Towards Situational Reference Model Mining – Main Idea, Procedure Model & Case Study

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Abstract. This contribution introduces the concept of Situational Reference Model Mining, i.e. the idea that automatically derived reference models, although based on the same input data, are intended for different use cases and thus have to meet different requirements. These requirements determine the reference model character and thus the technique that is best suited for mining it. Situational Reference Model Mining is based on well-known design principles for reference modeling, such as configuration, aggregation, specialization, instantiation, and analogy. We present a procedure model for Situational Reference Model Mining and demonstrate its usefulness by means of a case study. Existing techniques for Reference Model Mining are examined and mapped to their underlying design principles. This way, we are not only able to provide reference model designers with concrete guidelines regarding their choice of mining technique, but also point out research gaps for the development of new approaches to reference model mining.

Keywords: Reference Model Mining, Reference Model Design, Reference Model Design Principles, Reference Model Construction, Inductive Reference Model Development

1 Introduction

Reference models can be considered as special conceptual models that serve to be reused for the design of other conceptual models [1, 2]. They provide a template for process models in a certain industry and thus facilitate a resource-efficient implementation of the respective process and its adaption to the individual needs of an organization. This way, companies may benefit from best practices and industry-specific experience. The use of reference models is associated with a higher quality of processes and process models, as it simplifies internal communications by introducing a common terminology and considerably reduces the resources required for business process management [3].

Given a reuse-oriented conceptualization of reference models, their main purpose is to serve as an orientation in the design of new business process models. In this context, we decipher two general design processes [4]. Deriving an individual model from a reference model is known as "Design With Reuse" (DWR), i.e. an existing

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model is used as a blueprint offering guidance to the process model designer by giving suggestions for both content and design of the individual model. On the other hand, “Design For Reuse” (DFR) describes the process of constructing a (reference) model for the purpose of being reused, i.e. composing model parts and domain knowledge, such that they achieve a certain degree of universality.

Considering a model construction process, there exist several different techniques for deriving a conceptual model from another one. These so-called design principles describe how the content of the original model is adopted, adapted, and extended in order to create a new model. Five design principles are described in the literature [2]. Each configuration, instantiation, specialization, aggregation, and analogy may be used in the context of reference modeling and applied to both DFR and DWR.

Not every design principle may be applied to every reference model, nor may every intended target model be derived by any design principle. The principles differ in terms of concretization and usability. For example, the Configurable EPC (C-EPC) constitutes an application of the configuration principle to Event-Driven Process Chains [5]. Instead, the choice of model design principle depends on the situational circumstances, i.e. the requirements posed to the target model and the construction process itself. These factors also determine the character and thus the choice of an appropriate reference model for a certain application context.

Considering the situational circumstances and requirements is especially important when designing a reference model inductively, i.e. deriving it (semi-)automatically from a set of individual process models (Reference Model Mining). Besides the input models, the reference model content and character is determined by the choice of the mining technique. Different mining techniques yield different models, even when applied to the same set of input models. As the desired outcome depends on the intended reuse of the mined model (Design With Reuse), the situational circumstances also determine the recommended, or preferable, mining technique (Design For Reuse). This concept is called “Situational Reference Model Mining (S-RMM)”, i.e. extending RMM towards consciously considering the situational context when designing and using a reference model.

In this contribution, we follow a design-science research approach [6] in order to elaborate how existing concepts in reuse-oriented reference modeling can be applied to the relatively new field of Reference Model Mining. How to develop guidelines for reference model designers? What constitutes a context for applying S-RMM? Which concrete mining techniques instantiate which principle?

Therefore, we introduce important foundations in reuse-oriented reference modeling, reference model design principles, and reference model mining in Section 2 and analyze Related Work and the emerging research gaps in Section 3. Section 4 introduces the concept of S-RMM by explaining the conceptualization and idea, defining a procedure model, and analyzing existing mining techniques regarding their application in a situational context, in order to give concrete guidelines to reference model designers. In Section 5, the procedure model and accompanying guidelines are applied in terms of a case study. The paper is concluded with a discussion and an outlook in Section 6.

2 Foundations

2.1 Reuse-Oriented Reference Modeling

Reusing a reference model entails adopting the contents of a model as well as adapting and extending them to fit the specific application context. Figure 1 outlines a reuse-oriented reference model construction [2, 4]. In a typical model construction process, the model designer creates a model according to the user's requirements, employing specific methods. The construction process is influenced by both the model quality (effectiveness) and the required time and cost (efficiency). Reference models can be understood as tools that foster both the effectiveness and the efficiency of model construction. They include contents that are relevant for different application contexts ("Design For Reuse") and may serve as the basis for several construction processes ("Design With Reuse"). As the model contents do not have to be newly constructed and have already been applied, both effectiveness and efficiency are increased.

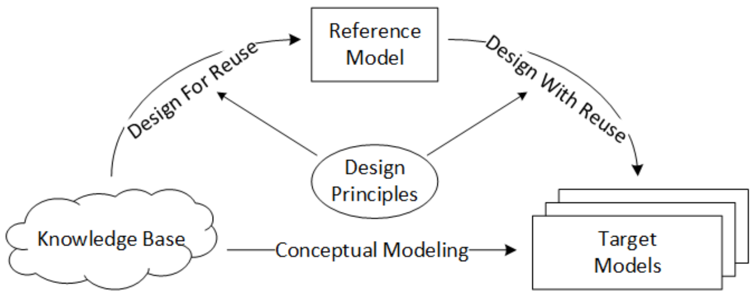

Figure 1: Reuse-Oriented Reference Modeling (cf. [2, 4])

2.2 Reference Model Design Principles

A design principle is a rule that describes how the content of one model is used in the construction process of another. This entails adopting as well as adapting and extending the model content. In his conceptualization of reuse oriented reference model design, vom Brocke identifies configuration, instantiation, specialization, aggregation, and analogy as particularly relevant [2]. As we base our work on this contribution, these are the principles we examine here. Others such as modification are specified in [7] and further elaborated in the discussion section.

- Configuration: Model parts are adopted according to the parametrization of the process domain. Individual model parts are selected and derived from a configurable component.
- Instantiation: General domain aspects are designed as a framework providing generic placeholders for plugging in model parts, considering the requirements of the application domain.

- Specialization: Entire contents of a generic model are adopted into a specific model, allowing individual modification and extension. The resulting model contains all contents of the individual model.
- Aggregation: Contents delivered by various part models are adopted into the new model, composed and extended as necessary. The resulting model is composed of the individual model parts.
- Analogy: Seemingly similar solutions are employed in a creative way to tackle new problems. The individual model is used as orientation for the design of the resulting model, such that they are perceived to be coinciding in certain aspects.

2.3 Reference Model Mining

Reference Model Mining describes the (semi-)automated derivation of a reference model from a set of individual models by identifying commonalities in a set of input models and constructing a new model on that basis (as illustrated in Figure 2).

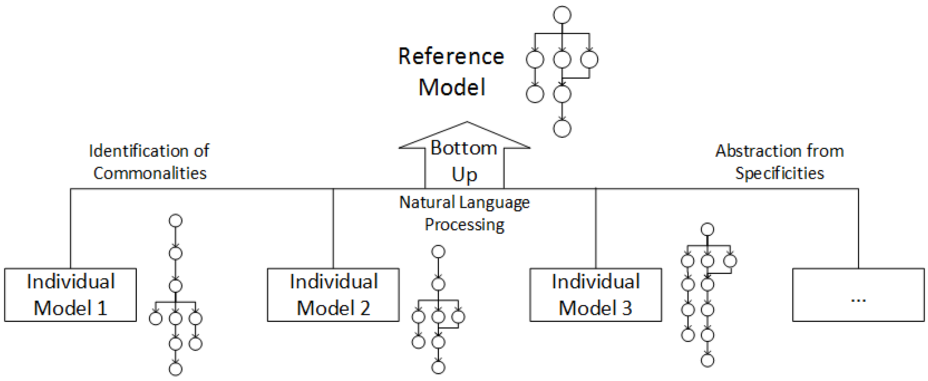

Figure 2: Reference Model Mining

3 Related Work

The concept of situational reference model construction based on design principles is not new, but has yet only been elaborated for deductive reference model development [1, 2]. Inductive reference model development has only recently gained attention in research, so there is little methodological seminal work. Fettke defines a seven-stage-framework for reference modeling methods [8]. First ideas towards S-RMM are presented in [9], where the choice of an appropriate mining technique is discussed.

A number of contributions describe concrete techniques and approaches to Reference Model Mining, but do not take on a methodological perspective, reflecting on the ways of model construction and the requirements of specific use cases. Process variants may either be mined in relation to an existing reference model or without one [10]. Different similarity measures, such as frequents common substructures [11] or heuristic approximations of the Graph-Edit Distance [12], are used to determine input model commonalities. Other approaches employ configurable process models [13], genetic algorithms [14, 15], or Process Model Abstraction [16]. While all of these contributions make the case for Reference Model Mining in general, none of them acknowledge the differences between existing approaches or indicate in which context their suggested technique would especially valuable. Different mining techniques employ different similarity measures (e.g. structural [12] or semantic [9]) and construction methods (e.g. deterministic [11] or heuristic [15]), resulting in differences between the mined reference models. In addition, due to restrictions on the input models, not every technique may be applied to every set of input models. Some contributions describe the influence of a certain parameter on the resulting reference model. For example, a frequency threshold as in [11, 12], will determine the model size and thus the character. The higher it is, the smaller and the more generic the resulting reference model. This is related to the underlying design principle, but not explicitly mentioned as such.

Some authors apply Situational Reference Model Mining by inductively developing reference models for a certain use case in a certain domain, without explicitly considering a generic procedure model or specific design principles [17-19]. Other techniques could generally be applied for Reference Model Mining, although that is not their primary use case. For example, Process Model Merging is primarily intended for process consolidation, but a consolidated model can also be interpreted as a reference model [20]. The same holds for Process Model Integration, especially in a hierarchical way [21]. If the reference model development is targeted towards certain quality aspects, it might make sense to choose it accordingly from process model configurations [22].

Our intention here is to extend the existing concept of RMM to consider the situational context, i.e. the intended target models, when choosing and executing a mining technique. Therefore, we want to create unified guidelines for S-RMM, which reference model designers can use for an easier and better application of Reference Model Mining. Depending on their individual use cases, designers should be able to make informed choices on their design principles and suitable mining techniques.

4 Situational Reference Model Mining

4.1 Idea and Conceptualization

Figure 3 describes the main idea behind S-RMM by extending and substantiating the reuse-oriented reference model design process from Figure 1. In Reference Model Mining, the reference model is automatically derived from a given set of input models, using a certain mining technique. The reference model is then used for the construction of the target models in a certain application context. Depending on the situational circumstances and the target model requirements, a certain design principle is applied to derive the target model from the reference model. This design principle poses certain restrictions and requirements to the reference model design, which is mainly influenced by the choice of the technique that was used to mine the reference model in the first place. Hence, the choice of mining technique is ultimately determined by the situational context of the reference model application.

Reference Model Mining itself is a way of constructing a reference model, i.e. an instantiation of Design For Reuse. Depending on the choice of mining technique, different techniques are used to determine the input model commonalities and construct the reference model. Hence, the choice of mining technique determines not only the content, but also the character of the reference model. It restricts the application of design principles for target model derivation, i.e. Design With Reuse, which is a use case for Reference Model Mining.

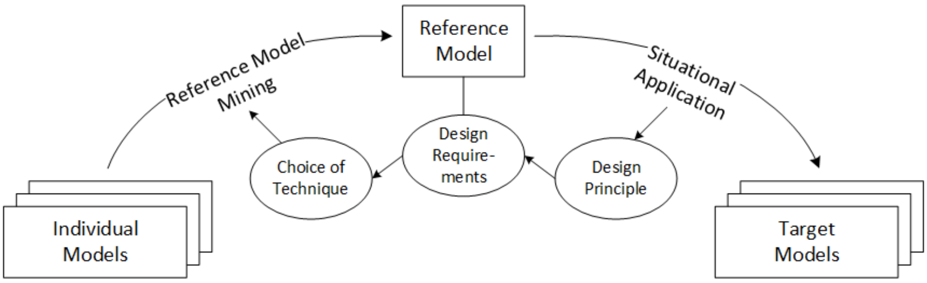

Figure 3: Main Idea behind Situational Reference Model Mining

4.2 Procedure Model

A general procedure model for Situational Reference Model Mining is shown in Figure 4. It is built around the conceptualization of S-RMM in Figure 3. The procedure model describes a generic execution process of an S-RMM application. It consists of ten steps, each of which belongs to one of the two generic design processes. DWR is concerned with the target model construction (i.e. the reference model application), whereas DFR focusses on the reference model construction (i.e. the actual mining). The generic S-RMM process starts with Design For Reuse, where seven steps are executed, and continues in Design With Reuse, with three steps.

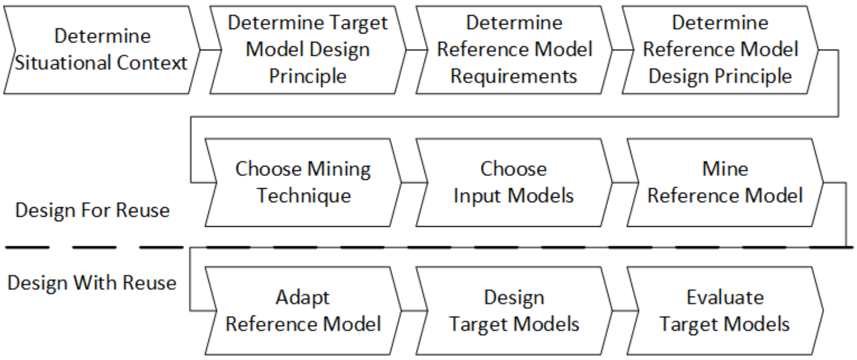

Figure 4: Procedure Model for Situational Reference Model Mining

1. Determine Situational Context: As a basis for any S-RMM application, the situational context has to be analyzed by determining the intended use for the target models and the required characteristics that follow from it. These may include defining the type of process, type of model, process domain, modeling language, level of abstraction, scope, or other target model characteristics. The situational context is also mainly influenced by the available input models, as their characteristics determine which design principles may be reasonably applied.
2. Determine Target Model Design Principle: Depending on the situational context and the inferred requirements, the target model design principle is chosen, based on the assessment which of the five principles satisfies the requirements the best.
3. Determine Reference Model Requirements: From the chosen design principle follow several requirements to the design of the reference model design. These are mainly independent from the situational context, as they follow mostly from the principle itself. For example, applying configuration requires a configurable reference model, while instantiation calls for generic process interfaces that can be individually specified.
4. Determine Reference Model Design Principle: Depending on the required design of the reference model, the process designer has to choose the design principle that should be applied in the mining process in order to fulfill these requirements.
5. Choose Mining Technique: Choosing an applicable and appropriate reference model mining technique is influenced by the chosen reference model design principle, but also the situational context that was previously analyzed, as the reference model has to fulfill a number of constraints. If several techniques qualify, it might be necessary to compare the resulting reference models to determine the best fit for the situational use case.
6. Choose Input Models: Usually, a set of input models is selected prior to beginning the mining process, as they determine the situational context. However, due to possible restrictions and requirements, the final set of input models can only be selected after the mining technique is chosen.
7. Mine Reference Model: The reference model is obtained by applying the mining technique to the chosen set of input models. As they depend on both the input data and the situational context, potential parameter configurations have to be individually determined to yield the best-fitting reference model.
8. Adapt Reference Model: As reference model mining techniques are usually fully automated, the resulting model may not fulfill all the requirements derived from the situational context. Hence, it may have to be manually adapted, for example by adding, deleting or renaming nodes, or complementing the reference model with deductively developed model parts.
9. Design Target Models: After the reference model is finalized, it can be used for the target model construction. Therefore, the design principle determined in step 2 is now applied to the reference model. Each target model undergoes a separate construction process, where the individual model requirements are addressed in the best possible way.
10. Evaluate Target Models: The goal of applying the S-RMM procedure model is to design a reusable and thus useful reference model and use this as a basis for high-

quality target models. Hence, in the last step, the target models are evaluated against the requirements derived from their intended use case. This step may lead to individual adaptations of the target models, but may also serve to enhance the reference model for further reusing. In addition, this step allows process designers to reflect on the S-RMM process as a whole, pointing out eventual improvements.

4.3 Analysis of Existing Mining Techniques

Table 1: Analysis of Existing Mining Techniques

Target Model Design Principle	Reference Model Requirements	Input Model Characteristics	Reference Model Design Principle	RMM Techniques
Configuration	Subsumes different characteristic values of a domain aspect (e.g. different process types).	Belong to the same domain, but describe different instantiations (e.g. subdomains).	Aggregation	[9-13, 20, 21]
			Analogy	[10, 14, 23]
Instantiation	Contains generic interfaces acting as placeholders for certain domain aspects (e.g. activities).	Come from the same domain, but differ in certain domain aspects that can be abstracted.	Aggregation	[16]
Specialization	Contains only universally applicable, contextually adaptable domain aspects.	Contain identical fragments representing universally valid domain aspects.	Aggregation	[9-12, 20]
			Analogy	[14, 23]
Aggregation	Requires several models, each covering one aspect relevant to the application context.	Originate from different backgrounds, but complement each other in terms of content.	--	
Analogy	Contains fragments that are directly applicable in target model context (i.e. in content and level of abstraction)	At least one is generic enough to serve as the basis for reference model design. The others can e.g. be derived variants.	Configuration	[13, 22]
			Aggregation	[9-12, 21]
			Analogy	[14, 23]

In order to provide a guideline for applying the procedure model for S-RMM, we analyze existing mining techniques regarding their underlying principles and requirements, as summarized in Table 1. For each target model design principle, we list the necessary reference model requirements and input model characteristics, such that this principle is applicable. Then, we suggest corresponding reference model design principles and, for each pair, a suitable mining technique. The analysis is restricted to those combinations of target and reference model design principle that are described in section 2.2 and actually substantiated by a mining technique, not those that generally exist or make sense.

Table 1 suggests both techniques that are specifically devised for Reference Model Mining (or Inductive Reference Model Development), such as Process Variant Clustering [10], and techniques that are originally intended for another use case, but can be employed accordingly, such as Process Model Merging [20]. Selection criteria were that the described technique (a) takes a set of models as input, (b) outputs a single model that is in some way based on the input models, (c) is fully automated, and (d) describes a domain-independent method that can be applied to any set of input models. This excludes methodical frameworks such as [8], partially manual approaches such as [17], or empirical, domain-specific reports such as [18]. The table is not intended as a complete list or a state-of-the-art analysis of Reference Model Mining, but as a complementary guideline to our procedure model.

5 Case Study

To illustrate the concept of Situational Reference Model Mining, we apply it in a case study. Figure 5 shows three auditing processes for three different types of retail business (wholesale, warehousing, central processing), translated and slightly adapted from their documentation in the Retail-H reference model [24]. These models will serve as both the target models and the individual models in our case study.

Determine Situational Context. Our target models treat the same process (auditing) in three different sub-domains of the retail domain, i.e. wholesaling, warehousing, and central processing. We assume that the objective is to design an inclusive reference model for auditing processes in retail, including all the differentiations in terms of business type. This means that the reference model should include the specificities of auditing in all three processes. Another option would be to design a model containing only those components that are present in all the input models, i.e. an excerpt.

Determine Target Model Design Principle. Since we intend to design an inclusive reference model, which represents several different sub-domains, the reference model scope is larger than the scope of the target models. Hence, parts of the reference model are irrelevant for each target model and should be deleted. Configuration appears to be a suitable design principle for the derivation of the reference model, as it allows for the selective adoption of applicable model parts and their adaption to the individual situation.

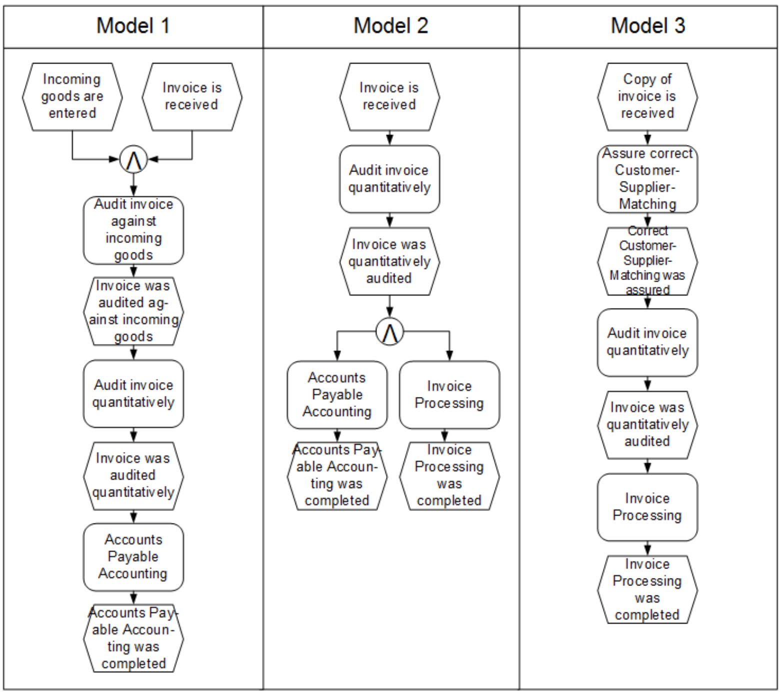

Figure 5: Example Models used for Case Study

Determine Reference Model Design Principle. Aggregation entails adopting and composing parts of several individual models, such that the resulting model subsumes the input models. Since all input models are equally considered, it is an applicable design principle for the reference model. If one input model were used as the basis for the reference model design, specialization or analogy would be more appropriate.

Choose Mining Technique. An inclusive reference model should be mined with a technique that preserves both the elements and the semantics of the individual model. The objective of Process Model Merging [20] is to construct a consolidated model out of a set of process models that share common fragments. As merged models are meant to subsume a set of process model variants, the mining technique is suited for our use case here.

Choose Input Models. For our case study, our input models are equivalent to the set of target models. As the merging algorithm is defined on Event-Driven Process Chains, it can be applied straightforwardly. A pairwise mapping between the input models is required as additional input. We assume that nodes carrying an identical label are mapped onto each other. Process Merging is defined on model pairs, however, the merging order should not have an influence on the resulting model.

Mine Reference Model. We mine the reference model by first merging model 1 and model 2 and then merging the resulting model with model 3. The resulting reference model is shown on the left of Figure 6.

Adapt Reference Model. Technically, the resulting reference model could be used for configuring the target models. However, the model is not syntactically correct, as an event ("Invoice is received") is followed by an XOR-connector. Hence, we adapt the model manually to include the differentiation between the warehousing and wholesale sub-domain. This way, we yield a syntactically correct EPC, which can be configured in the next step.

Design Target Models. The three target models are derived by configuring the adapted reference model. In our use case, this means that those model parts that are irrelevant for the individual sub-domain are removed from the model and the remaining relevant model parts are reordered and connected to form a valid EPC. If applicable, OR-connectors should be configured to be semantically precise.

Evaluate Target Models. In our use case, the target models were predefined, so there is no need for an evaluation in terms of process implementation. However, we can state that both chosen design principles were applicable to the use case. Configuration and aggregation are a suitable pair, but configuration could also be matched with specialization or analogy.

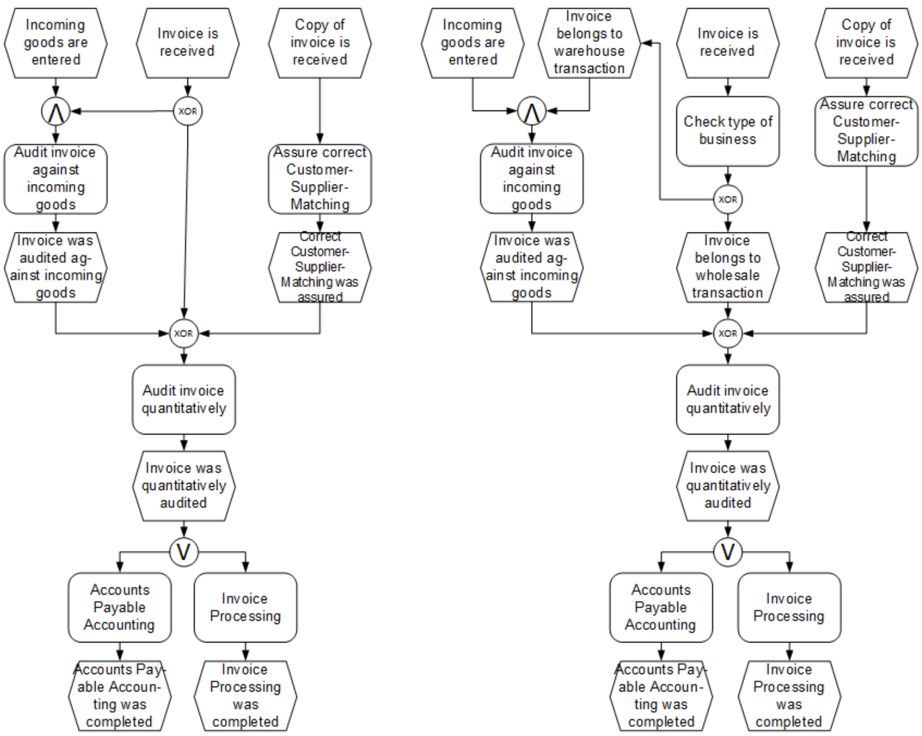

Figure 6: Merged reference model

6 Discussion and Conclusion

In this contribution, we introduce the concept of Situational Reference Model Mining. Based on the idea that the requirements to a reference model and thus the optimal mining technique depend on the situational context, we intend to give reference model designers a guideline for choosing the right mining technique for their individual purpose. As this idea has not yet been elaborated in the respective literature, our procedure model is intended as a first recommendation for a concrete approach. This way, we intend to increase the practical applicability of Reference Model Mining and make its advantages available to a wider range of users.

Our first assessment of S-RMM allows for several observations. First, different mining techniques yield different reference models, both in content and design, even when they are applied to the same set of input models. Parametrization may or may not be a decisive factor in reference model construction. The influence of parameters on the reference model contents and design has to be determined individually for each technique. For example, the order in process model merging should not influence the resulting model, while a frequency threshold (as for example in [11, 12]) determines whether a reference model is the intersection or the union of the input models. In this case, the parameter value also determines the design principle. Depending on the relative frequency of the reference model elements, configuration, analogy, or specialization are applicable. This is why multiple mining techniques apply to several combinations of target and reference model design principle, as seen in Table 1.

The results of the case study in section 5 underline our initial characterization of S-RMM. In order to apply Process Model Merging in a contextually meaningful way, we had to make a number of assumptions, such as the intended use of the reference model, the target models, and the related design principles. While all assumptions made above form a reasonable use case for reference modeling, there exists a plethora of other potential use cases, where the same input models would yield completely different results. Also, we saw that the combination of target and reference model design principle is not sufficient to choose an appropriate mining technique. As shown in Table 1, Process Model Merging is only one of many applicable techniques for the combination of aggregation/configuration. Applying another technique might not yield a reference model as the union of the input models, as seen in Figure 6. Nevertheless, it might be a meaningful reference model in a number of use cases.

Our analysis of existing mining techniques in Section 3.3 shows that the aggregation principle is predominant in reference model construction, while configuration is the mainly followed principle in reference model application. This is not surprising, given the nature of reference model mining. When deriving a reference model with a certain degree of universal applicability from a set of input models, aggregating their common features is evident but not the only technique to achieve a meaningful model. Basing the reference model on an input model and adapting it to reduce the difference to the remaining ones realizes the analogy principle, as for example in [10]. On the other hand, a reference model that aggregates aspects from different sub-domains has to be configured in order to obtain a model that applies to only one of them. However, aggregation may also yield the most common fragments (such as Process Model Intersection in [20]), where specialization or instantiation are appropriate design principles. To conclude, although aggregation/configuration is prominent, the pairwise combination of construction and application principle is not automatically given, but depends on the characteristics of the mining technique.

The analysis in Section 3.3 also shows that the instantiation principle is underrepresented in Reference Model Mining. Only if the reference model is constructed by means of process abstraction, the target models may be derived by means of instantiation. This is due to the fact that most existing approaches to Reference Model Mining are not capable of handling input models with varying degrees of abstraction. Hence, the abstraction level remains the same across all the input models and the reference model. The generic placeholder elements necessary for instantiation cannot be derived from differing, but more specific input models.

Our analysis also reveals that currently there exists no applicable technique for deriving the reference model by means of aggregation. That is because aggregation draws on several conceptual models covering different aspects of the situational context that are to be composed in the target model. None of the existing mining techniques is explicitly set out to mine several different reference models covering different aspects of the defined domain. However, such a scenario is realistic, for example when the reference model is supposed to cover a large domain, which should be divided into sub-domains to ensure the reference model applicability.

In this contribution we draw on the five principles configuration, instantiation, specialization, aggregation and analogy, as defined in [2]. However, these are not the only principles to be considered for reference model design. For example, Delfmann suggests modification as another design principle, allowing all changes to the reference model that do not result in erroneous or inconsistent models [7]. Besides that, principles like elimination or union might also be useful for reference model design. Elimination would allow designers to delete unnecessary elements from a reference model, whereas union would merge several models, without aggregating their contents.

Our analysis of existing mining techniques in Table 1 also acts as a gap analysis, identifying further research potentials and objectives and allowing for a more structural design of new mining techniques. The main motivation for this contribution is to increase the practical applicability of Reference Model Mining. Currently, there exist a number of publications that focus on technical and methodical aspects, as well as a few implementations, but few concrete suggestions for their application. By coining the term “Situational Reference Model Mining”, we emphasize that the choice of technique is relevant, i.e. they cannot always be interchangeably used. The procedure model, in combination with the analysis of existing techniques, is supposed to be a guideline for both reference modeling researchers and practitioners. However, it has not yet been evaluated by being applied in a large-scale context. Gaining more experience in practical applications of existing RMM techniques remains one of the major objectives of further reference modeling research. Our underlying assumptions, however, should be critically assessed. For example, in some cases it could make sense to develop situationally adequate target models instead of choosing an appropriate the mining technique.

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