge`	[BTG16, BTG17]
`knowledge`	[BTG16, BTG17, PM03]
`document`	[AKR07, BA13][2]
`artifact instance`	[DHV13, MS04]
`data store`	[HLBB13, Nat11]
`actor`	[HLBB13, ACRD16, BTG16, HLK11, AKR07, SAG10, MZ15, TIM05, RCE+14] [SM11, MS04, Nat11, SAJ+02, WJA+06]
`collective agent`	[BTG16, SAG10, MZ15, BTG17]
`organisation`	[HLBB13, ACRD16, BTG16, HLK11, TIM05, Nat11]
`organisation unit`	[BTG16, AKR07, LK06, SAG10, TIM05, WW11]
`human expert`	[BTG16, BTG17]
`internal agent`	[BTG16, LK06]
`external agent`	[BTG16, LK06]
`client`	[BTG16, LK06, WW11, WJA+06]
`assignment` to an actor	[AKR07, Nat11]
`position`	[AKR07, TIM05, WW11, RvdAtHE05]
`role`	[AKR07, LDtH+08, MZ15, GCSP05, HZS10, CAC13, TIM05, RCE+14, PM03] [HTZD08, SM11, Nat11, SAJ+02, RvdAtHE05]
`process owner`	[LK06, BA13]
`process participant`	[LK06, SAG10, RvB15, Nat11]
`person`	[LK06, MZ15, PM03]
`information` (as resource)	[BTG16, LK06, CAC13, SAJ+02]
`application`	[LK06, MS04, RRF08, BA13]
`resource`	[GCSP05, BTG16, AKR07, LK06, MZ15, CAC13, TIM05, RCE+14, PM03, Nat11] [WW11, SAJ+02, RvdAtHE05]
`material resource`	[BTG16, LK06, CAC13]
`immaterial resource`	[BTG16, LK06, CAC13]
`measure`	[LK06, RvB15, KL07]
`cost`	[KL07, HLK11]
`organisational objective`	[BTG16, LK06]
`goal`	[LK06, RvB15, KL07, RCE+14, DHV13, SAJ+02]

[1] In [WJA+06] an `artifact` is an object that acquired value.

[2] `document` is also present in [WW11] as a resource, rather than as data object, but this usage does not appear at least twice in the primary studies and is therefore not considered in the list.

context	[MZ15, RvB15]
business area	[MZ15, WW11]

Appendix C

Comparison between BPMLs and *LB meta-model*

Note that the entities markes with **S**omehow are not specified since there are not entities that correspond exactly (see Section 4.5.3).

		BPMN	UML-AD
BEV	Func	Task (**Y** - `activity`, `atomic activity`)	Action node (**Y** - `activity`, `atomic activity`)
		Subprocess (**Y** - `compound activity`)	Activity (**Y** - `compound activity`)
	Event	Start/End (**S**)	Start/End node (**S**)
		Intermediate (**S**)	Accept event action (**S**)
		Send/receive (**S**)	Send signal action (**S**)
	Flow	Gateway (**Y** - `gateway`)	Control node (**Y** - **`gateway`**)
		Sequence Flow (**N**)	Control Flow (**N**)
		Message Flow (**N**)	Object Flow (**N**)
	State	Guard on gateway (**S**)	Guard on control node (**S**)
			Pre- Post-condition on activity (**Y** - `event-EPC`, `precondition`)
DT		Data object (**Y** - `artefact`)	Object node (**Y** - `artefact`)
		Data input (**N**)	
		data output (**N**)	
		data store (**N**)	
ORG		Pool, Lane (**Y** - `actor`, `role`)	Activity Partition (**Y** - `actor`, `role`)

Table C.1: Rationale of the comparison between BPMLs and *LB meta-model* (1).

		EPC	CMMN	DECLARE
BEV	Func	Function (**Y** - `activity`) Process path (**N**)	Task (**Y** - `activity`, `atomic activity`) Stage (**Y** - `compound activity`)	Task (**Y**)
	Event	–	Timer (**S**) User Event Listener (**S**)	–
	Flow	Logical operators (**Y** - `gateway`) Control Flow (**N**) Info Flow (**N**)	Connector (**N**) Sentry (**S**)	Connector (**N**) Pattern (**S**)
	State	Event (**Y** - `event-BPMN`, `precondition`) Start/End event (**Y** - `event-BPMN`, `precondition`)	Sentry (**Y** - `precondition`) Milestone (**S**)	–
DT		(I/O) data object (**Y** - `artefact`, `resource`)	Case file item (**Y** - `artefact`)	–
ORG		Organization (**S**) Activity Owner (**Y** - `actor`, `role`)	–	

Table C.2: Rationale of the comparison between BPMLs and *LB meta-model* (2).

Appendix D

Pre_questionnaire

1. *I am a student enrolled at the ( ) year of ( )*
2. *My background is in (you can list up to 3 fields):*
   (a) ( )
   (b) ( )
   (c) ( )
3. *My experience in designing (e.g., ER models, UML models, BPMN models, . . .) is:*
   (a) Very poor (I have never designed a model)
   (b) Below average (I have designed less than 5 models)
   (c) Average (I have designed between 5 and 15 models)
   (d) Above average (I have designed between 15 and 30 models)
   (e) Excellent (I have designed more than 30 models)
4. *My knowledge in the Business Process Management field is:*
   (a) Very poor (I never heard about it)
   (b) Below average (I heard about it few times)
   (c) Average (I attended seminars on the topic)
   (d) Above average (I attended a course)
   (e) Excellent (I work in the field)
5. *My knowledge of BPMN is:*

(a) Very poor (I never heard about BPMN)
(b) Below average (I have read/designed BPMN models less than 5 times)
(c) Average (I have read/designed BPMN models between 5 and 15 times)
(d) Above average (I have read/designed BPMN models between 15 and 30 times)
(e) Excellent (I have read/designed BPMN models more than 30 times)

6. *My experience in designing business processes (e.g., BPMN, Petri net, UML activity diagrams, . . .) is:*

    (a) Very poor (I have never designed a business process)
    (b) Below average (I have designed less than 5 business processes)
    (c) Average (I have designed between 5 and 10 business processes)
    (d) Above average (I have designed between 15 and 30 business processes)
    (e) Excellent (I have designed more than 30 business processes)

7. *My experience in redesigning business process models is:*

    (a) Very poor (I have never redesigned a business process)
    (b) Below average (I have redesigned less than 3 business processes)
    (c) Average (I have redesigned between 3 and 5 business processes)
    (d) Above average (I have redesigned between 5 and 10 business processes)
    (e) Excellent (I have redesigned more than 10 business processes)

8. *The introduced dependence relationships are clear to me:*

    (a) Strongly disagree
    (b) Disagree
    (c) Undecided
    (d) Agree
    (e) Strongly agree

9. *The introduced motivations of dependence relationships are clear to me:*

    (a) Strongly disagree
    (b) Disagree
    (c) Undecided
    (d) Agree
    (e) Strongly agree

Appendix E

Post-questionnaire

At the end of the tasks of redesign and understandability without annotations (WOA) were provided the post-questionnaires without the questions concerning the annotations.

Evaluation of the clarity of the descriptions and of the tasks

1. *The description of the business process was clear:*
   (a) Strongly disagree
   (b) Disagree
   (c) Undecided
   (d) Agree
   (e) Strongly agree
2. *The comprehension question was clear:*
   (a) Strongly disagree
   (b) Disagree
   (c) Undecided
   (d) Agree
   (e) Strongly agree
3. *The redesign task was clear:*
   (a) Strongly disagree
   (b) Disagree

(c) Undecided
(d) Agree
(e) Strongly agree

Evaluation of the process model comprehension

1. *I found the effort required for understanding the business process model:*
    (a) Very low
    (b) Below average
    (c) On average
    (d) Above average
    (e) Very high
2. *I found the time spent for understanding the business process model:*
    (a) Very low
    (b) Below average
    (c) On average
    (d) Above average
    (e) Very high
3. *I found the effort required for answering the comprehension question about the business process model:*
    (a) Very low
    (b) Below average
    (c) On average
    (d) Above average
    (e) Very high
4. *I found the time spent for answering the comprehension question about the business process model:*
    (a) Very low
    (b) Below average
    (c) On average

(d) Above average
(e) Very high

5. *I found the effort required for the redesign task:*
   (a) Very low
   (b) Below average
   (c) On average
   (d) Above average
   (e) Very high
6. *I found the time spent for the redesign task:*
   (a) Very low
   (b) Below average
   (c) On average
   (d) Above average
   (e) Very high
7. *What difficulties did you encounter in answering the comprehension question and executing the task?*
   (a) Do you have any suggestion that could ease the process?

Evaluation of the redesigned process model

1. *How would you evaluate your level of satisfaction with respect to the comprehension question?*
   (a) Very low
   (b) Below average
   (c) On average
   (d) Above average
   (e) Very high
2. *How would you evaluate your level of satisfaction with respect to the redesigned process model?*
   (a) Very low

(b) Below average

(c) On average

(d) Above average

(e) Very high

Evaluation of the dependence annotations (*)[1]

1. *Understanding the dependence relationships (i.e., historical, causal and co-occurrence) in a process model is easy:*

   (a) Strongly disagree

   (b) Disagree

   (c) Undecided

   (d) Agree

   (e) Strongly agree

2. *Being aware of the dependence relationships (i.e., historical, causal and co-occurrence) in a process model is useful:*

   (a) Strongly disagree

   (b) Disagree

   (c) Undecided

   (d) Agree

   (e) Strongly agree

3. *What do you think could be the advantages of being aware of dependence relationships?*

4. *Would you add any further dependence relationship, or would you remove any of the proposed ones? Which one(s)?*

5. *Understanding the rationales of dependence relationships (i.e., law-of-nature, business goal, norm) in a process model is easy:*

   (a) Strongly disagree

   (b) Disagree

   (c) Undecided

[1]At the end of the tasks of redesign and understandability without annotations (WOA) were provided the post-questionnaires without the questions concerning the annotations.

(d) Agree

(e) Strongly agree

6. *Being aware of the rationales of dependence relationships (i.e., law-of-nature, business goal, norm) in a process model is useful:*

   (a) Strongly disagree

   (b) Disagree

   (c) Undecided

   (d) Agree

   (e) Strongly agree

7. *What do you think could be the advantages of being aware of the rationales of dependence relationships?*

8. *Would you add any further rationale for the dependence relationships, or would you remove any of the proposed ones? Which one(s)?*

9. *The way in which the dependence relationships and their rationales are represented in a process model is intuitive:*

   (a) Strongly disagree

   (b) Disagree

   (c) Undecided

   (d) Agree

   (e) Strongly agree

10. *Do you have any suggestion on how to improve the representation of dependence relationships and their rationale?*

Appendix F

Post-questionnaire annotations

Evaluation of the clarity of the descriptions and of the tasks

1. *The description of the business process was clear:*
   (a) Strongly disagree
   (b) Disagree
   (c) Undecided
   (d) Agree
   (e) Strongly agree
2. *The annotation task was clear:*
   (a) Strongly disagree
   (b) Disagree
   (c) Undecided
   (d) Agree
   (e) Strongly agree

Evaluation of the process model annotation

1. *I found the effort required for annotating business process models with dependence relationships (i.e., historical, causal and co-occurrence):*
   (a) Very low
   (b) Below average

(c) On average
(d) Above average
(e) Very high

2. *I found the time spent for annotating the business process model with dependence relationships (i.e., historical, causal and co-occurrence):*

    (a) Very low
    (b) Below average
    (c) On average
    (d) Above average
    (e) Very high

3. *I found the effort required for annotating business process models with the rationales of dependence relationships (i.e., law-of-nature, business goal, norm):*

    (a) Very low
    (b) Below average
    (c) On average
    (d) Above average
    (e) Very high

4. *I found the time spent for annotating the business process model with the rationales of dependence relationships (i.e., law-of-nature, business goal, norm):*

    (a) Very low
    (b) Below average
    (c) On average
    (d) Above average
    (e) Very high

5. *Were the proposed dependence relationships and rationales enough or did you need more? If yes, which one?*

6. *What difficulties did you encounter in annotating the process model with dependence annotations and their rationales? Do you have any suggestion to ease the process?*

Evaluation of the annotated process model

1. *How would you evaluate your level of satisfaction with respect to the annotations related to the dependence relationships?*
    (a) Very low
    (b) Below average
    (c) On average
    (d) Above average
    (e) Very high

Bibliography

[ABF$^+$18a] Greta Adamo, Stefano Borgo, Chiara Di Francescomarino, Chiara Ghidini, and Nicola Guarino. On the notion of goal in business process models. In *AI*IA 2018 - Advances in Artificial Intelligence - XVIIth International Conference of the Italian Association for Artificial Intelligence, Trento, Italy, November 20-23, 2018, Proceedings*, volume 11298 of *Lecture Notes in Computer Science*, pages 139–151. Springer, 2018.

[ABF$^+$18b] Greta Adamo, Stefano Borgo, Chiara Di Francescomarino, Chiara Ghidini, Nicola Guarino, and Emilio M. Sanfilippo. Business process activity relationships: Is there anything beyond arrows? In Mathias Weske, Marco Montali, Ingo Weber, and Jan vom Brocke, editors, *Business Process Management Forum - BPM Forum 2018, Sydney, NSW, Australia, September 9-14, 2018, Proceedings*, volume 329 of *Lecture Notes in Business Information Processing*, pages 53–70. Springer, 2018.

[ACG$^+$09] Elvira Rolón Aguilar, Jorge S. Cardoso, Félix García, Francisco Ruiz, and Mario Piattini. Analysis and validation of control-flow complexity measures with BPMN process models. In Terry A. Halpin, John Krogstie, Selmin Nurcan, Erik Proper, Rainer Schmidt, Pnina Soffer, and Roland Ukor, editors, *Enterprise, Business-Process and Information Systems Modeling, 10th International Workshop, BP-MDS 2009, and 14th International Conference, EMMSAD 2009, held at CAiSE 2009, Amsterdam, The Netherlands, June 8-9, 2009. Proceedings*, volume 29 of *Lecture Notes in Business Information Processing*, pages 58–70. Springer, 2009.

[ACRD16] Carlos Arévalo, María José Escalona Cuaresma, Isabel M. Ramos, and M. Domínguez-Muñoz. A metamodel to integrate business processes time perspective in BPMN 2.0. *Information & Software Technology*, 77:17–33, 2016.

[AGF19] Greta Adamo, Chiara Ghidini, and Chiara Di Francescomarino. What's my process model composed of? a systematic literature review of meta-models in bpm. 1910.05564 cs.OH, arXiv, 2019.

[AIA+15] Carlos L. B. Azevedo, Maria-Eugenia Iacob, João Paulo A. Almeida, Marten van Sinderen, Luís Ferreira Pires, and Giancarlo Guizzardi. Modeling resources and capabilities in enterprise architecture: A well-founded ontology-based proposal for archimate. *Inf. Syst.*, 54:235–262, 2015.

[AKR07] Björn Axenath, Ekkart Kindler, and Vladimir A. Rubin. AMFIBIA: a meta-model for integrating business process modelling aspects. *International Journal of Business Process Integration and Management*, 2(2):120–131, 2007.

[Ant96] Annie I. Anton. Goal-based requirements analysis. In *Proceedings of the 2Nd International Conference on Requirements Engineering (ICRE '96)*, ICRE '96, pages 136–, Washington, DC, USA, 1996. IEEE Computer Society.

[As04] Ruth Sara Aguilar-saven. Business process modelling: Review and framework. *Int. J. Prod. Econ*, pages 129–149, 2004.

[BA13] Mourad Bouneffa and Adeel Ahmad. Change management of bpm-based software applications. In Slimane Hammoudi, Leszek A. Maciaszek, José Cordeiro, and Jan L. G. Dietz, editors, *ICEIS 2013 - Proceedings of the 15th International Conference on Enterprise Information Systems, Volume 2, Angers, France, 4-7 July, 2013*, pages 37–45. SciTePress, 2013.

[Bac80] Kent Bach. Actions are not events. *Mind*, 89(353):114–120, 1980.

[Bao10] Nguyen Quoc Bao. A proposal for a method to translate bpmn model into uml activity diagram. In *13th International Conference on Business Information Systems*, 2010.

[BCA+00] David Botstein, J Ms Cherry, M Ashburner, CA Ball, JA Blake, H Butler, AP Davis, K Dolinski, SS Dwight, JT Eppig, et al. Gene ontology: tool for the unification of biology. *Nat Genet*, 25(1):25–9, 2000.

[BCGL06] Emanuele Bottazzi, Carola Catenacci, Aldo Gangemi, and Jos Lehmann. From collective intentionality to intentional collectives: An ontological perspective. *Cognitive Systems Research*, 7(2-3):192–208, 2006.

[BDLBR15] Chryssoula Bekiari, Martin Doerr, Patrick Le Bœuf, and Pat Riva. Frbr object-oriented definition and mapping from frbrer, frad and frsad (version 2.4). *International working group on FRBR and CIDOC CRM harmonisation*, 2015.

[BF09] Emanuele Bottazzi and Roberta Ferrario. Preliminaries to a DOLCE ontology of organisations. *IJBPIM*, 4(4):225–238, 2009.

[BG05] Conrad Bock and Michael Gruninger. PSL: A semantic domain for flow models. *Software and System Modeling*, 4(2):209–231, 2005.

[BG11] Jens Brüning and Martin Gogolla. UML metamodel-based workflow modeling and execution. In *Proceedings of the 15th IEEE International Enterprise Distributed Object Computing Conference, EDOC 2011, Helsinki, Finland, August 29 - September 2, 2011*, pages 97–106. IEEE Computer Society, 2011.

[BH18] Stefano Borgo and Pascal Hitzler. Some open issues after twenty years of formal ontology. In *FOIS 2018*, 2018.

[BKB+07a] Pearl Brereton, Barbara A. Kitchenham, David Budgen, Mark Turner, and Mohamed Khalil. Lessons from applying the systematic literature review process within the software engineering domain. *J. Syst. Softw.*, 80(4):571–583, April 2007.

[BKB+07b] Pearl Brereton, Barbara A. Kitchenham, David Budgen, Mark Turner, and Mohamed Khalil. Lessons from applying the systematic literature review process within the software engineering domain. *Journal of Systems and Software*, 80(4):571 – 583, 2007. Software Performance.

[BL07] Stefano Borgo and Paulo Leitão. Foundations for a core ontology of manufacturing. In *Ontologies*, pages 751–775. Springer, 2007.

[BM09] Stefano Borgo and Claudio Masolo. Foundational choices in DOLCE. In Steffen Staab and Rudi Studer, editors, *Handbook on Ontologies*, International Handbooks on Information Systems, pages 361–381. Springer, 2009.

[BM13] S. Borgo and C. Masolo. Foundational choices in DOLCE. In S. Staab and R. Studer, editors, *Handbook on Ontologies*. Springer Science & Business Media, 2013.

[BMW93] Ted J. Biggerstaff, Bharat G. Mitbander, and Dallas E. Webster. The concept assignment problem in program understanding. In Victor R. Basili, Richard A. DeMillo, and Takuya Katayama, editors, *Proceedings of the 15th International Conference on Software Engineering, Baltimore, Maryland, USA, May 17-21, 1993.*, pages 482–498. IEEE Computer Society / ACM Press, 1993.

[BPG+04] Paolo Bresciani, Anna Perini, Paolo Giorgini, Fausto Giunchiglia, and John Mylopoulos. Tropos: An agent-oriented software development methodology. *Autonomous Agents and Multi-Agent Systems*, 8:203–236, 05 2004.

[BRS11] Barry A. T. Brown, Stuart Reeves, and Scott Sherwood. Into the wild: challenges and opportunities for field trial methods. In Desney S. Tan, Saleema Amershi, Bo Begole, Wendy A. Kellogg, and Manas Tungare, editors, *Proceedings of the International Conference on Human Factors in Computing Systems, CHI 2011, Vancouver, BC, Canada, May 7-12, 2011*, pages 1657–1666. ACM, 2011.

[BRvU00] Jörg Becker, Michael Rosemann, and Christoph von Uthmann. Guidelines of business process modeling. In *Business Process Management*, 2000.

[BS14] Carla E. Brodley and Peter Stone, editors. *Proceedings of the Twenty-Eighth AAAI Conference on Artificial Intelligence, July 27 -31, 2014, Québec City, Québec, Canada*. AAAI Press, 2014.

[BS15] Vered Bernstein and Pnina Soffer. Identifying and quantifying visual layout features of business process models. In Khaled Gaaloul, Rainer Schmidt, Selmin Nurcan, Sérgio Guerreiro, and Qin Ma, editors, *Enterprise, Business-Process and Information Systems Modeling - 16th International Conference, BPMDS 2015, 20th International Conference, EMMSAD 2015, Held at CAiSE 2015, Stockholm, Sweden, June 8-9, 2015, Proceedings*, volume 214 of *Lecture Notes in Business Information Processing*, pages 200–213. Springer, 2015.

[BTG16] Mariam Ben Hassen, Mohamed Turki, and Faïez Gargouri. A proposal to model knowledge dimension in sensitive business processes. In *Intelligent Systems Design and Applications - 16th International Conference on Intelligent Systems Design and Applications (ISDA 2016) held in Porto, Portugal, December 16-18, 2016*, volume 557 of *Advances in Intelligent Systems and Computing*, pages 1015–1030. Springer, 2016.

[BTG17] Mariam Ben Hassen, Mohamed Turki, and Faiez Gargouri. Extending bpmn 2.0 with the knowledge dimension. In *Proceedings of the Seventh International Symposium on Business Modeling and Software Design*, pages 111–124. SciTePress, 2017.

[Bun77a] M. Bunge. *Treatise on Basic Philosophy. Ontology I: The Furniture of the World.* Boston, Riedel, 1977.

[Bun77b] M Bunge. *Treatise on Basic Philosophy: Volume 3: Ontology I: The Furniture of the World.* Reidel, Boston, MA, 1977.

[Bun12] Mario Bunge. *Treatise on basic philosophy: Ontology II: A world of systems*, volume 4. Springer Science & Business Media, 2012.

[CAC13] Samira Si-Said Cherfi, Sarah Ayad, and Isabelle Comyn-Wattiau. Improving business process model quality using domain ontologies. *J. Data Semantics*, 2(2-3):75–87, 2013.

[CAG12] Evellin Cardoso, João Almeida, and Renata Guizzardi. Analysing the relations between strategic and operational aspects of an enterprise: Towards an ontology-based approach'. *International Journal of Organisational Design and Engineering*, 2, 01 2012.

[CAGG11] Evellin C. S. Cardoso, João Paulo A. Almeida, Renata S. S. Guizzardi, and Giancarlo Guizzardi. A method for eliciting goals for business process models based on non-functional requirements catalogues. *IJISMD*, 2(2):1–18, 2011.

[Car06] Jorge S. Cardoso. Process control-flow complexity metric: An empirical validation. In *2006 IEEE International Conference on Services Computing (SCC 2006), 18-22 September 2006, Chicago, Illinois, USA*, pages 167–173. IEEE Computer Society, 2006.

[CdPL09] Lawrence Chung and Julio Cesar Sampaio do Prado Leite. On non-functional requirements in software engineering. In Alexander T. Borgida, Vinay K. Chaudhri, Paolo Giorgini, and Eric S. Yu, editors, *Conceptual Modeling: Foundations and Applications: Essays in Honor of John Mylopoulos*, pages 363–379. Springer Berlin Heidelberg, Berlin, Heidelberg, 2009.

[CGC+07] Benoît Combemale, Pierre-Loïc Garoche, Xavier Crégut, Xavier Thirioux, and François Vernadat. Towards a formal verification of process model's properties SIMPLEPDL and TOCL case study. In Jorge S. Cardoso, José Cordeiro, and Joaquim Filipe, editors, *ICEIS 2007 - Proceedings of the Ninth International Conference on Enterprise Information Systems, Volume EIS, Funchal, Madeira, Portugal, June 12-16, 2007*, pages 80–89, 2007.

[CH09] David Cohn and Richard Hull. Business artifacts: A data-centric approach to modeling business operations and processes. *IEEE Data Eng. Bull.*, 32(3):3–9, 2009.

[Che76] Peter Pin-Shan Chen. The entity-relationship model—toward a unified view of data. *ACM Transactions on Database Systems (TODS)*, 1(1):9–36, 1976.

[Chi96] Roderick M Chisholm. *A realistic theory of categories: An essay on ontology*. Cambridge University Press, 1996.

[Cor08] Fabrice Correia. Ontological dependence. *Philosophy Compass*, 3(5):1013–1032, 2008.

[CSJA+10] Evellin CS Cardoso, Paulo Sérgio Santos Jr, João Paulo A Almeida, Renata SS Guizzardi, and Giancarlo Guizzardi. Semantic integration of goal and business process modeling. In *IFIP International Conference on Research and Practical Issues of Enterprise Information Systems (CONFENIS 2010)*, 2010.

[CV08] Roberto Casati and Achille C. Varzi. Event concepts. In Thomas F. Shipley and Jeffrey M. Zacks, editors, *Understanding Events: From Perception to Action*, pages 31–54. New York: Oxford University Press, 2008.

[Dav69] Donald Davidson. The individuation of events. In *Essays in honor of Carl G. Hempel*, pages 216–234. Springer, 1969.

[Dav93] Thomas Davenport. *Process Innovation: Reengineering work through information technology*. Harvard Business School Press, Boston, 1993.

[DDM14] Giuseppe De Giacomo, Riccardo De Masellis, and Marco Montali. Reasoning on LTL on finite traces: Insensitivity to infiniteness. In Brodley and Stone [BS14], pages 1027–1033.

[DDO08] Remco M. Dijkman, Marlon Dumas, and Chun Ouyang. Semantics and analysis of business process models in BPMN. *Information & Software Technology*, 50(12):1281–1294, 2008.

[DFRGV14] Chiara Di Francescomarino, Marco Rospocher, Chiara Ghidini, and Andrea Valerio. The role of semantic annotations in business process modelling. In *2014 IEEE 18th International Enterprise Distributed Object Computing Conference*, pages 181–189. IEEE, 2014.

[DGMR03] Islay Davies, Peter Green, Simon Milton, and Michael Rosemann. Using meta models for the comparison of ontologies. In Siau, Halpin, and Krogstie, editors, *Proceedings of the Eighth CAISE/IFIP8.1 International Workshop on Evaluation of Modelling Methods in Systems Analysis and Design.:*, pages 160–169. CAISE, Austria, 2003.

[DHV13] Elio Damaggio, Richard Hull, and Roman Vaculín. On the equivalence of incremental and fixpoint semantics for business artifacts with guard-stage-milestone lifecycles. *Inf. Syst.*, 38(4):561–584, 2013.

[DMPS10] Antonio De Nicola, Michele Missikoff, Maurizio Proietti, and Fabrizio Smith. An open platform for business process modeling and verification. In *Database and Expert Systems Applications, 21st International Conference, DEXA 2010, Bilbao, Spain, August 30 - September 3, 2010, Proceedings, Part I*, volume 6261 of *Lecture Notes in Computer Science*, pages 76–90. Springer, 2010.

[Dod08] Yadolah Dodge. *Kruskal-Wallis Test*, pages 288–290. Springer New York, New York, NY, 2008.

[dPJ15] Silvia Inês Dallavalle de Pádua and Charbel José Chiappetta Jabbour. Promotion and evolution of sustainability performance measurement systems from a perspective of business process management: From a literature review to a pentagonal proposal. *Business Proc. Manag. Journal*, 21(2):403–418, 2015.

[DRM+12] Marlon Dumas, Marcello La Rosa, Jan Mendling, Raul Mäesalu, Hajo A. Reijers, and Nataliia Semenenko. Understanding business process models: The costs and benefits of structuredness. In Jolita Ralyté, Xavier Franch, Sjaak Brinkkemper, and Stanislaw Wrycza, editors, *Advanced Information Systems Engineering - 24th International Conference, CAiSE 2012, Gdansk, Poland, June 25-29, 2012. Proceedings*, volume 7328 of *Lecture Notes in Computer Science*, pages 31–46. Springer, 2012.

[DRMR13] Marlon Dumas, Marcello La Rosa, Jan Mendling, and Hajo A. Reijers. *Fundamentals of Business Process Management*. Springer Publishing Company, Incorporated, 2013.

[dS15] Alberto Rodrigues da Silva. Model-driven engineering: A survey supported by the unified conceptual model. *Computer Languages, Systems & Structures*, 43:139–155, 2015.

[DS17] Julian Dörndorfer and Christian Seel. A meta model based extension of BPMN 2.0 for mobile context sensitive business processes and applications. In *Towards Thought Leadership in Digital Transformation: 13. Internationale Tagung Wirtschaftsinformatik, WI 2017, St.Gallen, Switzerland, February 12-15, 2017.*, 2017.

[DSSK07] Marin Dimitrov, Alex Simov, Sebastian Stein, and Mihail Konstantinov. A bpmo based semantic business process modelling environment. In *Proceedings of the Workshop on Semantic Business Process and Product Lifecycle Management (SBPM-2007)*, volume 251, pages 1613–0073, 2007.

[DTD18] Ahmet Dikici, Oktay Türetken, and Onur Demirörs. Factors influencing the understandability of process models: A systematic literature review. *Information & Software Technology*, 93:112–129, 2018.

[DvdAtH05] Marlon Dumas, Wil M. van der Aalst, and Arthur H. ter Hofstede. *Process-aware Information Systems: Bridging People and Software Through Process Technology*. John Wiley & Sons, Inc., New York, NY, USA, 2005.

[Eve08] Joerg Evermann. A uml and owl description of bunge's upper-level ontology model. *Software & Systems Modeling*, 8:235–249, 04 2008.

[FB04] Scott Farrar and John Bateman. General ontology baseline. *Deliverable D1, I1-[OntoSpace]*, 2004.

[Fen00] Dieter Fensel. *Ontologies: Silver Bullet for Knowledge Management and Electronic Commerce*. Springer-Verlag, Berlin, 2000.

[FFG94] F. G. Fadel, M. S. Fox, and M. Gruninger. A generic enterprise resource ontology. In *Proc. of 3rd IEEE Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises*, pages 117–128, April 1994.

[FG08] Roberta Ferrario and Nicola Guarino. Towards an ontological foundation for services science. In John Domingue, Dieter Fensel, and Paolo Traverso, editors, *Future Internet - FIS 2008, First Future Internet Symposium, FIS 2008, Vienna, Austria, September 29-30, 2008, Revised Selected Papers*, volume 5468 of *Lecture Notes in Computer Science*, pages 152–169. Springer, 2008.

[Fin94] Kit Fine. Ontological dependence. *Proceedings of the Aristotelian Society*, 95(n/a):269–290, 1994.

[FL11] Kathrin Figl and Ralf Laue. Cognitive complexity in business process modeling. In Haralambos Mouratidis and Colette Rolland, editors, *Advanced Information Systems Engineering - 23rd International Conference, CAiSE 2011, London, UK, June 20-24, 2011. Proceedings*, volume 6741 of *Lecture Notes in Computer Science*, pages 452–466. Springer, 2011.

[FMS13] Kathrin Figl, Jan Mendling, and Mark Strembeck. The influence of notational deficiencies on process model comprehension. *J. AIS*, 14(6):1, 2013.

[FMSR10] Kathrin Figl, Jan Mendling, Mark Strembeck, and Jan Recker. On the cognitive effectiveness of routing symbols in process modeling languages. In Witold Abramowicz and Robert Tolksdorf, editors, *Business Information Systems, 13th International Conference, BIS 2010, Berlin, Germany, May 3-5, 2010. Proceedings*, volume 47 of *Lecture Notes in Business Information Processing*, pages 230–241. Springer, 2010.

[Fra11] Chiara Di Francescomarino. *Semantic annotation of business process models*. PhD thesis, University of Trento, 2011.

[FRM13] Kathrin Figl, Jan Recker, and Jan Mendling. A study on the effects of routing symbol design on process model comprehension. *Decision Support Systems*, 54(2):1104–1118, 2013.

[FSB07] Andrew D. H. Farrell, Marek J. Sergot, and Claudio Bartolini. Formalising Workflow : A CCS-inspired Characterisation of the YAWL Workflow Patterns. *Group Decision and Negotiation*, 16(3):213–254, May 2007.

[Gal90] Antony Galton. A critical examination of allen's theory of action and time. *Artif. Intell.*, 42(2-3):159–188, 1990.

[Gal05] Antony Galton. Eventualities. In Michael Fisher, Dov M. Gabbay, and Lluís Vila, editors, *Handbook of Temporal Reasoning in Artificial Intelligence*, volume 1 of *Foundations of Artificial Intelligence*, pages 25–58. Elsevier, 2005.

[Gal12a] Antony Galton. The ontology of states, processes, and events. In *Proc. of the 5th Interdisciplinary Ontology Meeting*, pages 35–45. Keio University Open Research Centre for Logic and Formal Ontology, 2012.

[Gal12b] Antony Galton. States, processes and events, and the ontology of causal relations. In Maureen Donnelly and Giancarlo Guizzardi, editors, *Formal Ontology in Information Systems - Proceedings of the Seventh International Conference, FOIS 2012, Gray, Austria, July 24-27, 2012*, volume 239 of *Frontiers in Artificial Intelligence and Applications*, pages 279–292. IOS Press, 2012.

[Gal14] Antony Galton. On generically dependent entities. *Applied Ontology*, 9(2):129–153, 2014.

[GC14] Carlos A. González and Jordi Cabot. Formal verification of static software models in mde: A systematic review. *Information & Software Technology*, 56:821–838, 2014.

[GCSP05] Reyes Grangel, Ricardo Chalmeta, Stefan Schuster, and Iñaki Peña. Exchange of business process models using the pop* meta-model. In *Business Process Management Workshops, BPM 2005 International Workshops, BPI, BPD, ENEI, BPRM, WSCOBPM, BPS, Nancy, France, September 5, 2005, Revised Selected Papers*, volume 3812 of *Lecture Notes in Computer Science*, pages 233–244. Springer, 2005.

[GD06] Dragan Gašević and Vladan Devedžić. Petri net ontology. *Knowledge-Based Systems*, 19(4):220 – 234, 2006.

[GdAFG08] Giancarlo Guizzardi, Ricardo de Almeida Falbo, and Renata S. S. Guizzardi. Grounding software domain ontologies in the unified foundational ontology (UFO): the case of the ODE software process ontology. In Maria Lencastre, João Falcão e Cunha, and Antonio Valecillo, editors, *Memorias de la XI Conferencia Iberoamericana de Software Engineering (CIbSE 2008), Recife, Pernambuco, Brasil, February 13-17, 2008*, pages 127–140, 2008.

[GG95] Nicola Guarino and Pierdaniele Giaretta. Ontologies and knowledge bases: Towards a terminological clarification. In *Towards very Large Knowledge bases: Knowledge Building and Knowledge sharing*, pages 25–32. IOS Press, 1995.

[GGA16] Giancarlo Guizzardi, Nicola Guarino, and João Paulo A. Almeida. Ontological considerations about the representation of events and endurants in business models. In Marcello La Rosa, Peter Loos, and Oscar Pastor, editors, *Business Process Management - 14th International Conference, BPM 2016, Rio de Janeiro, Brazil, September 18-22, 2016. Proceedings*, volume 9850 of *Lecture Notes in Computer Science*, pages 20–36. Springer, 2016.

[GGMO01] Aldo Gangemi, Nicola Guarino, Claudio Masolo, and Alessandro Oltramari. Understanding top-level ontological distinctions. In Asunción Gómez-Pérez, Michael Gruninger, Heiner Stuckenschmidt, and Michael Uschold, editors, *Proceedings of the IJCAI-01 Workshop on Ontologies and Information Sharing Seattle, USA, August 4-5, 2001.*, volume 47 of *CEUR Workshop Proceedings*. CEUR-WS.org, 2001.

[Gia01] George M. Giaglis. A taxonomy of business process modelling and information systems modelling techniques, 2001.

[GM02] Guido L. Geerts and William E. McCarthy. An ontological analysis of the economic primitives of the extended-rea enterprise information architecture. *Int. J. Account. Inf. Syst.*, 3(1):1–16, 2002.

[GNT16] Malik Ghallab, Dana Nau, and Paolo Traverso. *Automated Planning and Acting*. Cambridge University Press, 2016.

[GOS09] Nicola Guarino, Daniel Oberle, and Steffen Staab. What is an ontology? In Steffen Staab and Rudi Studer, editors, *Handbook on Ontologies*, International Handbooks on Information Systems, pages 1–17. Springer, 2009.

[GOV12] Asli Goksoy, Beliz Ozsoy, and Ozalp Vayvay. Business process reengineering: strategic tool for managing organizational change an application in a multinational company. *International Journal of Business and Management*, 7(2):89, 2012.

[GR99] Peter F. Green and Michael Rosemann. An ontological analysis of integrated process modelling. In Matthias Jarke and Andreas Oberweis, editors, *Advanced Information Systems Engineering, 11th International Conference CAiSE'99, Heidelberg, Germany, June 14-18, 1999, Proceedings*, volume 1626 of *Lecture Notes in Computer Science*, pages 225–240. Springer, 1999.

[GR00] Peter F. Green and Michael Rosemann. Integrated process modeling: An ontological evaluation. *Inf. Syst.*, 25(2):73–87, 2000.

[GR10] Guido Governatori and Antonino Rotolo. Norm compliance in business process modeling. In *Semantic Web Rules*, pages 194–209, Berlin, Heidelberg, 2010. Springer Berlin Heidelberg.

[Gru95] Thomas R. Gruber. Toward principles for the design of ontologies used for knowledge sharing? *Int. J. Hum.-Comput. Stud.*, 43(5-6):907–928, 1995.

[Grü09] Michael Grüninger. Using the psl ontology. In *Handbook on Ontologies*, pages 423–443. Springer, 2009.

[GS04] Pierre Grenon and Barry Smith. Snap and span: Towards dynamic spatial ontology. *Spatial Cognition & Computation*, 4(1):69–104, 2004.

[Gua98] Nicola Guarino. *Formal ontology in information systems: Proceedings of the first international conference (FOIS'98), June 6-8, Trento, Italy*, volume 46. IOS press, 1998.

[Gua09] Nicola Guarino. The ontological level: Revisiting 30 years of knowledge representation. In Alexander Borgida, Vinay K. Chaudhri, Paolo Giorgini, and Eric S. K. Yu, editors, *Conceptual Modeling: Foundations and Applications - Essays in Honor of John Mylopoulos*, volume 5600 of *Lecture Notes in Computer Science*, pages 52–67. Springer, 2009.

[Gui05] Giancarlo Guizzardi. *Ontological foundations for structural conceptual models*. PhD thesis, University of Twente, 10 2005.

[Gui06] Giancarlo Guizzardi. On ontology, ontologies, conceptualizations, modeling languages, and (meta)models. In Olegas Vasilecas, Johann Eder, and Albertas Caplinskas, editors, *Databases and Information Systems IV - Selected Papers from the Seventh International Baltic Conference, DB&IS 2006, July 3-6, 2006, Vilnius, Lithuania*, volume 155 of *Frontiers in Artificial Intelligence and Applications*, pages 18–39. IOS Press, 2006.

[GW00] Nicola Guarino and Christopher A. Welty. Ontological analysis of taxonomic relationships. In Alberto H. F. Laender, Stephen W. Liddle, and Veda C. Storey, editors, *Conceptual Modeling - ER 2000, 19th International Conference on Conceptual Modeling, Salt Lake City, Utah, USA, October 9-12, 2000, Proceedings*, volume 1920 of *Lecture Notes in Computer Science*, pages 210–224. Springer, 2000.

[GW04a] Nicola Guarino and Christopher A. Welty. An overview of ontoclean. In Steffen Staab and Rudi Studer, editors, *Handbook on Ontologies*, International Handbooks on Information Systems, pages 151–172. Springer, 2004.

[GW04b] Giancarlo Guizzardi and Gerd Wagner. Towards ontological foundations for agent modelling concepts using the unified fundational ontology (ufo). In *International Bi-Conference Workshop on Agent-Oriented Information Systems*, pages 110–124. Springer, 2004.

[GW04c] Giancarlo Guizzardi and Gerd Wagner. A unified foundational ontology and some applications of it in business modeling. *Business Systems Analysis with Ontologies*, pages 129–143, 01 2004.

[GW10a] Giancarlo Guizzardi and Gerd Wagner. Towards an ontological foundation of discrete event simulation. In *Proceedings of the 2010 Winter Simulation Conference, WSC 2010, Baltimore, Maryland, USA, 5-8 December 2010*, pages 652–664. IEEE, 2010.

[GW10b] Giancarlo Guizzardi and Gerd Wagner. Using the unified foundational ontology (ufo) as a foundation for general conceptual modeling languages. In *Theory and applications of ontology: computer applications*, pages 175–196. Springer, 2010.

[GW11a] Giancarlo Guizzardi and Gerd Wagner. Can BPMN be used for making simulation models? In Joseph Barjis, Tillal Eldabi, and Ashish Gupta, editors, *Enterprise and Organizational Modeling and Simulation - 7th International Workshop, EOMAS 2011, held at CAiSE 2011, London, UK, June 20-21, 2011. Selected Papers*, volume 88 of *Lecture Notes in Business Information Processing*, pages 100–115. Springer, 2011.

[GW11b] Giancarlo Guizzardi and Gerd Wagner. Towards an ontological foundation of agent-based simulation. In S. Jain, Roy R. Creasey Jr., Jan Himmelspach, K. Preston White, and Michael C. Fu, editors, *Winter Simulation Conference 2011, WSC'11, Phoenix, AZ, USA, December 11-14, 2011*, pages 284–295. IEEE, 2011.

[GWAG15] Giancarlo Guizzardi, Gerd Wagner, João Paulo Andrade Almeida, and Renata S. S. Guizzardi. Towards ontological foundations for conceptual modeling: The unified foundational ontology (UFO) story. *Applied Ontology*, 10(3-4):259–271, 2015.

[GWdAF+13] Giancarlo Guizzardi, Gerd Wagner, Ricardo de Almeida Falbo, Renata S. S. Guizzardi, and João Paulo A. Almeida. Towards ontological foundations for the conceptual modeling of events. In Wilfred Ng, Veda C. Storey, and Juan Trujillo, editors, *Conceptual Modeling - 32th International Conference, ER 2013, Hong-Kong, China, November 11-13, 2013. Proceedings*, volume 8217 of *Lecture Notes in Computer Science*, pages 327–341. Springer, 2013.

[Had06] Hisham Haddad, editor. *Proceedings of the 2006 ACM Symposium on Applied Computing (SAC), Dijon, France, April 23-27, 2006*. ACM, 2006.

[Har03] Jonathan M Harris. Sustainability and sustainable development. *International Society for Ecological Economics*, 1(1):1–12, 2003.

[HC93] Michael Hammer and James Champy. *Reengineering the Corporation: A Manifesto for Business Revolution*. Harper Business, 1993.

[HDF+11] Richard Hull, Elio Damaggio, Fabiana Fournier, Manmohan Gupta, Fenno (Terry) Heath, Stacy Hobson, Mark Linehan, Sridhar Maradugu, Anil Nigam, Piyawadee Sukaviriya, and Roman Vaculin. Introducing the guard-stage-milestone approach for specifying business entity lifecycles. In Mario Bravetti and Tevfik Bultan, editors, *Web Services and Formal Methods*, pages 1–24. Springer, 2011.

[Hen08] Boris Hennig. *What is Formal Ontology?*, chapter 2, pages 39 – 56. Frankfurt: ontos, 2008.

[HFL14] Constantin Houy, Peter Fettke, and Peter Loos. On the theoretical foundations of research into the understandability of business process models. In Michel Avital, Jan Marco Leimeister, and Ulrike Schultze, editors, *22st European Conference on Information Systems, ECIS 2014, Tel Aviv, Israel, June 9-11, 2014*, 2014.

[HK13] Juho Hamari and Jonna Koivisto. Social motivations to use gamification: An empirical study of gamifying exercise. In *ECIS*, volume 105, 2013.

[HLBB13] Farideh Heidari, Pericles Loucopoulos, Frances M. T. Brazier, and Joseph Barjis. A meta-meta-model for seven business process modeling languages. In *IEEE 15th Conference on Business Informatics, CBI 2013, Vienna, Austria, July 15-18, 2013*, pages 216–221. IEEE Computer Society, 2013.

[HLK11] Farideh Heidari, Pericles Loucopoulos, and Zoubida Kedad. A quality-oriented business process meta-model. In *Enterprise and Organizational Modeling and Simulation - 7th International Workshop, EOMAS 2011, held at CAiSE 2011, London, UK, June 20-21, 2011. Selected Papers*, volume 88 of *Lecture Notes in Business Information Processing*, pages 85–99. Springer, 2011.

[HTZD08] Taíd Holmes, Huy Tran, Uwe Zdun, and Schahram Dustdar. Modeling human aspects of business processes - A view-based, model-driven approach. In *Model Driven Architecture - Foundations and Applications, 4th European Conference, ECMDA-FA 2008, Berlin, Germany, June 9-13, 2008. Proceedings*, volume 5095 of *Lecture Notes in Computer Science*, pages 246–261. Springer, 2008.

[HZS10] Zhimin Hua, J. Leon Zhao, and Veda C. Storey. Exploring a domain ontology based approach to business process design. In *Proceedings of the International Conference on Information Systems, ICIS 2010, Saint Louis, Missouri, USA, December 12-15, 2010*. Association for Information Systems, 2010.

[JAG10] Paulo Sérgio Santos Jr., João Paulo A. Almeida, and Giancarlo Guizzardi. An ontology-based semantic foundation for organizational structure modeling in the

ARIS method. In *Workshops Proceedings of the 14th IEEE International Enterprise Distributed Object Computing Conference, EDOCW 2010, Vitória, Brazil, 25-29 October 2010*, pages 272–282. IEEE Computer Society, 2010.

[JAG13] Paulo Sérgio Santos Jr., João Paulo A. Almeida, and Giancarlo Guizzardi. An ontology-based analysis and semantics for organizational structure modeling in the ARIS method. *Inf. Syst.*, 38(5):690–708, 2013.

[JMPW93] Henry J. Johansson, Patrick McHugh, A. John Pendlebury, and William A. Wheeler. *Business Process Reengineering: Breakpoint Strategies for Market Dominance*. John Wiley & Sons, 1993.

[KBR08] Ilpo Koskinen, Finland Thomas Binder, and Johan Redström. Lab, field, gallery, and beyond. *Artifact: Journal of Design Practice*, 2(1):46–57, 2008.

[KC07] B. Kitchenham and S Charters. Guidelines for performing systematic literature reviews in software engineering. Technical Report EBSE 2007-001, Keele University and Durham University Joint Report, 2007.

[Kir02] Paul A Kirschner. Cognitive load theory: Implications of cognitive load theory on the design of learning, 2002.

[Kit04] Barbara Kitchenham. Procedures for performing systematic reviews. *Keele, UK, Keele University*, 33(2004):1–26, 2004.

[KKU13] Agnes Koschmider, Simone Kriglstein, and Meike Ullrich. Investigations on user preferences of the alignment of process activities, objects and roles. In Robert Meersman, Hervé Panetto, Tharam S. Dillon, Johann Eder, Zohra Bellahsene, Norbert Ritter, Pieter De Leenheer, and Dejing Dou, editors, *On the Move to Meaningful Internet Systems: OTM 2013 Conferences - Confederated International Conferences: CoopIS, DOA-Trusted Cloud, and ODBASE 2013, Graz, Austria, September 9-13, 2013. Proceedings*, volume 8185 of *Lecture Notes in Computer Science*, pages 57–74. Springer, 2013.

[KL07] Birgit Korherr and Beate List. Extending the EPC and the BPMN with business process goals and performance measures. In Jorge S. Cardoso, José Cordeiro, and Joaquim Filipe, editors, *ICEIS 2007 - Proceedings of the Ninth International Conference on Enterprise Information Systems, Volume EIS, Funchal, Madeira, Portugal, June 12-16, 2007*, pages 287–294, 2007.

[KLL09] Ryan K. L. Ko, Stephen Siang Guan Lee, and Eng Wah Lee. Business process management (bpm) standards: a survey. *Business Proc. Manag. Journal*, 15:744–791, 2009.

[KVDD09] Ned Kock, Jacques Verville, Azim Danesh-Pajou, and Dorrie DeLuca. Communication flow orientation in business process modeling and its effect on redesign success: Results from a field study. *Decis. Support Syst.*, 46(2):562–575, 2009.

[KYY14] Jyothi Kunchala, Jian Yu, and Sira Yongchareon. A survey on approaches to modeling artifact-centric business processes. In *Web Information Systems Engineering - WISE 2014 Workshops - 15th International Workshops IWCSN 2014, Org2 2014, PCS 2014, and QUAT 2014, Thessaloniki, Greece, October 12-14, 2014, Revised Selected Papers*, volume 9051 of *Lecture Notes in Computer Science*, pages 117–132. Springer, 2014.

[KZM+16] Julian Krumeich, Manuel Zapp, Dirk Mayer, Dirk Werth, and Peter Loos. Modeling complex event patterns in epc-models and transforming them into an executable event pattern language. *Multikonferenz Wirtschaftsinformatik (MKWI)*, pages 81–92, 2016.

[LDL03] Ann Lindsay, Denise Downs, and Ken Lunn. Business processes—attempts to find a definition. *Information and software technology*, 45(15):1015–1019, 2003.

[LDtH+08] Marcello La Rosa, Marlon Dumas, Arthur H. M. ter Hofstede, Jan Mendling, and Florian Gottschalk. Beyond control-flow: Extending business process configuration to roles and objects. In *Conceptual Modeling - ER 2008, 27th International Conference on Conceptual Modeling, Barcelona, Spain, October 20-24, 2008. Proceedings*, volume 5231 of *Lecture Notes in Computer Science*, pages 199–215. Springer, 2008.

[LIA10] Grzegorz Loniewski, Emilio Insfrán, and Silvia Mara Abrahão. A systematic review of the use of requirements engineering techniques in model-driven development. In *Proceedings of the International Conference on Model Driven Engineering Languages and Systems (MODELS 2010)*, volume 6395 of *Lecture Notes in Computer Science*, pages 213–227. Springer, 2010.

[LK06] Beate List and Birgit Korherr. An evaluation of conceptual business process modelling languages. In Haddad [Had06], pages 1532–1539.

[Low95] E. J. Lowe. The metaphysics of abstract objects. *The Journal of Philosophy*, 92(10):509–524, 1995.

[LSDS06] Severin Lemaignan, Ali Siadat, J-Y Dantan, and Anatoli Semenenko. Mason: A proposal for an ontology of manufacturing domain. In *IEEE Workshop on Distributed Intelligent Systems: Collective Intelligence and Its Applications (DIS'06)*, pages 195–200. IEEE, 2006.

[LYP02] Fu-ren Lin, Meng-Chyn Yang, and Yu-Hua Pai. A generic structure for business process modeling. *Business Process Management Journal*, 8:19–41, 03 2002.

[MB13] Sébastien Mosser and Mireille Blay-Fornarino. “ADORE”, a logical meta-model supporting business process evolution. *Sci. Comput. Program.*, 78(8):1035–1054, 2013.

[MBG+03] Claudio Masolo, Stefano Borgo, Aldo Gangemi, Nicola Guarino, and Alessandro Oltramari. WonderWeb deliverable D18 ontology library (final). Technical report, IST Project 2001-33052 WonderWeb: Ontology Infrastructure for the Semantic Web, 2003.

[MCR07] Viviana Mascardi, Valentina Cordì, and Paolo Rosso. A comparison of upper ontologies. In Matteo Baldoni, Antonio Boccalatte, Flavio De Paoli, Maurizio Martelli, and Viviana Mascardi, editors, *WOA 2007: Dagli Oggetti agli Agenti. 8th AI*IA/TABOO Joint Workshop "From Objects to Agents": Agents and Industry: Technological Applications of Software Agents, 24-25 September 2007, Genova, Italy*, pages 55–64. Seneca Edizioni Torino, 2007.

[Men08] Jan Mendling. *Event-Driven Process Chains (EPC)*, pages 17–57. Springer Berlin Heidelberg, Berlin, Heidelberg, 2008.

[MGKK15] Riichiro Mizoguchi, Antony Galton, Yoshinobu Kitamura, and Kouji Kozaki. Families of roles: A new theory of occurrent-dependent roles. *Applied Ontology*, 10(3-4):367–399, 2015.

[MGV+05] Claudio Masolo, Giancarlo Guizzardi, Laure Vieu, Emanuele Botazzi, and Roberta Ferrario. Relational roles and qua-individuals. In *Proc. of the AAAI Symp. on Roles, an interdisciplinary perspective*. AAAI Press, 2005.

[ML17] Andrea Marrella and Yves Lespérance. A planning approach to the automated synthesis of template-based process models. *Service Oriented Computing and Applications*, 11(4):367–392, 2017.

[Mod11] Business Process Model. Notation (bpmn) version 2.0. *OMG Specification, Object Management Group*, pages 22–31, 2011.

[Moo03] Daniel L. Moody. The method evaluation model: a theoretical model for validating information systems design methods. In Claudio U. Ciborra, Riccardo Mercurio, Marco de Marco, Marcello Martinez, and Andrea Carignani, editors, *Proceedings of the 11th European Conference on Information Systems, ECIS 2003, Naples, Italy 16-21 June 2003*, pages 1327–1336, 2003.

[Mou78] Alexander P. D. Mourelatos. Events, processes, and states. *Linguistics and Philosophy*, 2(3):415–434, 1978.

[MP00] Nuno Melão and Michael Pidd. A conceptual framework for understanding business processes and business process modelling. *Inf. Syst. J.*, 10(2):105–130, 2000.

[MR05] Selma Limam Mansar and Hajo A. Reijers. Best practices in business process redesign: validation of a redesign framework. *Comput. Ind.*, 56(5):457–471, 2005.

[MR07] Selma Limam Mansar and Hajo A. Reijers. Best practices in business process redesign: use and impact. *Business Proc. Manag. Journal*, 13(2):193–213, 2007.

[MR08] Jan Mendling and Hajo A. Reijers. The impact of activity labeling styles on process model quality. In Wolfgang Hesse and Andreas Oberweis, editors, *SIGSAND-EUROPE 2008: Proceedings of the Third AIS SIGSAND European Symposium on Analysis, Design, Use and Societal Impact of Information Systems, June 12 - 13, 2008, Marburg, Germany*, volume 129 of *LNI*, pages 117–128. GI, 2008.

[MRC07] Jan Mendling, Hajo A. Reijers, and Jorge S. Cardoso. What makes process models understandable? In Gustavo Alonso, Peter Dadam, and Michael Rosemann, editors, *Business Process Management, 5th International Conference, BPM 2007, Brisbane, Australia, September 24-28, 2007, Proceedings*, volume 4714 of *Lecture Notes in Computer Science*, pages 48–63. Springer, 2007.

[MRR10] Jan Mendling, Hajo A. Reijers, and Jan Recker. Activity labeling in process modeling: Empirical insights and recommendations. *Inf. Syst.*, 35(4):467–482, 2010.

[MS04] Mariusz Momotko and Kazimierz Subieta. Process query language: A way to make workflow processes more flexible. In *Advances in Databases and Information Systems, 8th East European Conference, ADBIS 2004, Budapest, Hungary, September 22-25, 2004, Proceesing*, volume 3255 of *Lecture Notes in Computer Science*, pages 306–321. Springer, 2004.

[MT17] Riichiro Mizoguchi and Fumiaki Toyoshima. YAMATO: yet another more advanced top-level ontology with analysis of five examples of change. In Stefano Borgo, Oliver Kutz, Frank Loebe, Fabian Neuhaus, Kemo Adrian, Mihailo Antovic, Valerio Basile, Martin Boeker, Diego Calvanese, Tommaso Caselli, Giorgio Colombo, Roberto Confalonieri, Laura Daniele, Jérôme Euzenat, Antony Galton, Dagmar Gromann, Maria M. Hedblom, Heinrich Herre, Inge Hinterwaldner, Andrea Janes, Ludger Jansen, Kris Krois, Antonio Lieto, Claudio Masolo, Rafael Peñaloza, Daniele Porello, Daniele P. Radicioni, Emilio M. Sanfilippo, Daniel Schober, Rossella Stufano, and Amanda Vizedom, editors, *Proceedings of the Joint Ontology Workshops 2017 Episode 3: The Tyrolean Autumn of Ontology,* *Bozen-Bolzano, Italy, September 21-23, 2017.*, volume 2050 of *CEUR Workshop Proceedings*. CEUR-WS.org, 2017.

[MTJ+10a] Hafedh Mili, Guy Tremblay, Guitta Bou Jaoude, Éric Lefebvre, Lamia Elabed, and Ghizlane El Boussaidi. Business process modeling languages: Sorting through the alphabet soup. *ACM Comput. Surv.*, 43(1):4:1–4:56, 2010.

[MTJ+10b] Hafedh Mili, Guy Tremblay, Guitta Bou Jaoude, Eric Lefebvre, Lamia Elabed, and Ghizlane El-Boussaidi. Business process modeling languages: Sorting through the alphabet soup. *ACM Comput. Surv.*, 43(1):4:1–4:56, 2010.

[MVB+04] Claudio Masolo, Laure Vieu, Emanuele Bottazzi, Carola Catenacci, Roberta Ferrario, Aldo Gangemi, and Nicola Guarino. Social roles and their descriptions. In Didier Dubois, Christopher A. Welty, and Mary-Anne Williams, editors, *Principles of Knowledge Representation and Reasoning: Proceedings of the Ninth International Conference (KR2004), Whistler, Canada, June 2-5, 2004*, pages 267–277. AAAI Press, 2004.

[MvH04] Deborah L. McGuinness and Frank van Harmelen. Owl web ontology language overview. Technical Report REC-owl-features-20040210, W3C, 2004.

[MW18] Dan Marshall and Brian Weatherson. Intrinsic vs. extrinsic properties. In Edward N. Zalta, editor, *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University, spring 2018 edition, 2018.

[MZ15] Paula Ventura Martins and Marielba Zacarias. Business process and practice alignment meta-model. *Procedia Computer Science*, 64:314–323, 2015.

[Nat11] Christine Natschläger. Towards a BPMN 2.0 ontology. In *Business Process Model and Notation - Third International Workshop, BPMN 2011, Lucerne, Switzerland, November 21-22, 2011. Proceedings*, volume 95 of *Lecture Notes in Business Information Processing*, pages 1–15. Springer, 2011.

[NI02] P Russel Norvig and S Artificial Intelligence. *A modern approach*. Prentice Hall, 2002.

[NKKT15] Phu H. Nguyen, Max Kramer, Jacques Klein, and Yves Le Traon. An extensive systematic review on the model-driven development of secure systems. *Inf. Softw. Technol.*, 68(C):62–81, December 2015.

[NLM07] Antonio De Nicola, Mario Lezoche, and Michele Missikoff. An ontological approach to business process modeling. In *Proceedings of the 3rd Indian International Conference on Artificial Intelligence, Pune, India, December 17-19, 2007*, pages 1794–1813. IICAI, 2007.

[NP01] Ian Niles and Adam Pease. Towards a standard upper ontology. In *2nd International Conference on Formal Ontology in Information Systems, FOIS 2001, Ogunquit, Maine, USA, October 17-19, 2001, Proceedings.*, pages 2–9. ACM, 2001.

[OHS02] Andreas Opdahl and Brian Henderson-Sellers. Ontological evaluation of the uml using the bunge–wand–weber model. *Software and System Modeling*, 1:43–67, 09 2002.

[OMG11a] OMG. Business Process Model and Notation (BPMN), Version 2.0, January 2011.

[OMG11b] OMG. OMG Unified Modeling Language (OMG UML), Superstructure, Version 2.4.1, August 2011.

[Pat08] Susanne Patig. A practical guide to testing the understandability of notations. In Annika Hinze and Markus Kirchberg, editors, *Conceptual Modelling 2008, Fifth Asia-Pacific Conference on Conceptual Modelling (APCCM 2008), Wollongong, New South Wales, Australia, January 22-25 2008.*, volume 79 of *CRPIT*, pages 49–58. Australian Computer Society, 2008.

[PM03] Giorgos Papavassiliou and Gregoris Mentzas. Knowledge modelling in weakly-structured business processes. *J. Knowledge Management*, 7(2):18–33, 2003.

[PSvdA07] Maja Pesic, Helen Schonenberg, and Wil M. P. van der Aalst. DECLARE: full support for loosely-structured processes. In *11th IEEE International Enterprise Distributed Object Computing Conference (EDOC 2007), 15-19 October 2007, Annapolis, Maryland, USA*, pages 287–300. IEEE Computer Society, 2007.

[PV00] Fabio Pianesi and Achille C Varzi. Events and event talk. *Speaking of events*, pages 3–47, 2000.

[PWZ+11] Paul Pichler, Barbara Weber, Stefan Zugal, Jakob Pinggera, Jan Mendling, and Hajo A. Reijers. Imperative versus declarative process modeling languages: An empirical investigation. In Florian Daniel, Kamel Barkaoui, and Schahram Dustdar, editors, *Business Process Management Workshops - BPM 2011 International Workshops, Clermont-Ferrand, France, August 29, 2011, Revised Selected Papers, Part I*, volume 99 of *Lecture Notes in Business Information Processing*, pages 383–394. Springer, 2011.

[PZW+11] Jakob Pinggera, Stefan Zugal, Matthias Weidlich, Dirk Fahland, Barbara Weber, Jan Mendling, and Hajo A. Reijers. Tracing the process of process modeling with modeling phase diagrams. In Florian Daniel, Kamel Barkaoui, and Schahram

Dustdar, editors, *Business Process Management Workshops - BPM 2011 International Workshops, Clermont-Ferrand, France, August 29, 2011, Revised Selected Papers, Part I*, volume 99 of *Lecture Notes in Business Information Processing*, pages 370–382. Springer, 2011.

[RA15] Matthias Rolf and Minoru Asada. What are goals? and if so, how many? In *Development and Learning and Epigenetic Robotics (ICDL-EpiRob), 2015 Joint IEEE International Conference on*, pages 332–339. IEEE, 2015.

[RCE+14] Marcela Ruiz, Dolors Costal, Sergio España, Xavier Franch, and Oscar Pastor. Integrating the goal and business process perspectives in information system analysis. In *Advanced Information Systems Engineering - 26th International Conference, CAiSE 2014, Thessaloniki, Greece, June 16-20, 2014. Proceedings*, volume 8484 of *Lecture Notes in Computer Science*, pages 332–346. Springer, 2014.

[RD07] Jan Recker and Alexander Dreiling. Does it matter which process modelling language we teach or use? an experimental study on understanding process modelling languages without formal education. *ACIS 2007 Proceedings*, page 45, 2007.

[Rei05] Hajo A Reijers. Process design and redesign., 2005.

[RFME11] Hajo A. Reijers, Thomas Freytag, Jan Mendling, and Andreas Eckleder. Syntax highlighting in business process models. *Decision Support Systems*, 51(3):339–349, 2011.

[RGdAF+17] Fabiano Borges Ruy, Giancarlo Guizzardi, Ricardo de Almeida Falbo, Cássio Chaves Reginato, and Victor A. Santos. From reference ontologies to ontology patterns and back. *Data Knowl. Eng.*, 109:41–69, 2017.

[RGI04] Michael Rosemann, Peter F. Green, and Marta Indulska. A reference methodology for conducting ontological analyses. In Paolo Atzeni, Wesley W. Chu, Hongjun Lu, Shuigeng Zhou, and Tok Wang Ling, editors, *Conceptual Modeling - ER 2004, 23rd International Conference on Conceptual Modeling, Shanghai, China, November 2004, Proceedings*, volume 3288 of *Lecture Notes in Computer Science*, pages 110–121. Springer, 2004.

[RGS14] Marco Rospocher, Chiara Ghidini, and Luciano Serafini. An ontology for the business process modelling notation. In *Formal Ontology in Information Systems - Proceedings of the Eighth International Conference, FOIS 2014, September, 22-25, 2014, Rio de Janeiro, Brazil*, volume 267 of *Frontiers in Artificial Intelligence and Applications*, pages 133–146. IOS Press, 2014.

[RI07] Jan Recker and Marta Indulska. An ontology-based evaluation of process modeling with petri nets. *IBIS*, 4:45–64, 2007.

[RM05] Hajo A Reijers and S Liman Mansar. Best practices in business process redesign: an overview and qualitative evaluation of successful redesign heuristics. *Omega*, 33(4):283–306, 2005.

[RM08] Hajo A. Reijers and Jan Mendling. Modularity in process models: Review and effects. In Marlon Dumas, Manfred Reichert, and Ming-Chien Shan, editors, *Business Process Management, 6th International Conference, BPM 2008, Milan, Italy, September 2-4, 2008. Proceedings*, volume 5240 of *Lecture Notes in Computer Science*, pages 20–35. Springer, 2008.

[RM11] Hajo A. Reijers and Jan Mendling. A study into the factors that influence the understandability of business process models. *IEEE Trans. Systems, Man, and Cybernetics, Part A*, 41(3):449–462, 2011.

[RPKC11] Catherine Roussey, François Pinet, Myoung-Ah Kang, and Oscar Corcho. an Introduction to Ontologies and Ontology Engineering. *Advanced Information and Knowledge Processing*, 1:9–38, July 2011.

[RRF08] Michael Rosemann, Jan Recker, and Christian Flender. Contextualisation of business processes. *International Journal of Business Process Integration and Management*, 3(1):47–60, 2008.

[RRIG09] Jan Recker, Michael Rosemann, Marta Indulska, and Peter F. Green. Business process modeling- A comparative analysis. *J. AIS*, 10(4):1, 2009.

[RRK07] Jan Recker, Michael Rosemann, and John Krogstie. Ontology- versus pattern-based evaluation of process modeling languages: A comparison. *CAIS*, 20:48, 2007.

[RRS+11] Gianna Reggio, Filippo Ricca, Giuseppe Scanniello, Francesco Di Cerbo, and Gabriella Dodero. A precise style for business process modelling: Results from two controlled experiments. In Jon Whittle, Tony Clark, and Thomas Kühne, editors, *Model Driven Engineering Languages and Systems, 14th International Conference, MODELS 2011, Wellington, New Zealand, October 16-21, 2011. Proceedings*, volume 6981 of *Lecture Notes in Computer Science*, pages 138–152. Springer, 2011.

[RSN+95] Alan L Rector, W Danny Solomon, W Anthony Nowlan, TW Rush, PE Zanstra, and WMA Claassen. A terminology server for medical language and medical information systems. *Methods of information in medicine*, 34(01/02):147–157, 1995.

[RvB15] Michael Rosemann and Jan vom Brocke. The six core elements of business process management. In *Handbook on Business Process Management 1, Introduction, Methods, and Information Systems, 2nd Ed.*, International Handbooks on Information Systems, pages 105–122. Springer, 2015.

[RvdAtHE05] Nick Russell, Wil M. P. van der Aalst, Arthur H. M. ter Hofstede, and David Edmond. Workflow resource patterns: Identification, representation and tool support. In *Advanced Information Systems Engineering, 17th International Conference, CAiSE 2005, Porto, Portugal, June 13-17, 2005, Proceedings*, volume 3520 of *Lecture Notes in Computer Science*, pages 216–232. Springer, 2005.

[SAG10] Paulo Sérgio Santos Jr., João Paulo A. Almeida, and Giancarlo Guizzardi. An ontology-based semantic foundation for ARIS epcs. In *Proceedings of the 2010 ACM Symposium on Applied Computing (SAC), Sierre, Switzerland, March 22-26, 2010*, pages 124–130. ACM, 2010.

[SAJ+02] Eva Söderström, Birger Andersson, Paul Johannesson, Erik Perjons, and Benkt Wangler. Towards a framework for comparing process modelling languages. In *Advanced Information Systems Engineering, 14th International Conference, CAiSE 2002, Toronto, Canada, May 27-31, 2002, Proceedings*, volume 2348 of *Lecture Notes in Computer Science*, pages 600–611. Springer, 2002.

[San17] Emilio M Sanfilippo. *Ontological foundations for feature-based product modelling*. PhD thesis, University of Trento, 2017.

[SBB+18] Emilio M. Sanfilippo, Sergio Benavent, Stefano Borgo, Nicola Guarino, Nicolas Troquard, Fernando Romero, Pedro Rosado, Lorenzo Solano, Farouk Belkadi, and Alain Bernard. Modeling manufacturing resources: An ontological approach. In *Product Lifecycle Management to Support Industry 4.0 - 15th IFIP WG 5.1 Int. Conf., PLM 2018, Proc.*, volume 540 of *IFIP Advances in Information and Communication Technology*, pages 304–313. Springer, 2018.

[SBK17] Thorsten Schoormann, Dennis Behrens, and Ralf Knackstedt. Sustainability in business process models: A taxonomy-driven approach to synthesize knowledge and structure the field. In Yong Jin Kim, Ritu Agarwal, and Jae Kyu Lee, editors, *Proceedings of the International Conference on Information Systems - Transforming Society with Digital Innovation, ICIS 2017, Seoul, South Korea, December 10-13, 2017*. Association for Information Systems, 2017.

[SBM14] Emilio M. Sanfilippo, Stefano Borgo, and Claudio Masolo. Events and activities: Is there an ontology behind bpmn? In Pawel Garbacz and Oliver Kutz, editors, *Formal Ontology in Information Systems - Proceedings of the Eighth International Conference, FOIS 2014, September, 22-25, 2014, Rio de Janeiro, Brazil*, volume

267 of *Frontiers in Artificial Intelligence and Applications*, pages 147–156. IOS Press, 2014.

[SC15] Barry Smith and Werner Ceusters. Aboutness: towards foundations for the information artifact ontology. In Francisco M. Couto and Janna Hastings, editors, *Proceedings of the International Conference on Biomedical Ontology, ICBO 2015, Lisbon, Portugal, July 27-30, 2015.*, volume 1515 of *CEUR Workshop Proceedings*. CEUR-WS.org, 2015.

[Sch02a] August-Wilhelm Scheer. *ARIS - vom Geschäftsprozess zum Anwendungssystem*. Springer, Berlin [u.a.], 4., durchges. aufl. edition, 2002.

[Sch02b] August-Wilhelm Scheer. Das basis-geschäftsprozeßmodell für aris. In *ARIS—Vom Geschäftsprozess zum Anwendungssystem*, pages 10–31. Springer, 2002.

[SJV+12] Iván Santiago, Álvaro Jiménez, Juan M. Vara, Valeria de Castro, Verónica Andrea Bollati, and Esperanza Marcos. Model-driven engineering as a new landscape for traceability management: A systematic literature review. *Information & Software Technology*, 54:1340–1356, 2012.

[SKW11] Pnina Soffer, Maya Kaner, and Yair Wand. Towards understanding the process of process modeling: Theoretical and empirical considerations. In Florian Daniel, Kamel Barkaoui, and Schahram Dustdar, editors, *Business Process Management Workshops - BPM 2011 International Workshops, Clermont-Ferrand, France, August 29, 2011, Revised Selected Papers, Part I*, volume 99 of *Lecture Notes in Business Information Processing*, pages 357–369. Springer, 2011.

[SM11] Mark Strembeck and Jan Mendling. Modeling process-related RBAC models with extended UML activity models. *Information & Software Technology*, 53(5):456–483, 2011.

[Smi03] Barry Smith. Ontology. In Luciano Floridi, editor, *The Blackwell guide to the philosophy of computing and information*, chapter 11, pages 155–166. John Wiley & Sons, 2003.

[Spe07] OMG Available Specification. Omg unified modeling language (omg uml), superstructure, v2. 1.2. *Object Management Group*, 70, 2007.

[SRvB12] Stefan Seidel, Jan Recker, and Jan vom Brocke. Green business process management. In *Green Business Process Management*, pages 3–13. Springer, 2012.

[STA05] August-Wilhelm Scheer, Oliver Thomas, and Otmar Adam. Process modeling using event-driven process chains. In *Process-Aware Information Systems*, 2005.

[Ste18] Helen Steward. Occurrent states. In Rowland Stout, editor, *Process, Action, and Experience*, pages 102–119. Oxford University Press, 2018.

[SV15] Danillo Sprovieri and Sandro Vogler. Run-time composition of partly structured business processes using heuristic planning. In *International Conference on Enterprise Systems, ES 2015, Basel, Switzerland, October 14-15, 2015*, pages 225–232. IEEE, 2015.

[SW01] Barry Smith and Christopher A. Welty. FOIS introduction: Ontology - towards a new synthesis. In *2nd International Conference on Formal Ontology in Information Systems, FOIS 2001, Ogunquit, Maine, USA, October 17-19, 2001, Proceedings*, pages iii–ix. ACM, 2001.

[Swe88] John Sweller. Cognitive load during problem solving: Effects on learning. *Cognitive Science*, 12(2):257–285, 1988.

[TIM05] Lucinéia Heloisa Thom, Cirano Iochpe, and Bernhard Mitschang. Improving workflow project quality via business process patterns based on organizational structure aspects. In *Proceedings of the Second GI-Workshop XML4BPM - XML for Business Process Management held at the 11th Conference Business, Technologie, and Web (BTW 2005) Karlsruhe (Germany), 01 March 2005.*, volume 145 of *CEUR Workshop Proceedings*, pages 65–80. CEUR-WS.org, 2005.

[TRV+16] Oktay Türetken, Tessa Rompen, Irene T. P. Vanderfeesten, Ahmet Dikici, and Jan van Moll. The effect of modularity representation and presentation medium on the understandability of business process models in BPMN. In Marcello La Rosa, Peter Loos, and Oscar Pastor, editors, *Business Process Management - 14th International Conference, BPM 2016, Rio de Janeiro, Brazil, September 18-22, 2016. Proceedings*, volume 9850 of *Lecture Notes in Computer Science*, pages 289–307. Springer, 2016.

[Try07] Robert Trypuz. *Formal Ontology of Action: a unifying approach*. PhD thesis, University of Trento, 01 2007.

[UJ99] Mike Uschold and Robert Jasper. A Framework for Understanding and Classifying Ontology Applications. In *IJCAI-99 Workshop on Ontologies and Problem-Solving Methods (KRR5)*, Stockholm, Sweden, 1999.

[Var00] Achille C. Varzi. Mereological commitments. *Dialectica*, 54(4):283–305, 2000.

[Var11] Achille C. Varzi. On doing ontology without metaphysics. *Philosophical Perspectives*, 25:407–423, 2011.

[Var19] Achille C Varzi. The magic of holes. *Ordinary Things and Their Extraordinary Meanings*, page 21, 2019.

[Ven57] Zeno Vendler. Verbs and times. *The Philosophical Review*, 66(2):143–160, 1957.

[vHH$^+$10] W. van der Aalst, K. van Hee, A. ter Hofstede, N. Sidorova, H. Verbeek, M. Voorhoeve, and M. Wynn. Soundness of workflow nets:classification, decidability, and analysis. *Formal Aspects of Comp.*, 23(3):333–363, 2010.

[VL01] Axel Van Lamsweerde. Goal-oriented requirements engineering: A guided tour. In *Requirements Engineering, 2001. Proceedings. Fifth IEEE International Symposium on*, pages 249–262. IEEE, 2001.

[WDAZ17] Max Willis, Antonella De Angeli, and Massimo Zancanaro. Experience probes: Immersion and reflection between reality and virtuality. In *IFIP Conference on Human-Computer Interaction*, pages 253–262. Springer, 2017.

[Wes12a] Mathias Weske. Business process management architectures. In *Business Process Management*, pages 333–371. Springer, 2012.

[Wes12b] Mathias Weske. *Business Process Management. Concepts, Languages, Architectures.* Springer, 2012.

[WHH03] Claes Wohlin, Martin Höst, and Kennet Henningsson. Empirical research methods in software engineering. In *Empirical methods and studies in software engineering*, pages 7–23. Springer, 2003.

[WJA$^+$06] Hans Weigand, Paul Johannesson, Birger Andersson, Maria Bergholtz, Ananda Edirisuriya, and Tharaka Ilayperuma. On the notion of value object. In *Advanced Information Systems Engineering, 18th International Conference, CAiSE 2006, Luxembourg, Luxembourg, June 5-9, 2006, Proceedings*, volume 4001 of *Lecture Notes in Computer Science*, pages 321–335. Springer, 2006.

[WR08] Y Wand and Weber RY. On the ontological expressiveness of information systems analysis and design grammars. *Information Systems Journal*, 3:217 – 237, 06 2008.

[WRH$^+$12] Claes Wohlin, Per Runeson, Martin Hst, Magnus C. Ohlsson, Bjrn Regnell, and Anders Wessln. *Experimentation in Software Engineering*. Springer Publishing Company, Incorporated, 2012.

[WSW99] Yair Wand, Veda C. Storey, and Ron Weber. An ontological analysis of the relationship construct in conceptual modeling. *ACM Trans. Database Syst.*, 24(4):494–528, 1999.

[WW88] Yair Wand and Ron Weber. An ontological analysis of some fundamental information systems concepts. In *Proceedings of the 9th International Conference on*

Information Systems, ICIS 1988, Minneapolis, Minnesota, USA, 1988, page 35. Association for Information Systems, 1988.

[WW90a] Y. Wand and R Weber. An ontological model of an information system. *IEEE Transactions on Software Engineering*, 16(11):1282–1292, 1990.

[WW90b] Yair Wand and Ron Weber. Towards a theory of the deep structure of information systems. In *11th International Conference on Information Systems*, pages 61–71. ACM Press, 1990.

[WW11] Burkhard Weiß and Axel Winkelmann. A metamodel based perspective on the adaptation of a semantic business process modeling language to the financial sector. In *44th Hawaii International International Conference on Systems Science (HICSS-44 2011), Proceedings, 4-7 January 2011, Koloa, Kauai, HI, USA*, pages 1–10. IEEE Computer Society, 2011.

[ZMG17] Marielba Zacarias, Paula Ventura Martins, and António Gonçalves. An agile business process and practice meta-model. *Procedia Computer Science*, 121:170–177, 2017.

[zMIK07] Michael zur Muehlen, Marta Indulska, and Gerrit Kamp. Business process and business rule modeling languages for compliance management: A representational analysis. In John C. Grundy, Sven Hartmann, Alberto H. F. Laender, Leszek A. Maciaszek, and John F. Roddick, editors, *Challenges in Conceptual Modelling. Tutorials, posters, panels and industrial contributions at the 26th International Conference on Conceptual Modeling - ER 2007. Auckland, New Zealand, November 5-9, 2007. Proceedings*, volume 83 of *CRPIT*, pages 127–132. Australian Computer Society, 2007.