Design Principles for Ensuring Compliance in Business Processes

A dissertation submitted for the degree of

Doctor rerum politicarum (Dr. rer. pol.)

to the Faculty of Economic and Social Sciences

of University of Rostock

submitted by

Andrea Zasada

Rostock, October 31, 2019

https://doi.org/10.18453/rosdok_id00002699

This thesis is cumulative.

Reviewers:

Prof. Dr. Michael Leyer, University of Rostock, Institute of Business Administration

Prof. Dr. Michael Fellmann, University of Rostock, Institute of Computer Science

Year of submission: 2019

Year of defense: 2020

No kuʻu ʻohana

Abstract

In contrast to process modeling, the modeling of legal requirements requires not only an understanding of processes but also a basic understanding of legal concepts for the interpretation of regulations. However, while process modelers and analysts who are trained in using formal methods may be experts in applying process logic, they do not necessarily understand the normative meanings of a regulation. Modeling languages that help this user group to identify relevant concepts are hence a great advantage in compliance modeling to avoid modeling errors. Paradoxically, these rule languages, also referred to as compliance languages, have yet to be evaluated in terms of their representational or cognitive complexity, so it is impossible to say whether these languages can be efficiently used. In this thesis, we close this research gap and evaluate the complexity and understandability of compliance languages. First, to calculate the complexity, we apply established software metrics and interpret the results with respect to the languages' expressiveness. As a measure of their expressiveness, we distinguish the normative concepts of legal requirements. Second, to investigate the languages' understandability, we use a cognitive model of the human problem-solving process and analyze how efficiently users perform a compliance modeling task. Our results have theoretical and practical implications that give directions for the development of compliance languages, and rule-based languages in general.

Statement of Authorship

I hereby declare that I have completed the present work without the unauthorized help of third parties and without the use aids other than those specified; the ideas taken directly or indirectly from external sources are identified as such. This work has not yet been submitted, either domestically or abroad, in the same or similar form to an examination authority for the purpose of obtaining an academic degree.

Rostock, October 31, 2019

Andrea Zasada

Contents

Part A

Synopsis

Abbreviations

BASEL	Basel Committee on Banking Supervision
BPC	Business Process Compliance
BPM	Business Process Management
BPMN	Business Process Model and Notation
BPMN-Q	Business Process Model and Notation Query Language
CRL	Compliance Request Language
DMQL	Diagramed Model Query Language
DR	Design Requirement
eCRG	extended Compliance Rule Graph
FCL	Formal Contract Logic
ISO	International Organization for Standardization
MiFID	Markets in Financial Institute Directive
PCL	Process Compliance Language
PENELOPE	Process Entailment from the Elicitation of Obligations and Permissions
RQ	Research Question
SOX	Sarbanes–Oxley Act

Figures

Tables

1 Introduction

This chapter provides basic insights into the topic and presents the motivation for research. It is divided into sections discussing the research context (Section 1.1), the problem description (Section 1.2), and the structure of the remainder of the thesis (Section 1.3).

1.1 Research Context

Compliance is the result of an organization fulfilling its obligations (Hashmi, Governatori, Lam, & Wynn, 2018). To achieve this result, an organization has to demonstrate its commitment to mandatory regulations and voluntary codes of conduct (ISO, 2014).[1] One of the first legal initiatives to ensure compliance was the American Sarbanes–Oxley Act (SOX, 2002), a U.S. federal law that had a significant impact on all financial reporting processes. Not only did the Act increase the transparency of financial reporting, it also paved the way for auditors to identify ineffective control mechanisms (Leone, 2007). Further regulations, such as BASEL[2] and MiFID[3] followed at European level in order to strengthen various aspects of financial reporting and to reinstate the principle of liability (COMPAS, 2008). Particularly with regard to the events of 2008 and 2009 in the financial industry, it became apparent that institutions did not have sufficient equity and liquidity to cover the relevant risks (Buch & Dages, 2018). However, compliance is not only an issue that arises from legislation; obligations can also result from codes of practice (Manders, De Vries, & Blind, 2016) and business contracts (Governatori, Milosevic, & Sadiq, 2006). In addition, more and more societal concerns have come to the fore, which entail new unexpected obligations. Large food-processing companies have experienced the consequences of ignoring these obligations, bringing their brands into great discredit due to inadequate labor conditions or a lack of environmental responsibility (Hartmann, 2011).

However, as important as it is for organizations to demonstrate compliance (Herath & Rao, 2009), there are also various reasons why compliance cannot be achieved. One of these reasons is that compliance depends on the cooperation of employees. If an organization fails to create a culture of compliance, employees may decide not to comply with regulations based on personal norms (Yazdanmehr & Wang, 2016), or beliefs about the outcomes and consequences of their actions (Bulgurcu, Cavusoglu, & Benbasat, 2010). Understanding what drives employees to adapt to compliance requirements therefore plays a major role in achieving compliance. Another reason why compliance could be thwarted is that the implementation of compliance requirements costs organizations significant resources (Brace et al., 2006). In 2013, for instance, 200 hedge fund managers around the world were asked about the costs of compliance. They estimated that the average spend on compliance tech-

[1] ISO 19600: “An effective, organization-wide compliance management system enables an organization to demonstrate its commitment to compliance with relevant laws, including legislative requirements, industry codes and organizational standards, as well as standards of good corporate governance, best practices, ethics and community expectations.”

[2] BASEL: Minimum capital requirements for banks of the Basel Committee on Banking Supervision.

[3] MiFID: Markets in Financial Institute Directive provides harmonized regulation for investment services.

nology, headcount, or strategy was more than 7% of their total operating costs. Based on these findings, the study concluded that compliance is costing the industry more than three billion USD a year. (Mirsky, Baker, & Baker, 2013). In view of the increasing number of regulations and regulatory changes, including those triggered by unexpected political events such as Brexit[4] (Busch & Matthes, 2016), the costs are further rising.

In the face of these challenges, research has sought to reduce the burden of compliance by investigating the employee's attitude towards compliance policies (e.g., Herath & Rao, 2009; Yazdanmehr & Wang, 2016), compliance management practices and reference models (e.g., Abdullah, Indulska, & Sadiq, 2016; Timm, Zasada, & Thiede, 2016), formal methods to represent and verify compliance rules (e.g., Knuplesch, Kumar, Reichert, & Kumar, 2015; Zasada & Fellmann, 2015), the role of information technologies in supporting compliance (e.g., Racz, Seufert, & Weippl, 2010; Zasada & Bui, 2018), as well as the economic viability of compliance activities (e.g., Kuehnel & Zasada, 2018; Schultz, 2013). The focus of this doctoral thesis is on the formal methods used to ensure compliance in business processes and, building on this, to develop design principles according to which existing methods can be improved.

1.2 Problem Description

Research in the area of business process compliance (BPC) is geared towards the formal representation of legal requirements. Driven by this purpose, its main tasks are to develop rule-oriented process languages and mappings to formal languages to automate compliance checking (Cleven & Winter, 2009). Since BPC is a cross-cutting topic, with links to compliance, human sciences, and business process management (BPM), possible research directions are correspondingly broad, and by no means limited to modeling compliance rules and model checking (Abdullah, Sadiq, & Indulska, 2010). Recent research has also reflected on the regulatory needs of emerging technologies in the context of big data (Antoniou et al., 2018), artificial intelligence (Arora, Sabetzadeh, Briand, & Zimmer, 2015), blockchain (Mendling, Decker, Reijers, Hull, & Weber, 2018), and how the new technical capabilities could help automate certain tasks further. One research goal in this regard is the automatic extraction of requirements and process models (van der Aa, Di Ciccio, Leopold, & Reijers, 2019), but as these techniques are in their infancy, compliance modeling is still a mainly manual task. In order to reduce the effort of compliance modeling, many researchers have engaged in the formal representation and automated verification of compliance rules.

The main problem in this research area is that regulations contain instructions that do not correspond to the structures that we naturally associate with process logic (e.g., the order of activities), but serve as normative judgments of a situation with various implications for a process.[5] Hence, every

[4] Brexit (a portmanteau of "British" and "exit") refers to the planned withdrawal of Britain from the European Union (EU).

[5] Consider the following example: "In setting common basic standards on aviation security, the size of the aircraft, the nature of the operation and/or the frequency of operations at airports should be taken into account with a view to permitting the grant of derogations" (EUR-Lex, 2008).

piece of information has to be interpreted in the context of the organization's business processes. Against a technical background, this poses two main challenges. First, after deciding which regulations apply, the requirements need to be modeled and mapped to a process in such a way that the rules can be interpreted by a BPM system (Harmon, 2010). This suggests a need not only for an availability of formal methods for modeling the properties of legal requirements, but also strategies for handling exceptions, violations, or compensations (Hashmi et al., 2018). Second, after the rules have been modeled, the process has to be checked for conformance (Rozinat & van der Aalst, 2005). That is, every process execution must be verified against former specifications. In the current work we focus on compliance modeling, answering questions related to the formal methods used in BPC to represent legal requirements.

As such, compliance languages play an important role in deriving suitable representations of relevant concepts. A common way of thinking is that the greater the number of concepts represented, the more expressive and useful the language is (Hashmi & Governatori, 2017; Ly, Maggi, Montali, Rinderle-Ma, & van der Aalst, 2015). Unfortunately, this thinking pattern has led to rather complex representations in the BPC domain (Becker, Delfmann, Eggert, & Schwittay, 2012), although it has been shown that overly complex representations hamper the understandability of process models and increases the probability of modeling errors (Dikici, Turetken, & Demirors, 2018; Petrusel, Mendling, & Reijers, 2017). Despite these findings, BPC research has so far only tried to describe the computational complexity of compliance checking algorithms (Knuplesch & Reichert, 2017; Tosatto, Governatori, & van Beest, 2019). The computational complexity of an algorithm is calculated based on the polynomial time it takes to execute the algorithm with respect to the elementary actions that are performed (e.g., properties being checked against a process model). Hence, computational complexity cannot be deployed to evaluate the complexity of the actual representation. Metrics, on the other hand, have proven to be a reliable method for measuring the complexity of a model (Cardoso, Mendling, Neumann, & Reijers, 2006). These methods, however, were first developed for software programs before being transferred to process models and adapted to capture more specific process features. In light of the legal details BPC deals with, existing methods cannot be applied to compliance rules without losing essential information. To close this gap, the first concern of this thesis is to determine the complexity of compliance rules for different compliance languages.

Given the high level of complexity of compliance representation, it is surprising that hardly any users of compliance languages have been involved during language development. In fact, only a few works have truly focused on user evaluations. These have explored the understandability of individual languages (Knuplesch & Reichert, 2017) and language-specific modeling problems, such as hidden dependencies (De Smedt, De Weerdt, Serral, & Vanthienen, 2016) or semantic differences between graphical elements of declarative models (Haisjackl & Zugal, 2014). More common than studies into understandability are conceptual evaluations of patterns (Elgammal, Turetken, van den Heuvel, & Papazoglou, 2016), process dimensions (Ly et al., 2015), and normative requirements (Hashmi &

Governatori, 2017) involved in compliance modeling. The primary goal of these evaluations has been to demonstrate the languages' semantic expressiveness. While concentrating on expressiveness, however, many compliance language studies have failed to conduct an appropriate evaluation from the user perspective, which poses a great challenge for assessing the languages' actual user-friendliness and efficiency. Another problem is that conducted user studies have focused on individual languages, so that the results cannot be compared or fit together in a broader theoretical context. In the few cases theories have been deployed to evaluate rule-based languages, these theories have been used to explain specific phenomena (e.g., related to declarative modeling techniques) that are unsuited for the comparison of languages with a different logic. Based on these considerations, the second concern investigated in this thesis is the cognitive understandability of compliance languages.

1.3 Structure of this Thesis

In the first part of this doctoral thesis (Part A), we present our findings in the larger research context and summarize the study's contribution. In the second part, we present the essays on which our findings are based (Part B). Part A is further structured to discuss the thematic and theoretical background (Section 2), research approach (Section 3), and conclusions (Section 4). Section 2 outlines the motivations for the research questions and provides detailed insights into the state of the art of the higher-level research area. More specifically, it delineates the two research subjects, complexity and understandability in the context of process modeling and cognitive psychology, for which we also discuss the design of selected compliance languages. Section 3 provides information on the methodical procedure used, which, after detailing the dominant research methodology, we divide into discussions on the design requirements (design science research) and the approach for evaluating compliance languages (empirical research). This section also provides an outlook on the obtained results. The main findings are discussed in Section 4. The focus is on the aggregation of results, which we use for the development of design principles. Design principles are developed to codify and formalize design knowledge so that best practices can be communicated and used to solve design problems (Fu, Yang, & Wood, 2016). An outline of future research perspectives completes this section. Part B presents the four essays that underpin our findings related to the complexity and understandability of compliance languages.

2 Thematic and Theoretical Background

This chapter provides an overview of the thematic and theoretical background to this thesis. Throughout the next two sections we describe the problem of compliance modeling by means of the complexity (Section 2.1) and understandability (Section 2.2) of compliance rules. In the last section, we provide an overview of the languages that are typically used to model compliance rules (Section 2.3).

2.1 Model Complexity

Complexity represents a significant challenge in both process and compliance modeling. However, only process modeling has developed successful strategies to evaluate the complexity of process models (Sánchez González, García Rubio, Ruiz González, & Piattini Velthuis, 2010). In the vast literature that has dealt with the quality assessment of process models, complexity is the third most reflected key area, after understandability and maintainability (Moreno-Montes De Oca, Snoeck, Reijers, & Rodríguez-Morffi, 2015). These three areas have not been researched in isolation, but rather in relation to each other. The goal is to establish best practices of process modeling and, in the case of complexity, to describe suitable coordination mechanisms to reduce the complexity of process models (Becker, Rosemann, & von Uthmann, 2000). The different use of the term in different domains, however, makes it important to understand what complexity means for the modeling of processes.

Coming from a pragmatic-philosophical direction, Edmonds (1999, p. 6) provided a suitable working definition, describing complexity simply as “That property of a language expression which makes it difficult to formulate its overall behavior, even when given almost complete information about its atomic components and their inter-relations.” Similarly, complexity has been interpreted by the process modeling community, which has considered not only the language expression as the product of modeling, but also the language itself (Hasic, De Smedt, & Vanthienen, 2017; Recker, zur Muehlen, Siau, Erickson, & Indulska, 2009). The first interpretation refers to the number of language constructs used in a model (known as practical complexity), whereas the second interpretation refers to the number of constructs specified by a whole language (known as theoretical complexity) (Erickson & Siau, 2007). In this thesis, we focus on the practical complexity of compliance languages. Specifically, as suggested by our definitions, we want to find out how many different elements of a language are used in a model. In this context, models are often referenced as conceptual models to avoid confusion with the model understanding of other schools of thought (Wand & Weber, 2002). Thus, models here consist of set of prepositions or statements expressing relationships among constructs, that in turn form the vocabulary of the domain (March & Smith, 1995).

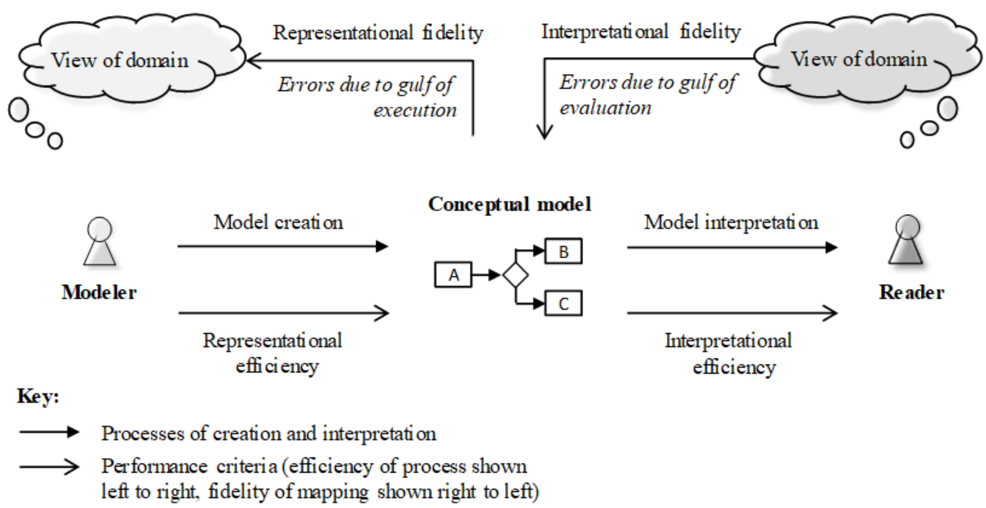

Fig. 1. Framework of conceptual modeling (adapted from Burton-Jones et al., 2009)

Fig. 1 describes the basis on which conceptual models are evaluated. The framework is based on the evaluation criteria for conceptual modeling grammars proposed by Burton-Jones, Wand, and Weber (2009). More specifically, it describes the processes involved in the creation and interpretation of conceptual models, which, in our interpretation, includes not only process models, but also models of compliance requirements. The processes are evaluated by means of effectiveness and efficiency (Burton-Jones et al., 2009). Effectiveness is assessed by the fidelity of a model, i.e., how faithfully the model represents someone's perception of the semantics of the domain. Efficiency is assessed by the cognitive resources users expend to create or interpret a model. Limitations regarding the representation or interpretation of a model can cause what Norman (1986) called the gulf of execution (i.e., the difference between the semantics assumed by the modeler and the semantics represented in the model), and the gulf of evaluation (i.e., the difference between the semantics represented in the model and the semantics interpreted by the reader), respectively. Both are negatively related to the model's fidelity. Complexity becomes, in this context, a key figure because it can affect both effectiveness and efficiency (Gemino & Wand, 2004; Wand & Weber, 2002)

In this regard, compliance modeling and process modeling share the same concerns. However, unlike process modeling, compliance modeling offers less guidance regarding the way a model can be formulated, essentially because there are no modeling rules or guidelines comparable to those that exist for process modeling languages (Becker et al., 2000; Mendling, Reijers, & van der Aalst, 2010). This also shows in the number of language constructs and the construct complexity (Teo, Chan, & Wei, 2006). For example, some compliance languages deploy significantly fewer modeling elements than others because the languages have their own concepts for a specific rule type. Other compliance languages may require more modeling elements, depending on how the languages link and aggregate compliance constructs. In terms of the model complexity, this could lead to major differences (Hashmi & Governatori, 2017). Hence, with our first research question (RQ) we aim to gain some clarity about the model complexity of compliance languages:

RQ1. How can we measure the model complexity of compliance languages?

In answering this question, we continue the research on process model complexity, which extends to different aspects of a process model. For example, Dijkman, Dumas, van Dongen, Käärik, and Mendling (2011) defined three metrics to investigate the similarity of process models based on matching activity labels, label distance, and causal relationships through which complex models can be identified. La Rosa, ter Hofstede, Wohed, Reijers, Mendling, and van der Aalst (2011) developed a solution to manage process complexity via syntax modifications. The identified patterns generalize and conceptualize modeling principles to change the visual representation of a process model. Gruhn and Laue (2006) compared common software metrics and assessed the significance of these for BPM, including a metric for measuring cognitive complexity. The metric introduces cognitive weights, which measure the relative time and effort required for understanding basic control structures (Shao &

Wang, 2003). Finally, Cardoso (2008) proposed a metric to analyze the control flow structure of a process based on a graph-theoretical complexity measure (McCabe, 1976).

According to the presented literature, a common approach to assess model complexity is to match the structures of a process model to those of the metric. The complexity is then calculated from the sum of the structures contained in the model. However, this approach implicitly assumes that the model under investigation is complete and correctly modeled. If this is not the case, the level of complexity cannot be interpreted in a meaningful way, since a low complexity is only positively associated with properly specified models. In order to support a clear interpretation of the complexity level, our aim is not only to determine how complex a model is, but also to evaluate whether relevant concepts can be expressed.

2.2 Model Comprehension

When investigating the complexity of process models, it becomes apparent that complexity is not only a formal topic that describes the parts of an abstract system, but also a topic in which human users are involved; or, as Edmonds (1999, p. 3) put it, “The complexity of an object is only revealed through interaction with the complexity of another system (typically us)”. However, in order to interact with the other system, users must first learn the language of representation. Ideally, to simplify the learning and adoption process, the language design must follow a clear, systematic concept that is easy for its regular users to understand (Corradini et al., 2018). In process modeling, understandability is one of the most recognized quality characteristics of conceptual models. It is associated with the degree to which information contained in a process model can be easily understood in the context of creating and interpreting a model (Reijers & Mendling, 2011).

In this thesis, we investigate the understandability of two languages in particular, namely Compliance Request Language (CRL) and Formal Contract Language (FCL). CRL is a pattern-based language that relies on textual expressions which are then translated into temporal logic, a verification technique for temporal statements which relies on the time dependence of events (Pnueli, 1977). FCL evaluates logical statements based on deontic logic (from the Greek *deon*, meaning duty). Deontic logic is a formal system that attempts to capture the essential features of normative concepts, such as obligation, permission, and prohibition (Carmo & Jones, 2002).

The rules of FCL are also formulated as textual expressions, but, unlike CRL, users have to interact directly with the deontic notions, which, even when they have a similar level of abstraction as patterns, can have a completely different semantic meaning (Governatori & Hashmi, 2015). Due to the differences between deontic and temporal logic, we are particularly interested in finding out which of the two languages is better understood by users, and thus potentially more useful to create faithful compliance models. Consequently, in our second research question we investigate the understandability of compliance languages that result from the use of different logics:

RQ2. How can we improve the understandability of compliance languages?

In answering this question, we expand the research on process model comprehension towards compliance languages. To the best of our knowledge, the only approaches dealing with the understandability of rule-based languages have addressed the understandability of Declare, a declarative modeling language for specifying process constraints (e.g., De Smedt et al., 2016; Weber, Reijers, Zugal, & Wild, 2009). The problem with many of these works is that their hypotheses have not been derived theoretically, so that empirically obtained results are based on operationalization rather than theory. Approaches that apply a theory have focused on specific aspects of declarative modeling and therefore utilized theories, such as the theory of mindshift learning (Haisjackl & Zugal, 2014) or mental operations theory (Fahland et al., 2009), which explain specific phenomena of conceptual modeling. However, to facilitate the evaluation of conceptual different languages, we need to investigate the high-level processes of cognitive modeling (Schmid, Ragni, Gonzalez, & Funke, 2011) and eliminate mismatches that can increase the task complexity (Liu & Li, 2012).

To this end, we utilize the theory of cognitive fit proposed by Vessey (1991). The theory suggests that to solve a problem an individual creates a mental representation of the problem and the problem-solving task. Consequently, a mismatch between the representation of problem and task prevents the individual from using similar cognitive processes to solve the problem efficiently. If, on the other hand, the problem representation is chosen so that it fits the structure of the problem, the same cognitive processes can be used, which improves the problem-solving performance (Vessey, 1994). With regard to the modeling of compliance rules, legal requirements represent the problem-solving task, while the compliance language determines the format of the problem representation. The choice of modeling language thus has a great effect on how efficiently the task can be solved.

Fig. 2 shows an extension of the model of cognitive fit proposed by Kelton, Pennington, and Tuttle (2010). The model illustrates the cognitive processes during execution of a problem-solving task. In contrast to the original model developed by Vessey (1991), the extended model divides the problem representation into internal representation of the problem domain, and external problem representation. The internal representation refers to the individual's prior task knowledge (e.g., modeling experience), whereas the external representation reflects the presentation of information (e.g., as a conceptual model). Consequently, the mental representation is formed not only from the factual problem representation, but from the interaction between the individual's knowledge about the task and the information presentation format. Therefore, in our study, we also control for personal factors that are likely to change the problem-solving performance.

In addition, Kelton et al. (2010) noted that problem-solving performance can change due to repeated use of the modeling tool or given feedback. In Fig. 2, we made these processes more identifiable by using different arrow types for processes that are primarily used for problem-solving and for processes that summarize potential learning effects. In our research we do not give feedback, nor do we let participants practice the languages, in order to show that compliance rules can be understood even by novice users who do not have special process modeling skills.

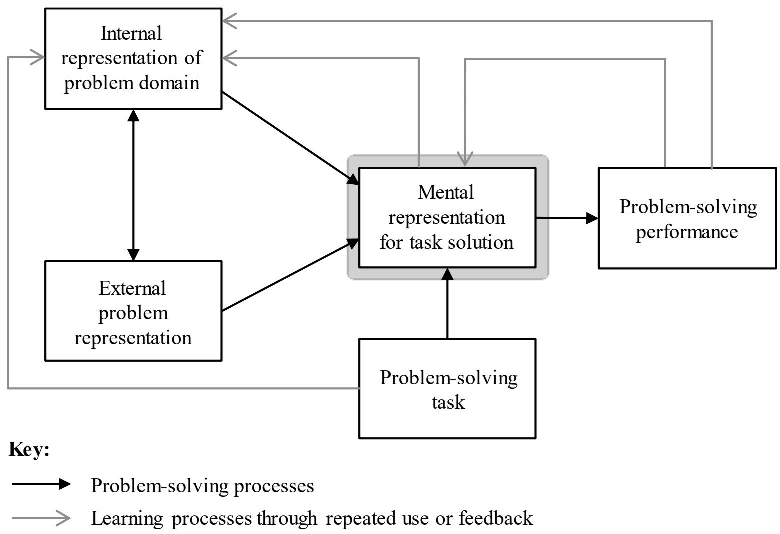

Fig. 2. Extended model of cognitive fit (adapted from Kelton et al., 2010)

2.3 Compliance Languages

Embedded in techniques for process modeling and analysis, BPC aims to design, analyze, and monitor compliance rules (Knuplesch, Reichert, & Kumar, 2017). Existing approaches in this field of research have allowed for compliance checking from various perspectives (control flow, resources, etc.), using a graphical or textual representation to formally express compliance rules for model checking (Sackmann, Kuehnel, & Seyffarth, 2018). That is, in contrast to process modeling languages, which can fulfill their purpose by just describing a process, compliance languages do not exist without a representation in a formal language to enable model checks. Since these languages usually have a much higher level of abstraction, most approaches offer modeling constructs that hide the complexity of the expressions written in the formal language (Knuplesch & Reichert, 2017).

Table 1 shows the languages we selected to investigate the model complexity of compliance languages (Essay B.1 and B.2). The sample includes an excerpt of the languages, which we identified during a systematic literature review (see Essay B.2). To be included, they had to be explicitly described as compliance languages and fulfill several other criteria, such as the existence of a metamodel or grammar, and a verification technique for compliance checking. Pure methodological work and transformation scenarios of existing languages, where compliance rules are predominantly hard-coded into the compliance-checking tool, were excluded.

To investigate the understandability of compliance languages (Essay B.3 and B.4), we limited the scope to CRL and FCL in order to analyze the languages in depth and have better control over the validity of our experiments. As outlined above, the choice of these two languages was predominantly motivated by the different logic used to formulate compliance rules. Furthermore, our previous analysis of the complexity (see Essay B.2) revealed that both languages have a relatively low model complexity, which makes them interesting for further analysis. Besides, compared to Declare and extended Compliance Rule Graph (eCRG), which have already been empirically evaluated, empirical insights into the understandability of both CRL and FCL are still missing.

Table 1. Selected compliance languages

Reference	Language	Modeling concept	Formalism
(Awad et al., 2011)	BPMN-Q	Structural querying	Computational tree logic
(Elgammal et al., 2016)	CRL	Compliance patterns	Linear temporal logic and metric temporal logic
(Pesic, 2008)	Declare	Declarative modeling	Linear temporal logic
(Delfmann et al., 2015)	DMQL	Structural querying	Graph theory
(Knuplesch & Reichert, 2017)	eCRG	Compliance rule graphs	First-order logic
(Hashmi et al., 2016; Governatori et al., 2006*)	PCL (FCL*)	Deontic modalities	Deontic and defeasible logic
(Goedertier & Vanthienen, 2006)	PENELOPE	Declarative modeling	Event calculus (extended by deontic logic expressions)

*FCL and PCL share the same semantics.

Finally, PENELOPE was excluded from the evaluation because, one the one hand, it is less expressive compared to CRL and FCL, and, on the other, it is based on the same logic as PCL. Thus, findings regarding PCL will be transferable to PENELOPE. The same applies to BPMN-Q, which describes a subset of CRL patterns in a different temporal logic. DMQL on the other hand, is based on graph theory, which is not representable with temporal logics and implies another level of semantic (and possibly cognitive) complexity that would go beyond the scope of our investigation.

3 Research Approach

This chapter forms the logical connection between the research context outlined in the previous chapter and the essays that provide answers to our research questions. In the first section, we explain the connection to design science research and highlight relevant constructs (Section 3.1). Thereafter, we discuss the overall approach to the language evaluation (Section 3.2), as well as the essays' combined contribution (Section 3.3).

3.1 Design Requirements

According to Walls, Widemeyer, and El Sawy (1992, p. 36), design theory is a "prescriptive theory which integrates normative and descriptive theories into design paths intended to produce more effective information systems." Design theory can be about both the principles underlying the form of design of an artifact and the act of implementation (Gregor & Jones, 2007). The principal idea of design theory is to understand and structure the design process of an artifact in order to reproduce artifacts of the same type. The first artifact types discussed in design science were constructs, models, methods, and implementations (March & Smith, 1995; Purao, 2002). Over the course of time artifacts became increasingly diverse, so that new typologies were devised, in which modeling languages emerged as a separate category (Offermann, Blom, Schönherr, & Bub, 2010).

In this thesis, we adopt a design science approach to summarize our conclusions for the design of compliance languages. As users of compliance languages we focus on process modelers and analysts, who usually have a profound knowledge of process modeling and formal verification techniques. However, as the high expenses for compliance suggest (Mirsky et al., 2013), it becomes increasingly important to empower more employees to be able to understand compliance rules so that they can assess and communicate the implications for their work and be more vigilant towards compliance violations. Our goal is therefore to improve the use of compliance languages for both user groups. As we have shown in the previous sections, compliance languages could help to achieve this goal if they fulfill certain design requirements.

In design science, design requirements are used to describe generic requirements that any artifact instantiated from the initial design should satisfy (Meth, Mueller, & Maedche, 2015). A design requirement is formulated as a brief statement about the desired properties of the artifact, and often responds to a concern or issue that needs to be addressed. In the following we postulate two requirements, which reflect the two main concerns of this thesis (see Section 1.2). The first design requirement refers to the complexity of compliance representations. As argued above, less complex models are more likely to be understood and are less prone to errors, which is why it is important to prevent models from getting too complex (Petrusel et al., 2017). To avoid the risks associated with complex models, modeling languages should provide suitable coordination mechanisms to reduce the model complexity (see Section 2.1). Hence, our first design requirement (DR) calls for such coordination mechanisms that reduce the complexity of compliance rules:

DR1. Compliance languages should reduce the complexity of compliance rules.

The second design requirement addresses the understandability of compliance representations. As shown above, the problem-solving performance indicates how well a user is able to understand compliance representations (see Section 2.2). In the context of process modeling, problem-solving performance is associated with the correctness of a model (Thalheim, 2012). This means that the fewer errors that are made throughout the modeling process, the better suited the modeling language is to creating a faithful representation of the application domain (Burton-Jones et al., 2009). According to the theory of cognitive fit, performance differences are particularly likely to occur when the concept used to represent the problem does not match the task (Vessey, 1994). Therefore, the purpose of the second design requirement is to identify concepts that improve the understandability of compliance rules:

DR2. Compliance languages should improve the understandability of compliance rules.

Based on these two design requirements, we develop six design principles that embody the actions that should be taken to address the issues identified by the design requirement. To develop the design principles we follow the recommendations of Fu et al. (2016). The authors propose two competing ways of formulating design principles, i.e., prescriptive versus descriptive. Prescriptive design principles are action-centered, focused on making requests, and giving directions or instructions on how to successfully implement design. In contrast, descriptive design principles explain the nature of a problem, for example, to describe the current state of the field or a foundational theory behind an area of application. Since our research aims to improve the design of a language as a typical design science artifact, we apply the prescriptive approach to formulate design principles. Each of our design principles includes a prescriptive action for a designer to take in a particular context (i.e., representing compliance rules), as well as a consequence as result of its application.

3.2 Evaluation Procedure

Our research incorporates two evaluation methods. First, we use a heuristic approach in which the rule complexity is calculated from the formal representation of a requirement in the respective language using Halstead's (1977) complexity metrics (Essay B.1). The metrics describe a set of mathematical functions that calculate the effort used to read or write a formal statement based on the vocabulary and length of the expression. In the course of our investigation, we extend our evaluation scope by applying an existing classification framework to show how complex a model is and whether relevant concepts can be expressed (Essay B.2). The framework distinguishes the normative meanings of legal requirements (Hashmi et al., 2016). By mapping the modeling constructs of a language to the classes of the framework, we are using the framework to describe how expressive a language is in terms of the representable legal concepts. Note that the framework does not assess the importance of individual concepts, as expressiveness only measures whether a language can capture the possible meanings of a requirement (Hashmi & Governatori, 2017).

Second, we use an empirical approach to evaluate the understandability of CRL and FCL. To this end, we develop two controlled experiments. A controlled experiment is usually designed as a single-factor experiment, which means that all factors are held constant expect for one (Basten & Sunyaev, 2014). The single factor (i.e., modeling language) can be composed of other variables, but, in contrast to multi-factor experiments, it is not possible to decode and isolate the relative contribution of these factors (i.e., modeling constructs) through statistical analysis (Basili & Weiss, 1984). The single-factor design is implemented via treatment and control comparisons (Essay B.3) if the main focus is only on one investigation subject, or via repeated measurement (Essay B.4) if more than one variation of the investigation subject exists (Weber, Mutschler, & Reichert, 2010).

In the first experiment, we conduct a modeling task in which we compare patterns with text notes. In the second experiment, we compare CRL with FCL and a variation of FCL, first using comprehension questions and then by means of a modeling task. The variation of FCL is used to adopt the same level of abstraction as CRL. In both experiments, we measure the understandability of a language (independent variable) by assessing the performance, in terms of the modeling errors, and the modeling time, in terms of the time taken to complete the modeling task (dependent variables). Finally, we ensure the validity of our experiments by checking the effect of cognitive reflection, modeling difficulty (respectively emotional response), cognitive load, and modeling experience.

Table 2. Evaluation criteria

Essay	Language	Evaluation subject	Study context	Method	Sample	Measures	Variable
B.1	CRL Declare PCL	Complexity	Process model complexity	Formal analysis	Airport security procedures	Complexity metrics Information flow metric Control flow metric	Modeling construct
B.2	BPMN-Q CRL Declare DMQL eCRG PCL PENELOPE	Expressiveness Complexity	Process model complexity	Formal analysis	Securities purchase process	Normative concepts Process dimensions Complexity metrics	Modeling construct
B.3	CRL	Modeling performance Modeling time	Process model comprehension	Experiment	Post- and under-graduate students	Cognitive reflection Modeling difficulty Cognitive load Modeling experience	Control
B.4	CRL PCL (FCL*)	Modeling performance Modeling time Model comprehension	Process model comprehension	Experiment	Post- and under-graduate students	Cognitive reflection Emotional response Cognitive load Modeling experience	Control

Acronyms: Business Process Model and Notation Query Language (BPMN-Q), Compliance Request Language (CRL), Diagramed Model Query Language (DMQL), extended Compliance Rule Graph (eCRG), Formal Contract Logic (FCL), Process Compliance Language (PCL), Process Entailment from the Elicitation of Obligations and Permissions (PENELOPE). *FCL is the base language of PCL.

Table 2 specifies the evaluation criteria for our research. The "Essay" column refers to the four research essays presented in Part B of this doctoral thesis. The table was inspired by Mendling, Recker, Reijers, and Leopold (2018), who classified comprehension experiments in the process modeling domain according to the study context, measures, variables, and sample population. In addition, Table 2 captures the investigated modeling language, the evaluation subject, and, as our investigation focuses on more than one method, the applied research method.

3.3 Overview of the Essays

This thesis investigates two fundamental questions related to the design of compliance languages. To answer these questions we evaluate the languages from two perspectives. First, we investigate the complexity of compliance rules in terms of the modeling language used. Second, we investigate the understandability of the language. Due to the variant nature of these research problems, we choose a qualitative-interpretative approach for the first two essays, where the results are formally derived, and a quantitative-empirical approach for the other two essays, where the results are obtained experimentally. Table 3 provides on overview of the research essays and their contribution to the literature.

The first essay, B.1, identifies relevant metrics for computing the complexity of software programs, and provides the definitions that are required to apply these metrics to compliance rules. The challenge is that, unlike process models, compliance rules represent only fractions of the entire model and focus on very specific details. Software metrics, on the other hand, mostly investigate structures in larger contexts. In the essay, we compare the most commonly used software metrics that have already found applications in process modeling, and identify structures that can be transferred to compliance rules. These included Halstead's (1977) complexity metrics, Henry and Kafura's (1981) information flow metric, as well as Cardoso's (2008) control flow metric. Based on the compliance details that the metrics are able to represent, we decided to base our evaluation on Halstead's (1977) complexity metrics.

The study described in the second essay, B.2, compares and evaluates compliance languages regarding their semantic expressiveness and lexical complexity. Due to the fairly heterogeneous pool of compliance languages (see Table 1) we chose to organize our approach into three phases. In phase 1, we reviewed the literature and classified the identified languages according to their modeling concept and formalism. In phase 2, we modeled a sample of compliance requirements with selected languages. In phase 3, we evaluated the formally specified rules in regard to their expressiveness and complexity. To implement phase 3, we applied Halstead's (1977) metrics and continued the definitions developed in Essay B.1. Moreover, we extended the evaluation scope by introducing a measure for expressiveness based on representable normative concepts. Thereby, we were able to evaluate the model complexity of compliance languages in relation to their expressive power.

Table 3. Overview of the essays

Essay	Title (Author)	Research subject and findings
B.1	How Complex Does Compliance Get? (Andrea Zasada)	• Overview and discussion of metrics used in software engineering to compute the complexity of programs • Mapping between metrics and compliance details • Demonstrated applicability of complexity metrics for measuring the complexity of compliance rules
B.2	Evaluation of Compliance Rule Languages for Modeling Regulatory Compliance Requirements (Andrea Zasada, Mustafa Hashmi, Michael Fellmann, David Knuplesch)	• Classification of compliance languages regarding modeling concept and formalism • Detailed analysis of compliance modeling languages regarding: – Expressiveness measured by representable normative concepts – Model complexity measured by Halstead's (1977) complexity metrics • Determined relationship between semantic expressiveness and rule complexity for common compliance languages
B.3	Finding a Match: Modeling Compliance Rules with Compliance Patterns (Andrea Zasada, Michael Leyer, Michael Fellmann)	• Meta-model of pattern-based compliance languages • Transfer of the theory of cognitive fit to explain the performance of compliance patterns • Empirical evidence that predefined patterns (compared to taking text notes) positively influence modeling performance
B.4	Compliance Meets Performance: Understanding the Differences between Compliance Representations (Andrea Zasada, Michael Leyer, Guido Governatori)	• Differentiation of compliance patterns and deontic modalities • Transfer of the theory of cognitive fit to explain performance differences between compliance representations • Empirical evidence that less formal linguistic expressions of deontic modalities influence performance and comprehension positively (compared to compliance patterns)

The third essay, B.3, shifts the focus of investigation from the objective complexity of formal representations to its subjective understanding. To this end, we studied the mental processes involved in the human problem-solving process as embodied in the model of cognitive fit (Vessey, 1991). After choosing a suitable model (see Fig. 2) and transferring it to the new application context, we derived hypotheses, which we verified experimentally. One of our hypotheses was that pattern-based languages are, in general, more understandable. We checked the hypothesis by comparing the performance of users in a modeling task stipulating the use of either compliance patterns or taking text notes to solve the task. The results indicate that predefined patterns positively influence the modeling performance, compared to taking text notes.

The final essay, B.4 is concerned with the understandability of different compliance representations. Accordingly, we expanded our comparison to another text-based language using the insights from Essay B.2. In Essay B.2, we found that the model of deontic modalities was less complex compared to the model of compliance patterns. Hence, in the last essay we compared compliance patterns with deontic modalities with the goal of finding out whether users' performance or comprehension of the language changes for either approach. In the case of more abstract deontic modalities, we considered not only formal expressions, but also linguistic expressions that focus on the semantics of the modalities. The results suggest that, although compliance patterns are more comprehensible in direct comparison with deontic modalities, less formal linguistic expressions are superior in both modeling performance and model comprehension.

4 Conclusions

This chapter highlights the findings of this thesis. It includes a summary and discussion of results (Section 4.1), an outline of the implications for science and practice (Section 4.2), and, to conclude, a summary of the limitations of this work, as well as an outlook on future research (Section 4.3).

4.1 Summary and Discussion of Results

Compliance modeling studies the formal methods used to represent legal requirements. Some research approaches in this area have stressed the versatility of temporal logics for transforming process rules into compliance patterns (Awad et al., 2011; Elgammal et al., 2016), whilst others have argued that temporal logics are, in general, unsuited to capturing legal notions (Governatori & Hashmi, 2015). However, recent evaluations have shown that, surprisingly, many concepts can be mapped to legal notions and form a suitable representation of the requirement's meanings (Hashmi & Governatori, 2017; Knuplesch et al., 2017). The concepts used by the different languages to represent a requirement form regular expressions that have become increasingly complex. Remarkably, compliance languages have only been evaluated to date in terms of their expressiveness, without considering the effect of design decisions on their complexity (Becker et al., 2012). Moreover, most compliance languages have not been presented to potential user groups, though this is necessary in order to assess how users cope with the design of the language, and whether modeling problems can be efficiently solved.

With this doctoral thesis, we contribute to overcoming these limitations and fill a gap in research concerning evaluation of the complexity and understandability of compliance languages. Despite the diversity of the two research subjects, we have built a consistent chain of argumentation and shown the applicability of models and frameworks from cognitive psychology and information systems research to the evaluation of compliance languages. In the following, we summarize the key findings of our investigation from the point of view of the research questions. The first research question was concerned with the complexity of compliance representations:

RQ1. How can we measure the model complexity of compliance languages?

In answering this question, the goal was to determine the complexity of compliance languages in relation to their semantic expressiveness. A high level of expressiveness is associated with languages that can express any kind and number of concepts within the application domain (Hommes & van Reijswould, 2000). Fig. 3 illustrates the trade-off between the complexity and expressiveness of compliance languages. Each language is marked as a different type of circle (to represent graph, pattern, query, or logic) depicting the same classes of languages we introduced in Table 2 of Essay B.2.

The way the information in Fig. 3 is presented was inspired by the work of Becker et al. (2012), who classified model-based compliance-checking approaches in terms of the capability to generalize from the modeling technique and represent compliance rules of varying complexity. They use the notion of complexity to divide approaches into supported process dimensions. By contrast, in our evaluation the classification into process dimensions serves only the selection of requirements. For the actual evaluation we used a heuristic approach, in which the rule complexity was calculated from the formal representation of a requirement in the respective language using Halstead's (1977) complexity metrics. In the context of these metrics, complexity is interpreted as the effort it takes to read or write a model in a specific language. The definitions used to apply the metrics to compliance rules were outlined in Essay B.1.

In Fig. 3, we summarize our findings based on the evaluation results reported in Tables 17 and 18 of Essay B.2. The horizontal axis of the diagram is divided into three complexity intervals ranging from low (< 30), through medium (< 90), to high (> 90). The size of the intervals is roughly determined from the average complexity of the compliance rules. The vertical axis of the diagram is divided into categories that refer to the representable normative concepts presented in Essay B.2. In order to gain a better overview, we split the concepts into three categories (i.e., some, basic, all). The category "some" is used for languages that can model achievement obligations and at least one of the other normative concepts. The category "basic" indicates that languages can distinguish between preemptive and non-preemptive achievement obligations, and various other normative concepts. Finally, the category "all" refers to languages that can represent all normative concepts.

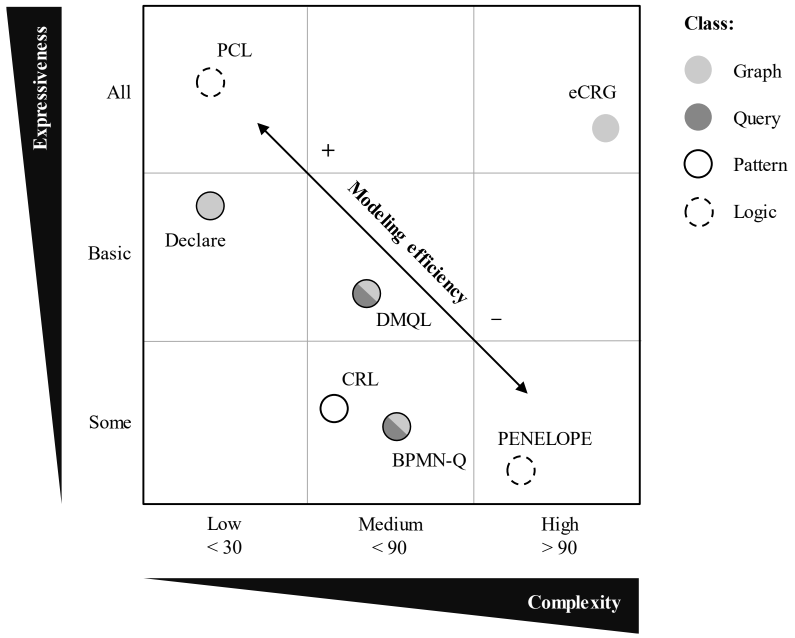

Fig. 3. Classification of compliance languages

To illustrate how complexity correlates with the expressiveness of a language, we adopted an idea posited by Paas, Tuovinen, Tabbers, and Van Gerven (2003). The authors showed how the combined effect of two factors gives directions for the increase or decrease of another factor. Following their example, we define the modeling efficiency as the combined effect of complexity and expressiveness. In Fig. 3, the modeling efficiency is displayed as a diagonal which indicates that the lower the complexity and the higher the expressiveness, the higher (+) the modeling efficiency, and vice versa. That is, the higher the complexity and the lower the expressiveness, the lower (–) the modeling efficiency.

In the comparison, PCL achieves the highest modeling efficiency, whereas PENELOPE achieves the lowest. Since both are based on deontic logic, the result cannot be linked to the language class. Rather, it becomes clear that the complexity depends on the formalism used to represent the information. As we reported in Table 1, PENELOPE uses event calculus, which belongs to the same family of logics as first-order logic, which in turn is the base language of eCRG. It is hence not surprising that both languages are extremely complex. However, in contrast to the text-based expressions of PENELOPE, the graphic elements of eCRG are a lot more expressive. Equally expressive as eCRG but much less complex is PCL, since it is specifically designed to express the properties of normative requirements. The current version, however, does not provide modeling support for defining exceptions from a rule. In addition, PCL does not specify all combinations of deontic modalities that are described by the framework, and are thus at least theoretically possible. Given the fact that some of these constructs are less common than others, it can be said that of all languages PCL is by far the most efficient.

Interestingly, all languages that utilize patterns (i.e., BPMN-Q, CRL, Declare, and DMQL) and operate on temporal logics have a low to medium complexity. It also seems as if query languages, such as BPMN-Q and DMQL, which use visual patterns, are slightly more complex compared to the textual patterns of CRL. This is because visual languages often require the repetition of modeling constructs in order to be able to model certain requirements. Their expressiveness, however, is not too different from that of CRL, since they basically rely on the same patterns as those developed by Dwyer, Avrunin, and Corbett (1999). Only Declare, which achieves the second highest efficiency, differs significantly from these languages, mainly because it uses another modeling technique. All imperative modeling techniques presented above take an “inside-out” approach, where every possible process execution must be modeled, whereas declarative techniques take an “outside-in” approach, where only the essential constraints of a process are specified (Reijers, Slaats, & Stahl, 2013). Therefore, our recommendation is to further explore the applicability of declarative modeling languages for compliance modeling. Beside the model complexity, another important aspect that influences the efficiency of a modeling language is the understandability of compliance languages, which we addressed with our second research question:

RQ2. How can we improve the understandability of compliance languages?

In investigating this research question, the goal was to discover which compliance languages influence the understandability of compliance rules positively. Or, more precisely, which information presentation format has a positive effect on compliance modeling. The focus of the investigation was on comparing two languages for representing compliance patterns and deontic modalities.[6] Their understandability was evaluated on the basis of selected modeling constructs. Although such selection is common practice to manage the total duration of experiments, the main reason why it can be better to include fewer modeling constructs than the modeling language defines is that users are usually not aware of all available modeling constructs. In fact, Muehlen, Recker, and Indulska (2007) were able to show that only 25% of the constructs of the core set of Business Process Model and Notation (BPMN) are actually deployed by users. This means that even though users handle a much smaller subset of modeling constructs, they are still able to derive a correct solution. Hence, by choosing the core constructs of our compliance languages we ensured that our study has high external validity.

Table 4 summarizes the results of the two experiments. In the first experiment, we tested whether users principally understand compliance patterns (Essay B.3). As a reference, we used the models that users created by making text notes of the same information that we presented to the user of compliance patterns. The results confirmed the hypothesis that compliance patterns lead to better modeling performance, but not the hypothesis that compliance patterns reduce the modeling time.

Thus, with this experiment, we were able to show the existence of a mechanism by which even inexperienced users can understand compliance rules. The mechanism is based on the theory that patterns provide a structure for the external problem representation that matches the modeling task, so that, through existing cognitive fit, the problem-solving performance improves. With this, we offer an

[6] Note that in the following we are talking about compliance patterns when we refer to the language constructs used by CRL, and deontic modalities when we refer to the language constructs used by FCL and PCL.

understanding of the cognitive processes behind compliance modeling, but also show how to improve compliance support through a modeling language. Although we would have expected that using an auxiliary tool such as patterns would reduce the modeling effort, the use of patterns did not affect the modeling time. One possible explanation for this phenomenon is that the cognitive load is neither low enough nor high enough to affect the cognitive capacity of the individual.

Table 4. Summary of results

Hypotheses	**Results**
Compliance patterns improve performance	
H1: Modeling performance is positively influenced by the use of compliance patterns.	Supported
H2: Modeling time is positively influenced by the use of compliance patterns.	Not supported
Linguistic expressions improve performance and comprehension	
H1: Modeling performance is positively influenced by the treatments.*	Supported for linguistic expressions
H2: Modeling time is positively influenced by the treatments.	Not supported
H3: Model comprehension is positively influenced by the treatments.	Supported for linguistic expressions Supported for compliance patterns versus deontic modalities

*Treatments comprise compliance patterns, deontic modalities, and linguistic expressions. A linguistic expression is a less formal expression of the deontic modality.

In the second experiment, we tested whether the use of compliance patterns or obligation modalities results in better modeling performance, modeling time, and model comprehension (Essay B.4). Since obligation modalities consist of more formal statements than compliance patterns, we evaluated deontic modalities by their formal expressions but also based on a less formal notation of deontic modalities, which we call linguistic expressions. The results provided supporting evidence for the hypotheses that modeling performance and model comprehension are both positively influenced by linguistic expressions. Moreover, we found that model comprehension is also positively influenced by compliance patterns. However, as in the first experiment, modeling time was not significantly different for any of the treatments.

Our first conclusion is that because each pattern expresses only one meaning (for example, the order or occurrence of activities), their meaning is more intuitive than is the meaning of deontic modalities. The problem with deontic modalities is that instead of expressing only one meaning at a time, each deontic expression consists of a combination of deontic modalities, whose initial letters are used in the formal notation. This semantic overlap makes the interpretation of each expression considerably more difficult. It forces users to apply additional cognitive resources to distinguish and memorize the different normative concepts before deciding which concepts to use. The less formal linguistic expressions of deontic modalities, on the other hand, express the same concepts in natural language, which, according to our findings, facilitates their understanding and application even in comparison to compliance patterns. Hence, our second conclusion is that normative concepts provide, in general, a better external problem representation because they reflect the meaning of legal requirements, which, as explained before, results in improved problem-solving performance.

Note that the reported findings apply primarily to CRL and FCL, and thus PCL. However, in some respects the results are also transferable to other pattern-based languages, as many languages, such as BPMN-Q and Declare, use patterns that express the same constraint. This applies, for example, to control flow rules (i.e., existence, response, and precedence) that are used to model simple order and occurrence relationships of activities. As for languages that deploy deontic modalities, such as PENELOPE, we can conclude that the positive effect of linguistic expressions, being easier to understand, also applies to the deontic properties of another language, but only if they have the same level of abstraction as linguistic expressions.

4.2 Implications for Science and Practice

In the course of this thesis, we applied a rigorous evaluation methodology to identify levers to reduce the complexity of compliance models and improve their understandability. Hence, on the one hand, with our research we have created the theoretical and methodical framework by which to evaluate compliance languages. On the other hand, as output of our language evaluation, our research provides essential information about the complexity and understandability of compliance languages. As we have shown in the previous sections, both can lead to errors in the execution and evaluation of business processes, which underlines the practical importance of compliance. By indicating the inefficiencies in the design of compliance languages, our research makes a significant contribution to ensuring compliance in business processes.

In particular, our research reveals issues with the design of current compliance languages that increase the complexity of compliance rules. Moreover, our research makes a useful contribution regarding the evaluation of other rule-based languages whose main purpose may not be compliance checking, but which are nevertheless suitable to model and verify compliance rules. The results of our formal analysis suggest, for example, that declarative modeling languages still have untapped compliance modeling capabilities. With respect to the normative meanings of compliance requirements, however, rule-based languages must use other strategies to maintain the balance between expressiveness and complexity. As many of them use the same modeling patterns, it is important that the use of patterns is motivated theoretically, and not just formally.

In this regard, by comparing CRL and FCL, we uncovered that normative concepts are better suited to represent legal requirements than are patterns. By providing not only the theoretical foundation for the evaluation of compliance languages but also empirical evidence for the usefulness of specific modeling concepts, we contribute to a number of interrelated fields of research, such as conceptual modeling, compliance modeling, and pattern specification. Besides, in contrast to other works that have evaluated only one language, or languages of the same type, we have presented detailed information of the representation and interpretation of compliance rules as conceptual models that allowed us to determine performance differences between two languages with a different modeling logic. Thus, our language evaluation has strategic implications for both science and practice in terms of which language should be deployed for compliance modeling tasks, and why. In addition, with our results, we provided the basis on which the design of current and future compliance languages can be improved to better fulfill compliance modeling tasks. Based on these results, we propose the following design principles (DPs):

DP1. Balance expressiveness and complexity to prevent modeling errors and reduce the effort it takes to create and interpret a model.

DP2. Support modular requirement modeling to enable the recognition of patterns that improve the comprehension of a model.

DP3. Define model behavior declaratively to enable a more compact specification that improves the modeling efficiency.

DP4. Retain the normative meanings of legal requirements to avoid modeling errors and improve the model's fidelity.

Fig. 4 depicts the relationship between design requirements and design principles, in which every design requirement represents one research focus and every design principle represents the means to achieve the requirement. The figure was inspired by the design science research approach of Kuehnel, Trang, and Lindner (2019), who described the development of a software artifact for the economic analysis of compliance activities. In our work, we use design principles to conclude our analysis with a summary of the results. It should be noted that all findings should be interpreted in light of the fact that we specified design principles separate from the individual language but in relation to the underling modeling concept. By incorporating our research findings into the design of the languages, we hope to improve the adoption of compliance languages and thereby solve some of the problems that hinder the implementation of compliance requirements and increase the costs of compliance.

As one of our primary findings, expressivity can indeed influence the complexity of a model. However, as PCL shows, high expressiveness does not necessarily indicate high model complexity, just as high complexity does not necessarily indicate that the expressiveness of the modeling language is also high, as PENELOPE shows. That is, the exact effect can only be assessed in the context of the respective language, or rather its modeling constructs. Therefore, in DP1, we stipulate a balance between the expressiveness and complexity of compliance languages, rather than strengthening the expressiveness one-sidedly as before. For this purpose, we suggest evaluating languages according to the framework on conceptual modeling and the complexity metrics described in this work. Just like DP1, DP2 and DP3 are both rooted in the complexity analysis, which showed that both pattern-based and declarative modeling techniques increase the expressiveness of a language while maintaining a moderate model complexity. The reason for this is, as our experiments revealed, that it results in greater comprehensibility of the patterns. The same can be said about Declare due to the existing empirical works. Finally, in DP4 we describe the most intriguing discovery of our research, that normative concepts support the modeling of legal requirements better than do existing pattern systems.

However, it has to be noted at this point that we pursued two different goals in our research. As a consequence, except for DP1, which is compatible with all other design principles, the compatibility between design principles of different design requirements is limited. For example, while DP2 and DP3 describe a compatible principle, combining patterns and declarative modeling, there is to date no approach that combines patterns and deontic logic as required by DP2 and DP4. Approaches combining declarative and deontic features, as implied by DP3 and DP4, however, do exist, as PENELOPE demonstrates. This means that, in addition to fundamental design principles, we have also raised some technical questions for future research.

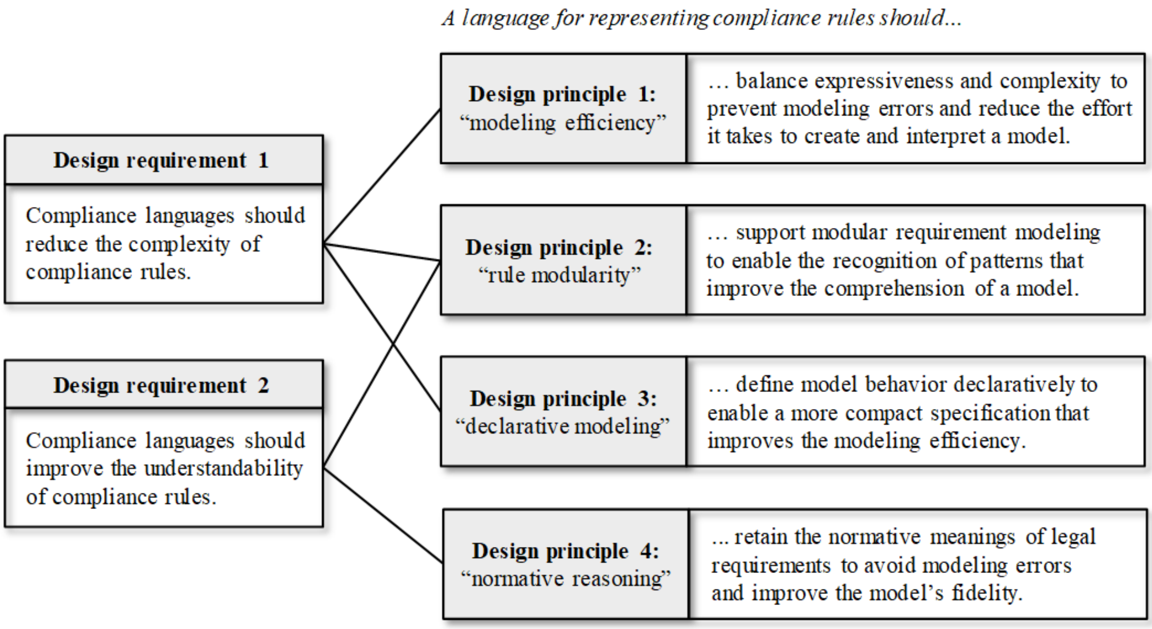

Fig. 4. Design principles for developing compliance languages

4.3 Limitations and Future Research

In the context of this thesis, we determined the effects of design on the complexity and understandability of compliance languages. Corroborating evidence was provided through the research essays. In the essays, we systematically extended the scope from the application of formal methods for measuring complexity (Essay B.1) to measuring complexity in relation to expressiveness (Essay B.2), and from experimental designs for assessing the understandability (Essay B.3) to the comparative evaluation of compliance languages (Essay B.4). Since specific methodological limitations in this approach have already been addressed in the individual essays, we now focus on limitations of a more conceptual nature in the context of BPM and neighboring disciplines to identify research gaps in the direction of which research could be expanded.

The main aim of this doctoral thesis was to expand knowledge about the design of languages and patterns for modeling compliance rules so that users derive better models and spend less time on modeling. The greatest limitation in this respect is that the effect of individual factors cannot be differentiated (Basili & Weiss, 1984). In order to achieve a better understanding of conceptual models, we need to exploit methods and theories that can help us understand how users comprehend visual information at a more basic cognitive level (Petrusel et al., 2017). To date, research has arrived at detailed questions in which the use of tools, such as eye tracking, helps to determine the factors influencing process model comprehension (Zimoch, Pryss, Probst, Schlee, & Reichert, 2017). To take advantage of all technical possibilities, we suggest extending this field of research to neuroscientific methods (e.g., functional magnetic resonance imaging) that allow analysis of the cognitive response to different forms of representations and levels of complexity. In this way, it should be possible to elicit more information about language features that capture the attention of users, or that distract and confuse them.

Once a process has been formally specified it enables the analysis of process models, which provides insights and improvements in performance, quality, compliance, forecasting, and planning (Polyvyanyy, Ouyang, Barros, & van der Aalst, 2017). Querying large process model repositories is, however, comparable to searching for a needle in a haystack. In other words, a poorly worded query leads to incorrect responses (De Nicola, Missikoff, & Smith, 2012). To support the formulation of queries, we suggest, as an extension of our research, combining cognitive theories with semantic theories. Cognitive theories provide a wide range of explanations for human behavior in decision-making situations by explaining the nature of problem-solving (Houy, Fettke, & Loos, 2014). Semantic theories, on the other hand, are concerned with the conceptual representation of natural language for use in information retrieval, inference, planning, and so on (Bos, 2011). Both theories are often considered separately, although they can supplement each other. In combining them, we can explore not only the modeling language at a conceptual level, but also its formal semantics.

While conceptual modeling implies rather traditional methods, with this last research proposal we move to a rather unexplored field of research that is closer to the digital pulse of our economy and responds to the need to develop new resources. As recent trends in BPM show, research is continually discovering data-driven approaches that are able to process more- and less-structured data (Mendling, Decker, et al., 2018). As such, cognitive computing is gaining increasing interest for BPM (Hull & Motahari-Nezhad, 2016). Cognitive computing describes an approach for exploiting emerging technologies to advance the collaboration of information systems and human users (Wang et al., 2012). It requires systems to learn and reason, and humans to devise new human–computer interactions that enable process learning (Zasada, 2019). In the context of BPC, cognitive computing could play a major role in rethinking common structures of traditional modeling techniques, extending the level of process automation, and developing human–computer interactions that improve productivity and decision making.

References

Abdullah, N. S., Indulska, M., & Sadiq, S. (2016). Compliance management ontology – a shared conceptualization for research and practice in compliance management. *Information Systems Frontiers*, *18*(5), 995–1020. https://doi.org/10.1007/s10796-016-9631-4

Abdullah, N. S., Sadiq, S., & Indulska, M. (2010). Emerging challenges in information systems research for regulatory compliance management. In *International Conference on Advanced Information Systems Engineering* (pp. 251–265). https://doi.org/10.1007/978-3-642-13094-6_21

Antoniou, G., Baryannis, G., Batsakis, S., Governatori, G., Robaldo, L., Siragusa, G., & Tachmazidis, I. (2018). Legal reasoning and big data: Opportunities and challenges. In *Proceedings of the 2018 Workshop on MIning and REasoning with Legal texts*. https://doi.org/10.29007/tkmv

Arora, C., Sabetzadeh, M., Briand, L., & Zimmer, F. (2015). Automated checking of conformance to requirements templates using natural language processing. *IEEE Transactions on Software Engineering*, *41*(10), 944–968. https://doi.org/10.1109/TSE.2015.2428709

Awad, A., Weidlich, M., & Weske, M. (2011). Visually specifying compliance rules and explaining their violations for business processes. *Journal of Visual Languages & Computing*, *22*(1), 30–55. https://doi.org/10.1016/j.jvlc.2010.11.002

Basili, V. R., & Weiss, D. M. (1984). A methodology for collecting valid software engineering data. *IEEE Transactions on Software Engineering*, *SE-10*(6), 728–738. https://doi.org/10.1109/TSE.1984.5010301

Basten, D., & Sunyaev, A. (2014). A systematic mapping of factors affecting accuracy of software development effort estimation. *Communications of the Association for Information Systems*, *34*(1), 51–86. https://doi.org/10.17705/1cais.03404

Becker, J., Delfmann, P., Eggert, M., & Schwittay, S. (2012). Generalizability and applicability of model based business process compliance checking approaches a state of the art analysis and research roadmap. *BuR-Business Research*, *5*(2), 221–247.

Becker, J., Rosemann, M., & von Uthmann, C. (2000). Guidelines of business process modeling. In W. van der Aalst, J. Desel, & A. Oberweis (Eds.), *Business Process Management* (pp. 30–49). https://doi.org/10.1007/3-540-45594-9_3

Bos, J. (2011). A survey of computational semantics: Representation, inference and knowledge in wide-coverage text understanding. *Language and Linguistics Compass*, *5*(6), 336–366.

Brace, J., Rozwell, C., Feiman, B., Kirwin, B., & Bace, J., Rozwell, C., Feiman, J., & Kirwin, B.

(2006). Understanding the costs of compliance. Gartner Research. logic.stanford.edu/poem/externalpapers/understanding_the_costs_of_c_138098.pdf

Buch, C., & Dages, G. B. (2018). Structural changes in banking after the crisis. Committee on the Global Financial Systems, CGFS No 60. https://www.bis.org/publ/cgfs60.pdf

Bulgurcu, B., Cavusoglu, H., & Benbasat, I. (2010). Information security policy compliance: An empirical study of rationality-based beliefs and information security awareness. *MIS Quarterly*, *34*(3), 523–548. https://doi.org/10.1093/bja/aeq366

Burton-Jones, A., Wand, Y., & Weber, R. (2009). Guidelines for empirical evaluations of conceptual modeling grammars. *Journal of the Association for Information Systems*, *10*(6), 495–532. https://doi.org/Article

Busch, B., & Matthes, J. (2016). *Brexit—the economic impact: A meta-analysis*. Köln: Institut der deutschen Wirtschaft (IW). https://www.econstor.eu/handle/10419/157171

Cardoso, J. (2008). Business process control-flow complexity: Metric, evaluation, and validation. *International Journal of Web Services Research*, *5*(2), 49–76.

Cardoso, J., Mendling, J., Neumann, G., & Reijers, H. A. (2006). A discourse on complexity of process models. In *Proceedings of the 4th International Conference on Business Process Management (BPM'06)* (Vol. 4103 LNCS, pp. 117–128). Springer. https://doi.org/10.1007/11837862_13

Carmo, J., & Jones, A. J. I. (2002). Deontic logic and contrary-to-duties. In *Handbook of philosophical logic* (Vol. 8, pp. 265–343). Springer.

Cleven, A., & Winter, R. (2009). Regulatory compliance in information systems research—Literature analysis and research agenda. In *Lecture Notes in Business Information Processing* (Vol. 29 LNBIP, pp. 174–186). https://doi.org/10.1007/978-3-642-01862-6_15

COMPAS. (2008). D2.1 State-of-the-art in the field of compliance languages: Compliance-driven models, languages, and architectures for services. Report D2.1, Tilburg University, The Netherlands.

Corradini, F., Ferrari, A., Fornari, F., Gnesi, S., Polini, A., Re, B., & Spagnolo, G. O. (2018). A Guidelines framework for understandable BPMN models. *Data and Knowledge Engineering*, *113*, 129–154. https://doi.org/10.1016/j.datak.2017.11.003

De Nicola, A., Missikoff, M., & Smith, F. (2012). Towards a method for business process and informal business rules compliance. *Journal of Software: Evolution and Process*, *24*(3), 341–360. https://doi.org/10.1002/smr.553

De Smedt, J., De Weerdt, J., Serral, E., & Vanthienen, J. (2016). Improving understandability of declarative process models by revealing hidden dependencies. In *Proceedings of the 28th Advanced Information Systems Engineering International Conference (CAiSE'16), June 13–17, 2016*, *3084*, (pp. 83–98). Ljubljana, Slovenia. https://doi.org/10.1016/0162-0134(85)85020-0

Delfmann, P., Breuker, D., Matzner, M., & Becker, J. (2015). Supporting information systems analysis through conceptual model query—The Diagramed Model Query Language (DMQL). *Communications of the Association for Information Systems Volume*, *37*, 472–506.

Dijkman, R. M., Dumas, M., van Dongen, B., Käärik, R., & Mendling, J. (2011). Similarity of business process models: Metrics and evaluation. *Information Systems*, *36*(2), 498–516. https://doi.org/DOI: 10.1016/j.is.2010.09.006

Dikici, A., Turetken, O., & Demirors, O. (2018). Factors influencing the understandability of process models: A systematic literature review. *Information and Software Technology*, *93*, 112–129. https://doi.org/10.1016/j.infsof.2017.09.001

Dwyer, M. B., Avrunin, G. S., & Corbett, J. C. (1999). Patterns in property specifications for finite-state verification. In *Proceedings of the 21st International Conference on Software Engineering (ICSE'99)* (pp. 411–420). https://doi.org/10.1145/302405.302672

Edmonds, B. (1999). What is complexity? The philosophy of complexity per se with application to some examples in evolution. In *The evolution of complexity* (pp. 1–17). Kluwer, Dordrecht.

Elgammal, A., Turetken, O., van den Heuvel, W.-J. J., & Papazoglou, M. (2016). Formalizing and appling compliance patterns for business process compliance. *Software and Systems Modeling*, *15*(1), 119–146. https://doi.org/10.1007/s10270-014-0395-3

Erickson, J., & Siau, K. (2007). Theoretical and practical complexity of modeling methods. *Communications of the ACM*, *50*(8), 46–51. https://doi.org/Article

EUR-Lex. (2008). Regulation (EC) No 300/2008 of the European Parliament and of the Council of 11 March 2008 on common rules in the field of civil aviation security and repealing Regulation (EC) No 2320/2002. https://eur-lex.europa.eu/eli/reg/2008/300/2010-02-01

Fahland, D., Lübke, D., Mendling, J., Reijers, H., Weber, B., Weidlich, M., & Zugal, S. (2009). Declarative versus imperative process modeling languages: The issue of understandability. In *Proceedings of the 14th International Conference on Exploring Modeling Methods in Systems Analysis and Design (EMMSAD'09)* (pp. 353–366).

Fu, K. K., Yang, M. C., & Wood, K. L. (2016). Design principles: Literature review, analysis, and future directions. *Journal of Mechanical Design*, *138*(10).

Gemino, A., & Wand, Y. (2004). A framework for empirical evaluation of conceptual modeling techniques. *Requirements Engineering*, *9*(4), 248–260. https://doi.org/10.1007/s00766-004-0204-6

Goedertier, S., & Vanthienen, J. (2006). Designing compliant business processes with obligations and permissions. In J. Eder & S. Dustdar (Eds.), *Proceedings of the 4th Business Process Management Workshops* (pp. 5–14). Berlin, Heidelberg: Springer. https://doi.org/10.1007/11837862_2

Governatori, G., & Hashmi, M. (2015). No time for compliance. In *IEEE 19th International Enterprise Distributed Object Computing Workshop* (pp. 9–18). https://doi.org/10.1109/EDOC.2015.12

Governatori, G., Milosevic, Z., & Sadiq, S. (2006). Compliance checking between business processes and business contracts. In *IEEE 10th International Enterprise Distributed Object Computing Workshop* (pp. 221–230). https://doi.org/10.1109/EDOC.2006.22

Gregor, S., & Jones, D. (2007). The anatomy of a design theory. *Journal of the Association of Information Systems*, *8*(5), 312–335. https://doi.org/10.17705/1jais.00129

Haisjackl, C., & Zugal, S. (2014). Investigating differences between graphical and textual declarative process models (pp. 194–206). https://doi.org/10.1007/978-3-319-07869-4

Halstead, M. H. (1977). Elements of software science. In *Operating and Programming Systems Series, 7*. New York: Elsevier.

Harmon, P. (2010). The scope and evolution of business process management. In *Handbook on Business Process Management 1* (pp. 37–81). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-00416-2_3

Hartmann, M. (2011). Corporate social responsibility in the food sector. *European Review of Agricultural Economics*, *38*(3), 297–324.

Hashmi, M., & Governatori, G. (2017). Norms modeling constructs of business process compliance management frameworks: a conceptual evaluation. *Artificial Intelligence and Law*, *26*(3), 251–305. https://doi.org/10.1007/s10506-017-9215-8

Hashmi, M., Governatori, G., Lam, H. P., & Wynn, M. T. (2018). Are we done with business process compliance: State of the art and challenges ahead. *Knowledge and Information Systems*, *57*(1), 79–133. https://doi.org/10.1007/s10115-017-1142-1

Hashmi, M., Governatori, G., Wynn, M. T., & Thandar, M. (2016). Normative requirements for regulatory compliance: An abstract formal framework. *Information Systems Frontiers*, *18*(3), 429–455. https://doi.org/10.1007/s10796-015-9558-1

Hasic, F., De Smedt, J., & Vanthienen, J. (2017). Towards assessing the theoretical complexity of the decision model and notation (DMN) research-in-progress. *CEUR Workshop Proceedings*, *1859*, 64–71.

Henry, S., & Kafura, D. (1981). Software structure metrics based on information flow. *IEEE Transactions on Software Engineering*, *7*(5), 510–518. https://www.computer.org/csdl/trans/ts/1981/05/01702877-abs.html

Herath, T., & Rao, H. R. (2009). Protection motivation and deterrence: A framework for security policy compliance in organisations. *European Journal of Information Systems*, *18*(2), 106–125. https://doi.org/10.1057/ejis.2009.6

Hommes, B. J., & van Reijswould, V. (2000). Assessing the quality of business process modelling techniques. In *Proceedings of the Hawaii International Conference on System Sciences*. https://ieeexplore.ieee.org/abstract/document/926591/

Houy, C., Fettke, P., & Loos, P. (2014). On the theoretical foundations of research into the understandability of business process models. In *Proceedings of the European Conference on Information Systems* (pp. 1–38). https://doi.org/10.1080/07474938.2014.944470

Hull, R., & Motahari-Nezhad, H. R. M. (2016). Rethinking BPM in a cognitive world: Transforming how we learn and perform business processes. In *Lecture Notes in Computer Science* (Vol. 9850 LNCS, pp. 3–19). https://doi.org/10.1007/978-3-319-45348-4_1

ISO (2014). Compliance Management Systems — Guidelines, ISO19600:2014(E), International Standard, 1st ed.

Kelton, A. S., Pennington, R. R., & Tuttle, B. M. (2010). The effects of information presentation format on judgment and decision making: A review of the information systems research. *Journal of Information Systems*, *24*(2), 79–105.

Knuplesch, D., Kumar, A., Reichert, M., & Kumar, A. (2015). Visually monitoring multiple perspectives of business process compliance. In *Business Process Management* (pp. 263–279). https://doi.org/10.1007/978-3-319-23063-4_19

Knuplesch, D., & Reichert, M. (2017). A visual language for modeling multiple perspectives of business process compliance rules. *Software & Systems Modeling*, *16*(3), 715–736.

Knuplesch, D., Reichert, M., & Kumar, A. (2017). A framework for visually monitoring business process compliance. *Information Systems*, *64*, 381–409. https://doi.org/10.1016/j.is.2016.10.006

Kuehnel, S., Trang, S. T.-N., & Lindner, S. (2019). Conceptualization, design, and implementation of EconBPC – A software artifact for the economic analysis of business process compliance. In *In-*

ternational Conference on Conceptual Modeling (pp. 378–386). Cham: Springer. https://doi.org/10.1007/978-3-030-33223-5_31

Kuehnel, S., & Zasada, A. (2018). An approach toward the economic assessment of business process compliance. In *Proceedings of the 5th International Workshop on Conceptual Modeling in Requirements and Business Analysis (MREBA) held in conjunction with the 37th International Conference on Conceptual Modeling (ER)* (Vol. 11158 LNCS, pp. 228–238). October 22–25. Xiang, China. https://doi.org/10.1007/978-3-030-01391-2_28

La Rosa, M., ter Hofstede, A. H. M., Wohed, P., Reijers, H. A., Mendling, J., & van der Aalst, W. M. P. (2011). Managing process model complexity via abstract syntax modifications. *IEEE Transactions on Industrial Informatics*, *7*(4), 614–629. https://doi.org/10.1109/TII.2011.2166795

Gruhn, V. & Laue, R. (2006). Complexity metrics for business process models. In *Proceedings of the 9th International Conference on Business Information Systems* (Vol. 85, pp. 1–12).

Leone, A. J. (2007). Factors related to internal control disclosure: A discussion of Ashbaugh, Collins, and Kinney (2007) and Doyle, Ge, and McVay (2007). *Journal of Accounting and Economics*, *44*(1), 224–237. https://doi.org/https://doi.org/10.1016/j.jacceco.2007.01.002

Liu, P., & Li, Z. (2012). Task complexity: A review and conceptualization framework. *International Journal of Industrial Ergonomics*, *42*(6), 553–568. https://doi.org/10.1016/j.ergon.2012.09.001

Ly, L. T., Maggi, F. M., Montali, M., Rinderle-Ma, S., & van der Aalst, W. M. P. (2015). Compliance monitoring in business processes: Functionalities, application, and tool-support. *Information Systems*, *54*, 209–234. https://doi.org/http://dx.doi.org/10.1016/j.is.2015.02.007

Manders, B., De Vries, H. J., & Blind, K. (2016). ISO 9001 and product innovation: A literature review and research framework. *Technovation*, *48–49*, 41–55. https://doi.org/10.1016/j.technovation.2015.11.004

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, *15*(4), 251–266. https://doi.org/10.1016/0167-9236(94)00041-2

McCabe, T. J. (1976). A complexity measure. *IEEE Transactions on Software Engineering*, *SE-2*(4), 308–320.

Mendling, J., Decker, G., Reijers, H. A., Hull, R., & Weber, I. (2018). How do machine learning, robotic process automation, and blockchains affect the human factor in business process management? *Communications of the Association for Information Systems*, *43*(1), 297–320. https://doi.org/10.17705/1CAIS.04319

Mendling, J., Recker, J., Reijers, H. A., & Leopold, H. (2018). An empirical review of the connection between model viewer characteristics and the comprehension of conceptual process models. *Information Systems Frontiers*, *21*(5), 1–25. https://doi.org/10.1007/s10796-017-9823-6

Mendling, J., Reijers, H. A., & van der Aalst, W. M. P. (2010). Seven process modeling guidelines (7PMG). *Information and Software*.

Meth, H., Mueller, B., & Maedche, A. (2015). Designing a requirement mining system. *Journal of the Association of Information Systems*, *16*(9), 799–837. https://doi.org/10.17705/1jais.00408

Mirsky, R., Baker, A., & Baker, R. H. (2013). *The cost of compliance. KPMG/AIMA/MFA Global Hedge Fund Survey*. http://www.kpmg-institutes.com/content/dam/kpmg/kpmginstitutes/pdf/2013/cost-of-compliance-2013.pdf

Moreno-Montes De Oca, I., Snoeck, M., Reijers, H. A., & Rodríguez-Morffi, A. (2015). A systematic literature review of studies on business process modeling quality. *Information and Software Technology*, *58*, 187–205. https://doi.org/10.1016/j.infsof.2014.07.011

Muehlen, M. Z., Recker, J., & Indulska, M. (2007). Sometimes less is more: Are process modeling languages overly complex? In *Proceedings of IEEE International Enterprise Distributed Object Computing Workshop (EDOC'07)*. https://doi.org/10.1109/EDOCW.2007.30

Norman, D. (1986). Cognitive engineering. In *User Centered Design: New Perspectives on Human Computer Interaction* (pp. 31–61). Hillsdale: Lawrence Erlbaum Associates. https://pdfs.semanticscholar.org/57f1/76992f92ae559d9c110211d7f04c5143cb44.pdf

Offermann, P., Blom, S., Schönherr, M., & Bub, U. (2010). Artifact types in information systems design science – A literature review. In *Global Perspectives on Design Science Research* (Vol. 6105 LNCS, pp. 77–92). https://doi.org/10.1007/978-3-642-13335-0_6

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist*, *38*(1), 63–71.

Pesic, M. (2008). *Constraint-Based Workflow Management Systems: Shifting Control to Users*. Eindhoven University of Technology. https://doi.org/Urn:nbn:nl:ui:25-638413

Petrusel, R., Mendling, J., & Reijers, H. A. (2017). How visual cognition influences process model comprehension. *Decision Support Systems*, *96*, 1–16. https://doi.org/10.1016/j.dss.2017.01.005

Pnueli, A. (1977). The temporal logic of programs. In *Proceedings of the 18th Annual Symposium on Foundations of Computer Science* (pp. 46–57). IEEE.

Polyvyanyy, A., Ouyang, C., Barros, A., & van der Aalst, W. M. P. (2017). Process querying: Enabling business intelligence through query-based process analytics. *Decision Support Systems*, *100*, 41–56. https://doi.org/10.1016/j.dss.2017.04.011

Purao, S. (2002). Design research in the techonology of information systems: Truth or dare. *Information Systems*.

Racz, N., Seufert, A., & Weippl, E. R. (2010). A process model for integrated IT governance, risk, and compliance management. In *Proceedings of the 9th Baltic Conference on Databases and Information Systems (DB&IS'10)* (pp. 155–170).

Recker, J., zur Muehlen, M., Siau, K., Erickson, J., & Indulska, M. (2009). Measuring method complexity : UML versus BPMN. In *Proceedings of the 15th Americas Conference on Information Systems* (pp. 1–9). https://doi.org/10.1057/kmrp.2014.7

Reijers, H. A., & Mendling, J. (2011). A study into the factors that influence the understandability of business process models. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, *41*(3), 449–462. https://doi.org/10.1109/TSMCA.2010.2087017

Reijers, H. A., Slaats, T., & Stahl, C. (2013). Declarative modeling—An academic dream or the future for BPM? In *Lecture Notes in Computer Science* (Vol. 8094 LNCS, pp. 307–322). https://doi.org/10.1007/978-3-642-40176-3_26

Rozinat, A., & van der Aalst, W. M. P. (2005). Conformance testing: Measuring the fit and appropriateness of event logs and process models. In *Lecture Notes in Computer Science* (Vol. 3812 LNCS, pp. 163–176). https://link.springer.com/chapter/10.1007/11678564_15

Sackmann, S., Kuehnel, S., & Seyffarth, T. (2018). Using business process compliance approaches for compliance management with regard to digitization: Evidence from a systematic literature review. In *Proceedings of the 16th International Conference Business Process Management (BPM'18)*.

Sánchez González, L., García Rubio, F., Ruiz González, F., & Piattini Velthuis, M. (2010). Measurement in business processes: A systematic review. *Business Process Management Journal*, *16*(1), 114–134. https://doi.org/10.1108/14637151011017976

Schmid, U., Ragni, M., Gonzalez, C., & Funke, J. (2011). The challenge of complexity for cognitive systems. *Cognitive Systems Research*. https://doi.org/10.1016/j.cogsys.2010.12.007

Schultz, M. (2013). Towards an empirically grounded conceptual model for business process compliance. In *Lecture Notes in Computer Science* (Vol. 8217 LNCS, pp. 138–145). https://doi.org/10.1007/978-3-642-41924-9_13

Shao, J., & Wang, Y. (2003). A new measure of software complexity based on cognitive weights. *Canadian Journal of Electrical and Computer Engineering*, *28*(2), 69–74.

https://doi.org/10.1109/CJECE.2003.1532511

SOX. (2002). Sarbanes–Oxley Act of 30 July 2002, 15 USC 7201 note, Public Law 107-204, 107th Congress, 116 Statistics Act, Sec. 404.

Teo, H. H., Chan, H. C., & Wei, K. K. (2006). Performance effects of formal modeling language differences: A combined abstraction level and construct complexity analysis. *IEEE Transactions on Professional Communication*, *49*(2), 160–175. https://doi.org/10.1109/TPC.2006.875079

Thalheim, B. (2012). The art of conceptual modelling. *Frontiers in Artificial Intelligence and Applications*, *237*, 149–168. https://doi.org/10.3233/978-1-60750-992-9-149

Timm, F., Zasada, A., & Thiede, F. (2016). Building a reference model for anti-money laundering in the financial sector. In *Proceedings of the 18th Conference on Learning, Knowledge, Data, Analytics (LWDA'16)* (Vol. 1670, pp. 111–120). September 12–14. Potsdam, Germany. https://pdfs.semanticscholar.org/df36/c1ee1d256010d566b27513d5d34a6206c087.pdf

Tosatto, S. C., Governatori, G., & van Beest, N. (2019). Checking regulatory compliance: Will we live to see it? In *International Conference on Business Process Management (BPM'2019)*, *September 1–6*. Vienna, Austria.

van der Aa, H., Di Ciccio, C., Leopold, H., & Reijers, H. A. (2019). Extracting declarative process models from natural language. In *International Conference on Advanced Information Systems*. Cham: Springer.

Vessey, I. (1991). Cognitive fit: A theory-based analysis of the graphs versus tables literature. *Decision Sciences*, *22*(2), 219–240. https://doi.org/10.1111/j.1540-5915.1991.tb00344.x

Vessey, I. (1994). The effect of information presentation on decision making: A cost–benefit analysis. *Information & Management*, *27*(2), 103–119. https://doi.org/10.1016/0378-7206(94)90010-8

Walls, J. G., Widmeyer, G. R., & El Sawy, O. A. (1992). Building an information system design theory for vigilant EIS. *Information Systems Research*, *3*(1), 36–59. https://doi.org/10.1287/isre.3.1.36

Wand, Y., & Weber, R. (2002). Research commentary information systems and conceptual modeling—A research agenda. *Information Systems Research*, *13*(4), 363–376. https://doi.org/10.1287/isre.13.4.363.69

Wang, Y., Berwick, R. C., Haykin, S., Pedrycz, W., Kinsner, W., Baciu, G., Du, Z., Bhavsar, V. C., & Gavrilova, M. (2012). Cognitive informatics and cognitive computing in year 10 and beyond. *International Journal of Cognitive Informatics and Natural Intelligence*, *5*(4), 1–21. https://doi.org/10.4018/jcini.2011100101

Weber, B., Mutschler, B., & Reichert, M. (2010). Investigating the effort of using business process management technology: Results from a controlled experiment. *Science of Computer Programming*, *75*(5), 292–310. https://doi.org/10.1016/j.scico.2009.12.003

Weber, B, Reijers, H. A., Zugal, S., & Wild, W. (2009). The declarative approach to business process execution: An empirical test. In *21st International Conference on Advanced Information Systems Engineering (CAiSE)* (pp. 470–485). https://doi.org/10.1007/978-3-642-02144-2_37

Yazdanmehr, A., & Wang, J. (2016). Employees' information security policy compliance: A norm activation perspective. *Decision Support Systems*, *92*, 36–46. https://doi.org/10.1016/j.dss.2016.09.009

Zasada, A. (2019). How cognitive processes make us smarter. In *Proceedings of 3rd International Workshop in Artificial Intelligence for Business Process Management, held in conjunction with the 17th International Business Process Management Conference (BPM'19),* September 1–6. Vienna, Austria.

Zasada, A., & Bui, T. (2018). More than meets the eye: A case study on the role of IT affordances in supporting compliance. In *Proceedings of the 24th Americas Conference on Information Systems (AMCIS'18)*, August 16–18. New Orleans, LA. https://aisel.aisnet.org/amcis2018/OrgTrasfm/Presentations/5

Zasada, A., & Fellmann, M. (2015). A pattern-based approach to transform natural text from laws into compliance controls in the food industry. In *Proceedings of the 17th Learning, Knowledge, Adaption (LWA'15)* (Vol. 1458, pp. 230–238), September 5–9. Vienna, Austria.

Zimoch, M., Pryss, R., Probst, T., Schlee, W., & Reichert, M. (2017). Cognitive insights into business process model comprehension: Preliminary results for experienced and inexperienced individuals. In *Lecture Notes in Business Information Processing* (Vol. 287, pp. 137–152). https://doi.org/10.1007/978-3-319-59466-8_9

Part B

Essays

B.1 How Complex Does Compliance Get?

Abstract. Metrics have been applied in software engineering to manage the complexity of program code. This paper explores a new application area of the classic software engineering metrics to determine the complexity of compliance rules in business processes. Despite the critical voices noting the rather weak theoretical foundation, metrics provide effective measures for overlooking the concepts that may drive the complexity of a program. Their scope, scalability, and perceived ease of use do not diffuse these doubts, but provide ample reasons to believe that there is more to complexity analysis than numbers, and that a better methodological approach can help to reveal their true potential. Utilizing this potential would be of great importance, not only for establishing effective and efficient compliance management, but also for providing innovative solutions to digitalization trends and increasing data stacks. While some extant work has shown the applicability of software metrics for analyzing the complexity of process models, metrics have not been applied so far to manage the complexity of compliance rules. The approach presented in this paper provides an integrated view on the complexity of compliance rules that are modeled with conceptually different compliance languages. To this end, we review and discuss the literature on software metrics to derive the definitions needed to compute the complexity of compliance rules, and to refurbish the methodological foundation of software engineering metrics.

Keywords: Complexity Metrics, Compliance Rules, Business Process, Model Complexity, Compliance Modeling.

B.2 Evaluation of Compliance Rule Languages for Modeling Regulatory Compliance Requirements

Abstract. Ensuring compliance in business processes has become an enterprise-wide responsibility. With the growing and ever-changing body of regulations, the implementation of compliance requirements can be seen as complex, time-consuming, and costly task. To integrate regulations more efficiently into business processes, compliance research strives towards the formal representation of compliance requirements, not only to build a properly specified process model, but also to enable automated checks that point towards compliance violations. Since compliance requirements affect multiple process dimensions, such as control flow, data, time, and resources, a major challenge lies in representing all these conceptually different constraints. To this end, current approaches to business process compliance utilize a varied set of languages. However, every approach relies on a different motivating scenario and usually abstracts from real-world requirements that are hampering the evaluation of their expressiveness. To establish a uniform evaluation basis, we introduce a running example for evaluating the expressiveness and complexity of compliance rule languages identified through a systematic literature review. By modeling a sample of legal requirements, we demonstrate the languages' grammar and vocabulary. The semantics are evaluated by adopting a normative classification framework, which conveys a distinction for deontic effects. In addition, for each language we apply software metrics to calculate the volume, difficulty, and effort to better understand its lexical complexity in relation to its expressiveness.

Keywords: Conceptual Modeling, Business Process Compliance, Compliance Rule Modeling, Regulatory Compliance, Business Process.

B.3 Finding a Match: Modeling Compliance Rules with Compliance Patterns

Abstract. The specification of compliance rules entails a process of formalizing requirements. In business process compliance research, these requirements are typically formalized with respect to information about the process, such as the control flow. In this regard, compliance patterns seem to be promising since they have the potential to serve two purposes: capturing compliance requirements in a way that is easy to understand for non-experts while, at the same time, being precise enough to support automated compliance checking. However, to date there exists no empirical evidence on the efficiency of using patterns for compliance modeling. In this paper, we use an experiment to provide empirical evidence that compliance patterns support the modeling of compliance rules. Our results show that the modeling performance is positively influenced by patterns without having an effect on the modeling time. We therefore contribute to the evaluation of pattern-based approaches for compliance modeling.

Keywords: Business Process Compliance, Compliance Pattern, Regulatory Compliance, Business Process Modeling.

B.4 Compliance Meets Performance: Understanding the Differences between Compliance Representations

Abstract. A major shortcoming in organizations lies in finding how to best support employees in relation to compliance information to ensure that they make compliant decisions in their daily work activities. In this regard, available competing representations focus on Compliance Request Language (CRL) compliance patterns and Formal Contract Logic (FCL) deontic modalities. As there is no evidence so far as to which one is better for helping process modelers and analysts in organizations to understand their compliance regulations, drawing on cognitive fit theory we conduct an experiment that compares these two forms of representation. Our sample consists of 85 participants that are given tasks regarding the representation and interpretation of compliance information. The results show that participants deal best with structuring their ideas regarding compliance, as well as understanding compliance information, with a less formal notation of FCL deontic modalities (linguistic expressions). These results imply that users can make use of the basic deontic effects, but have severe problems with using formal language. Theoretical implications of this are that deontic modalities match best with the structuring of mental concepts regarding compliance rules among individuals. Practical implications suggest that companies should use deontic languages to communicate compliance rules, but stick to linguistic expressions in their descriptions.

Keywords: Compliance Modeling, Understandability, Compliance Rules, Business Process Compliance, Empirical Evaluation.