Technische Universiteit Eindhoven
Department of Mathematics and Computer Science

Master's Thesis

Configurable *Declare*

by

Dennis Schunselaar

Supervisors

dr. Natalia Sidorova
dr. Fabrizio M. Maggi
dr. George Fletcher

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Abstract

In literature, there is an increasing interest in configurable process models [Got09]. Configurable process models are process models which can be (slightly) altered, for instance, by adding or removing tasks from the model. This allows companies to adjust the process models to their processes, instead of adjusting their processes to the process models.

Unfortunately, the existing configurable process models are all based on imperative languages, which makes them rigid. Everything which is not stated to be allowed is forbidden. When we move to environments with high variability, e.g. a hospital, one has to choose between maintainability of the system, versus the possibility to cope with the variability. We can best compare the consideration between maintainability and variability with a road network. It is easier and cheaper to maintain a small road network instead of a large road network (maintainability). However, a large road network is more flexible and it is able to cope with, for instance, traffic jams, road reconstruction, disasters, etc. (variability).

Since imperative languages are very rigid, i.e. you can only drive on the roads, we move to declarative languages, and *Declare* in particular. Within *Declare* everything is allowed unless stated otherwise, we can best compare *Declare* with the sea where we are allowed to sail everywhere except where the beacons disallow. This removes the rigidity from process models. However, companies still want to be able to adjust the models to their processes. More specifically, they want to have flexibility at configuration-time, i.e. between design-time and run-time, whilst maintaining the flexibility at run-time. Therefore, we develop *Configurable Declare*, a true extension of *Declare*.

Configurable Declare allows the removal of tasks and constraints from models as well as the substitution of a constraint by a different constraint. We define rules to maintain implicit constraints, i.e. constraints that are not explicitly encoded in the model but deducible from other constraints, e.g. if task Opening the patient for surgery is always followed by Inserting pacemaker and Inserting pacemaker is always followed by Closing the patient after surgery then implicitly task Opening the patient for surgery will always be followed by Closing the patient after surgery. Using these rules, we are able to remove activities from the model whilst maintaining the implicit constraints. Furthermore, we use these rules to combine a set of *Declare* models into a single minimal *Configurable Declare* model, i.e. we use the rules to remove constraints already encoded implicitly. After that, we define configurations which, when applied to the *Configurable Declare* model, yield the original set of *Declare* models.

We have implemented the combining of the different *Declare* models into a single *Configurable Declare* model, as well as transforming a configured *Configurable Declare* model into a *Declare* model. Furthermore, we show with a case study that we can apply our approach on real life models.

Keywords: Declare, Configurable Declare, Configurable Models, Configuration, Patterns

Contents

1 Introduction

Process models are everywhere and each branch of industry uses its own set of process models. However, within the same branch, the process models are often very similar due to legislation and standardisation, e.g. registering a birth or extending a driving license. The maintainability of this set of (very similar) process models is very low. For instance, when legislation changes, all process models have to be updated to support the new legislation. Furthermore, a one-size-fits-all approach is usually incorporated, i.e. although different companies use slightly different processes, they are all forced to use the same process model.

Within the industry, [Got09] (amongst others) partly solves the aforementioned problems by introducing configurable process models. Such process models allow the user to change or remove parts of the model so that the model adheres more closely to the user's processes. This solves the one-size-fits-all problem and improves maintainability because it is possible to describe several slightly different models by a single configurable model. When the configurable model is changed, all process models will be updated automatically. Examples of configurable process modelling languages are: *C-SAP WebFlow*, *C-BPEL*, and *C-YAWL* [Got09].

However, the aforementioned configurable process modelling languages are all imperative and thus inherently rigid, i.e. if something is not specified as allowed, it is forbidden. If such languages would be used in an environment with high variability, e.g. a hospital, one has to choose between the maintainability of the system versus the possibility to cope with the high variability. Imperative models become very complex when they have to cope with variability, i.e. every possible execution path has to be encoded in the model, and complex models are harder to maintain than simple models. For instance, for a hospital one has to choose between the maintainability of the system versus the freedom of the medical staff to perform their tasks.

To address this problem, we use a declarative approach and the declarative language *Declare*. Within *Declare* [PvdA06, PSvdA07], everything is allowed unless stated otherwise (differently from imperative languages in which everything is forbidden unless stated otherwise). For instance, when applied to a hospital, we only need to prohibit executions which are against legislation or hospital policies and *Declare* allows the medical staff to perform their task the way they want.

Declare partly solves our problems, since it removes the rigidity from the models, but is does not allow us to solve the one-size-fits-all problem neither present a solution to increase maintainability. To solve the one-size-fits-all and maintainability problems, we create *Configurable Declare*, a true extension of *Declare*. *Configurable Declare* is new and it has not been defined earlier, we consider this thesis as a starting point for *Configurable Declare*. Due to time limitations, we were not able to address all issues identified in this thesis. However, in the future work section (Section 8), we show that most issues (which still exist) can be easily addressed.

Imperative configurable process models have to support a number of operations, e.g. the removal of a task from the process model. Some patterns have been identified to support these operations [DRvdA$^+$06, SLS10, BDKK04, Got09]. We want that *Configurable Declare* supports the identified patterns which entail the model itself, i.e. which reason about the control-flow instead of, for instance, the different views on the model.

Our goal in this thesis is to define *Configurable Declare* so that it supports similar configuration possibilities as in imperative configurable process models. Furthermore, it should support the patterns identified in literature w.r.t. the control-flow. *Configurable Declare* should maintain the implicit constraints after the removal of a task. Finally, *Configurable Declare* should be applicable to real life models.

Almost every *Declare* model has implicit constraints. Implicit constraints are constraints which are derived from other constraints, e.g. if task Opening the patient for surgery is always followed by Inserting pacemaker and Inserting pacemaker is always followed by Closing the patient after surgery then implicitly task Opening the patient for surgery will always be followed by Closing the patient after surgery.

We present a conversion from a *Configurable Declare* model and a configuration to a *Declare* model whilst maintaining the aforementioned implicit constraints. These implicit constraints are encoded as a set of rules where, in case there is a constraint between A and B, and between B and C, we specify the implicit constraint between A and C. Each of these rules reason on a semantic level w.r.t. the constraints.

We also present a conversion from a set of *Declare* models into a single *Configurable Declare* model. This allows organisations to use *Configurable Declare* on their current set of *Declare* models without the need to create the *Configurable Declare* model from scratch. This *Configurable Declare* model can be manually configured to obtain the original set of *Declare* models. We use the aforementioned rules to minimise the *Configurable Declare* model by removing constraints deducible from other constraints present in the *Configurable Declare* model.

We present an implementation of the conversion in both directions. We will elaborate on the encoding of the application of the rules. We use this implementation for a case study involving a set of *Declare* models describing business processes of different Dutch municipalities. These models represent the production of an excerpt from the civil registration and all models are combined into a single *Configurable Declare* model. On this *Configurable Declare* model, we manually define configurations that, when applied to the *Configurable Declare* model, yield the set of input models. This case study represents a real application of the proposed approach.

This document is structured as follows: Section 2 gives an extensive explanation of *Declare*. In Section 3, an overview of related work with respect to configurable models is given as well as the configuration patterns found in literature. *Configurable Declare* is explained in Section 4 along with a further explanation of the configuration patterns listed in Section 3. In Section 5, we explain how to combine a set of *Declare* models into a single *Configurable Declare* model. The implementation of the conversions is described in Section 6. Section 7 presents the case study where we apply our approach. Finally, future work and the conclusion are presented in Section 8 and 9 respectively.

2 Preliminaries

In this section, we explain the notion of process flexibility, *Declare*, and Linear Temporal Logic. All three notions are used throughout this thesis in different sections.

2.1 Process flexibility

In [Sof05], a number of definitions are given for flexibility. The main idea of these definitions is: flexibility is the ability to react to (unexpected) changes. A number of patterns associated with flexibility can be found in [MvdAR]. One of the patterns mentioned in [MvdAR] is the *Flexibility by design* pattern in which the flexibility is encoded in the process model, i.e. instead of allowing only one path through the model, multiple paths have been defined through the model to offer some flexibility.

We use two types of flexibility: (1) flexibility of the process, i.e. the amount of paths through the model, and (2) flexibility of the process model, i.e. the amount of paths which can be altered or added to the model.

The amount of paths through a model is closely related to the notion of an imperative modelling language. In an imperative modelling language, everything has to be modelled which is allowed. When a certain order of activities is allowed, we have to model this explicitly. To allow flexibility by design, one has to encode this in the model using constructs like parallelism, choice, iteration, etc. This means that the model becomes less structured and harder to maintain.

When we move to a declarative approach, we only specify what it disallowed instead of what is allowed, the opposite of imperative modelling. This yields greater flexibility without the need to add extra information to the model. Within declarative models, we have in general that: the smaller the model the more flexible it becomes. The *Flexibility by design* is automatically supported by declarative languages because any path is allowed through the model unless stated otherwise.

2.2 *Declare*

In order to understand *Configurable Declare*, we first explain *Declare*. *Declare* is a constraint-based language proposed in [PvdA06, PSvdA07]. If certain events in *Declare* are not explicitly allowed nor explicitly forbidden, these events are allowed to take place. *Declare* consists of a graphical front-end and a formal back-end, expressed in Linear Temporal Logic [Pnu77]. We only focus on the graphical front-end, i.e. we take the different constraints of *Declare* as regular constructs like the AND-split in process management systems.

We choose to focus on the graphical front-end, since this makes the reasoning better understandable. Most results obtained in this thesis can also be deduced from the formal back-end. However, in some case, we want to rewrite the formula into a non-equivalent formula which captures the semantic meaning. We elaborate further on these cases in the future work section (Section 8).

Within *Declare*, there are four sets of templates: *existence*, *relation*, *negative relation*, and *choice*. We go over each of those four sets of templates and present the informal definition and the graphical representation. We, furthermore, give the order of the different templates within a set of templates. This order denotes which template is stronger than the other template, i.e. whenever a template is valid also another template is valid, the first template is considered to be stronger.

Apart from the term template, we also use the term constraint. Constraints are instances of templates, i.e. templates are the different constructs of the language while constraints are the application of the constructs on the events.

Meta-model

Figure 1 depicts the meta-model of *Declare* which is used in this thesis. Here, a *Model* class consists of a set of *Events* and *Constraints*, and a *Constraint* is associated with at least one *Event*. The *choice* constraints have a m and a n associated with them to denote that m out of the n connected events are performed, and the *existence* constraints have a n associated with them to denote the bound.

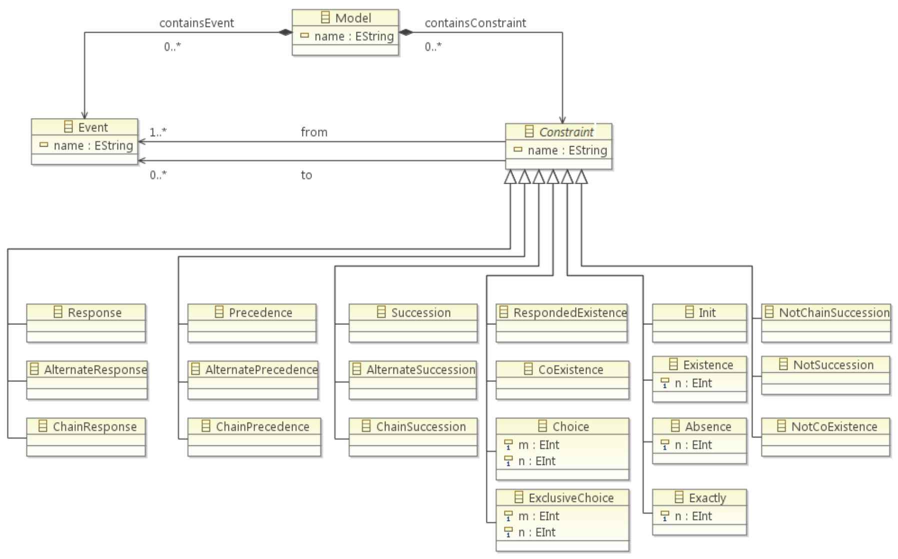


Figure 1: Meta-model of *Declare*

Existence templates

The *existence* templates in *Declare* are listed in Table 1. In Figure 2, the order between the different *existence* templates is depicted. We do not have a stronger/weaker relation between the different *exactly* templates because they are incomparable. The *exactly* template is the conjunction of the *existence* and *absence*, and when the *existence* template is stronger, the *absence* template is weaker and vice versa.

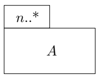
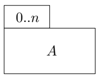
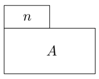
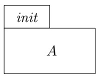
Template name	Informal definition	Graphical representation
existence(n, A)	Event A has to happen at least n times	
absence$(n+1, A)$	Event A can happen at most n times	
exactly(n, A)	Both *existence*(n, A) and *absence*$(n+1, A)$ have to hold	
init(A)	Event A has to be the first event which is executed	

Table 1: The *existence* templates

$$\begin{tikzcd}
\boxed{absence_{n+2}} & \boxed{exactly_{n+1}} \arrow[l] \arrow[r] & \boxed{existence_{n+1}} \arrow[d] \\
\boxed{absence_{n+1}} \arrow[u] & \boxed{exactly_{n}} \arrow[l] \arrow[r] & \boxed{existence_{n}} \arrow[d] \\
\boxed{absence_{n}} \arrow[u] & \boxed{exactly_{n-1}} \arrow[l] \arrow[r] & \boxed{existence_{n-1}} \\
 & \boxed{init} &
\end{tikzcd}$$

Figure 2: The order between the *existence* templates in *Declare*

Relation templates

The *relation* templates are listed in Table 2. In Figure 3, the ordering between the different constraints is shown. Note that *co-existence*(A, B) is equivalent to *co-existence*(B, A), therefore, *succession*(A, B) is stronger than *co-existence*(A, B) and *co-existence*(B, A). We have a similar relation between *co-existence* and *responded existence*, i.e. *co-existence*(A, B) is stronger than *responded existence*(A, B) and *responded existence*(B, A).

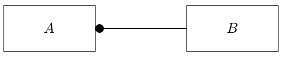
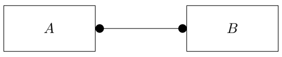
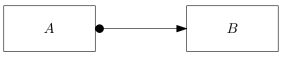
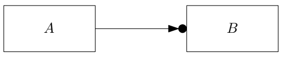
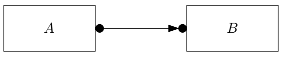
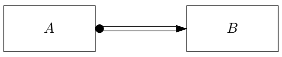
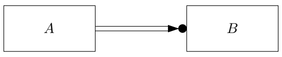
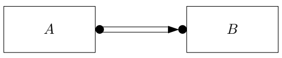
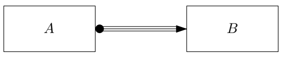
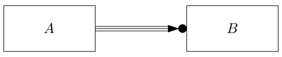
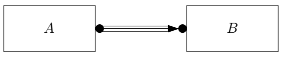
Template name	Informal definition	Graphical
responded existence(A, B)	If event A happens event B should also happen	
co-existence(A, B)	Both *responded existence*(A, B) and *responded existence*(B, A) have to hold	
response(A, B)	If event A happens event B should eventually follow	
precedence(A, B)	Event B has to be preceded by event A	
succession(A, B)	Both *response*(A, B) and *precedence*(A, B) have to hold	
alternate response(A, B)	Event A should be followed by event B and we cannot have an A in between	
alternate precedence(A, B)	Event B has to be preceded by event A and we cannot have a B in between	
alternate succession(A, B)	Both *alternate response*(A, B) and *alternate precedence*(A, B) have to hold	
chain response(A, B)	Event A should be directly followed by event B	
chain precedence(A, B)	Event B should be directly preceded by event A	
chain succession(A, B)	Both *chain response*(A, B) and *chain precedence*(A, B) have to hold	

Table 2: The *relation* templates

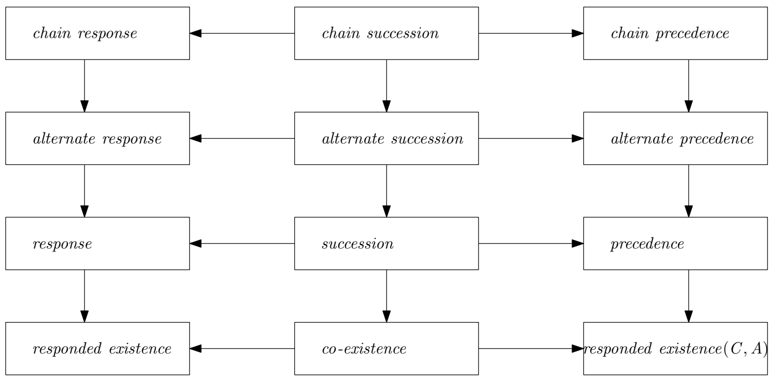


Figure 3: The order between the *relation* templates in *Declare*

Negative relation templates

The different *negative relation* templates are listed in Table 3. Furthermore, the ordering between the *negative relation* templates is depicted in Figure 4.

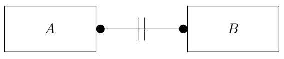
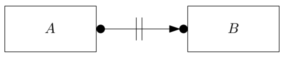
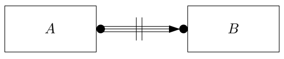
Template name	Informal definition	Graphical
not co-existence(A, B)	Event A and event B do not occur together in a trace	
not succession(A, B)	Event B does not follow event A	
not chain succession(A, B)	Event B does not follow event A directly	

Table 3: The *negative relation* templates

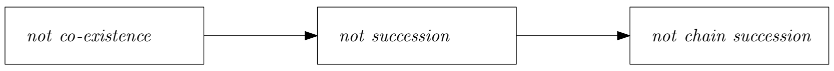


Figure 4: The order between the *negative relation* templates in *Declare*

Choice templates

In Table 4, the different *choice* templates are listed. The ordering between the templates is shown in Figure 5. When we have to execute n *of* n events, there is an equivalence between *choice* and *exclusive choice*, i.e. *choice*$(n$ *of* $n)$ is equivalent to *exclusive choice*$(n$ *of* $n)$, because we have to execute all events. We do not have a stronger/weaker relation between the different *exclusive choice* templates because the different templates exclude each other. When *exclusive choice*$(m$ *of* $n)$ is valid, exactly m events have to be executed, which means that we do not execute exactly $m - 1$ or exactly $m + 1$ events.

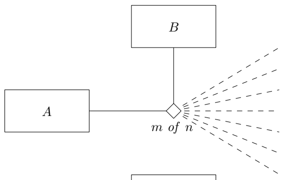
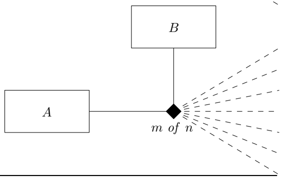
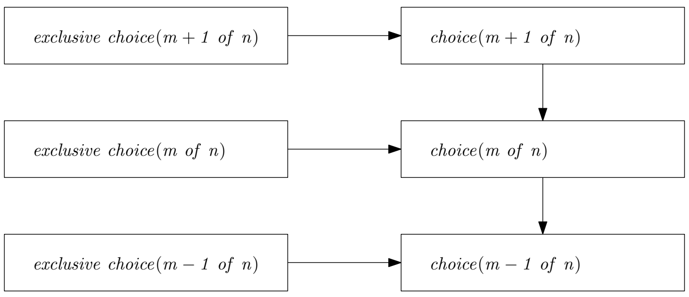
Template name	Informal definition	Graphical
choice $(m$ *of* $n)$ $(A, B, \cdots)$	at least m out of the n events have to occur	
exclusive choice $(m$ *of* $n)$ $(A, B, \cdots)$	exactly m out of the n events have to occur	

Table 4: The *choice* templates



exclusive choice$(m + 1$ *of* $n)$
choice$(m + 1$ *of* $n)$
exclusive choice$(m$ *of* $n)$
choice$(m$ *of* $n)$
exclusive choice$(m - 1$ *of* $n)$
choice$(m - 1$ *of* $n)$

Figure 5: The order between the *choice* templates in *Declare*

Branched Declare

For each of the aforementioned templates, except the *choice* templates, we also have a branched variant in *Branched Declare*. A branched variant means that, instead of a single event, we have a multitude of events. Consider, for instance, the *response* template, in *Branched Declare*, we have instead of *response*(A, B) two sets of events: *response*$(\{A_1, \cdots A_n\}, \{B_1 \cdots B_m\})$ denoting that if either event A_1 or A_2 etc. happens, eventually event B_1 or B_2 etc. should happen. In the tables for the different templates, one needs to read A_1 or A_2 etc. instead of A and B_1 or B_2 etc. instead of B.

Apart from a different semantic, *Branched Declare* also has a different graphical representation. Instead of a single arrow between two events, we now have an arrow with multiple heads and tails between the different events. In Figure 6, an example of a branched *response* constraint is shown.

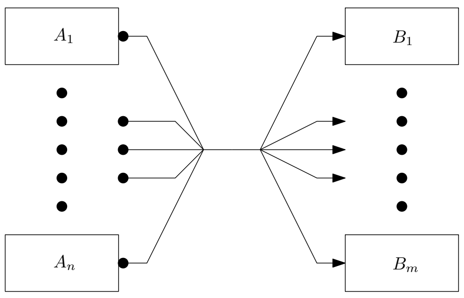


Figure 6: An example of a branched response

2.3 Linear Temporal Logic

Linear Temporal Logic [Pnu77], or LTL for short, is a logic which reasons about paths through some model, e.g. an automaton. For instance, if we have a set of traces, we can view each trace as a path through the process model that generated those traces. Using LTL, we can validate whether the traces, and to some extent also the process model, adheres to certain constraints on the paths through the process model. For instance, if we never want to see a B directly following an A, we can express this with: $\Box(A \Rightarrow \neg \bigcirc (B))$. Using a model checker, we can validate this formula on our set of traces.

It goes beyond the scope of this thesis to give a full explanation of LTL. We would like to refer the interested reader to [Pnu77] for a more extensive explanation on LTL. We give a formal definition of the different constructs of LTL. In Table 5, the main LTL constructs are listed which are used in this thesis.

We use the following variables: let A be the set of actions, $A = \{b, c, d, e, \cdots\}$, w a sequence of actions, i.e. $w = a_1, a_2, a_3, \cdots$ and let w_i denote the ith action in the sequence, i.e. $w_i = a_i$. With w^j, we denote the suffix of w, i.e. $w^j = a_j, a_{j+1}, \cdots$. The satisfaction relation $\models$ between a sequence of actions and a LTL formula is now defined for the different operators of LTL in Table 5, note that $p \in A$ is a single action, where ψ and ϕ are arbitrary formulas.

LTL construct	Formal meaning
$w \models p$	if $p \in w_1$
$w \models \neg\psi$	if $w \not\models \psi$
$w \models \psi \vee \phi$	if $w \models \psi$ or $w \models \phi$
$w \models \psi \wedge \phi$	if $w \models \psi$ and $w \models \phi$
$w \models \psi \Rightarrow \phi$	if $w \models \neg\psi \vee \phi$
$w \models \psi \Leftrightarrow \phi$	if $w \models \phi \Rightarrow \psi \wedge \psi \Rightarrow \phi$
$w \models true$	if $w \models p \vee \neg p$
$w \models \bigcirc\psi$	if $w^2 \models \psi$
$w \models \psi U \phi$	if there exists $i > 0$ such that $w^i \models \phi$ and for all $0 < k < i$, $w^k \models \psi$
$w \models \Diamond(\psi)$	$w \models true\, U \psi$
$w \models \Box(\psi)$	$w \models \neg\Diamond(\neg\psi)$
$w \models \psi W \phi$	$w \models (\psi U \phi) \vee \Box(\psi)$

Table 5: LTL constructs

3 Known Configuration Patterns

Some configuration patterns have been identified in literature. We list the papers from which we have used configuration patterns as a starting point for *Configurable Declare*. Each paper we consider is accompanied by a small introduction and a table listing the different patterns considered in those papers.

As mentioned in the introduction, we want that *Configurable Declare* supports a number of patterns. These patterns, or configuration patterns, are a collection of constructs or operations which have to be supported by the process model, i.e. they can be used in the process model. We have two types of configuration patterns: patterns related to the views on the process model, and patterns related to the process model itself. Note that we use the terms workflow and process interchangeable to stay consistent with the papers.

In [DRvdA$^+$06] (Table 6), a process model is designed but it can later on be (slightly) altered at build-time, i.e. certain parts of the model can be substituted or removed. E.g. the user has the option to change the relation between different events, so instead of both events occurring the user can choose that exactly one of the events occurs. Similarly, in *Configurable Declare*, we want that after the creation of the configurable process model the user has the option to (slightly) alter parts of the model.

Pattern Name	Effects	Will be considered
Optionality (Sect. 4.4)	Choose to execute a task or not (build-time)	Yes, we want to have the flexibility to remove events from the configurable model prior to executing the model
Inter-relationship (Sect. 4.1)	Execution of a task depends on the execution of another task	No, we will not consider this as a pattern since the language constructs already allow such behaviour when specified. E.g. *co-existence* or *not co-existence*
Interleaved parallel routing (Sect. 4.1)	Choose in which order a set of tasks is executed	No, we will not consider this as a pattern since the language constructs already allow such behaviour when specified. E.g. *precedence*
Parallel split (OR) (Sect. 4.1)	Choose a subset of the tasks	No, we will not consider this as a pattern since the language constructs already allow such behaviour when specified. E.g. *choice* in combination with the *optionality* pattern

Table 6 continues on the next page

Pattern Name	Effects	Will be considered
Exclusive choice (Sect. 4.1)	Choose exclusively a task	No, we will not consider this as a pattern since the language constructs already allow such behaviour when specified. E.g. *exclusive choice*
Multi choice (Sect. 4.1)	XOR, OR, and AND split	No, we will not consider this as a pattern since the language constructs already allow such behaviour when specified. E.g. *choice* and *exclusive choice* in combination with the *optionality* pattern

Table 6: Configuration patterns [DRvdA+06]

[Got09] (Table 7) gives an overview of adding configurations to different workflow management systems, and workflow languages. [Got09], furthermore, gives an approach to configure a process model by hiding or blocking inflow and outflow ports, i.e. the incoming and outgoing arcs. These patterns are similar to some patterns in [DRvdA+06].

Pattern Name	Effects	Will be considered
(optional) Blocking	Choose to block (not execute) or not to block (execute) an event	No, we will not consider this as a pattern since the language constructs already allow such behaviour when specified. E.g. *absence*$_1$ in combination with the *optionality* pattern
(optional) Hiding	Choose to hide or not to hide an event	Yes, similar to the *optionality* pattern

Table 7: Configuration patterns [Got09]

In [SLS10] (Table 8), the authors assume a static model in which different users want different views on a workflow model, e.g. a sales manager needs different information than a programmer. One has to be able to support a number of actions with respect to different views, e.g. within the *abstraction* patterns one can choose from which parts of the model to abstract in a certain view. We only support the patterns by [SLS10] which can be transformed in patterns for the process model itself, e.g. *abstraction*, since *Declare* reasons about process models and not about the views on the process model.

Pattern Name	Effects	Will be considered
Omission (Sect. 4.4)	Same as *optionality* pattern	Yes, we want to have the flexibility to remove events from the configurable model
Abstraction	Do not state explicitly what is happening, i.e. we know something is happening but we do not know exactly what	No, since it is part of the view on the model and thus outside the scope of this thesis
Insertion	Insert an event	No, gives room for too diverse models which are harder to maintain, and a designer of a configurable model can already include a multitude of events to suit the processes of the different users in combination with the *optionality* pattern
Aggregation (Sect. 4.1)	Combine events into one event	No, we will not consider this as a pattern since the language constructs already allow such behaviour when specified. E.g. *chain succession*
Alteration (Sect. 4.4)	Change properties of the model	Yes, but only the constraints between the events, and only based on rules specified by the designer of the configurable model
Preservation (Sect. 4.1)	States whether a pattern can be applied	Yes, implicit in the model, i.e. which parts can be changed
Presentation Patterns	Change the representation of constructs	No, outside the scope of the thesis

Table 8: Configuration patterns [SLS10]

Within [BDKK04] (Table 9), a number of patterns are described which allow the user to change her view on the process model. These patterns entail that the user can select sets of "similar" process elements and hide these, each pattern defines a different kind of similarity between process elements. E.g. the user can select all objects which have a certain value for a certain attribute. We only support a slightly altered *Relationship type selection* pattern.

Pattern Name	Effects	Will be considered
Object Type Selection	Selecting all events of a particular type	No, can be done manually

Table 9 continues on the next page

Pattern Name	Effects	Will be considered
Representation Variations	Change the representation of constructs	No, outside the scope of the thesis
Attribute-based object selection	Selecting or hiding events with a certain value for a certain attribute	No, can be done manually
Term-based object selection	Selecting or hiding events based on an expression with respect to some identifiers	No, can be done manually
Relationship type selection (Sect. 4.4)	Choose the type of the relationship which one wants to hide or wants to show	Yes, can be done by switching constraints on or off

Table 9: Configuration patterns [BDKK04]

There are no configuration patterns for *Declare* or for *Configurable Declare*, therefore, we use a number of patterns mentioned in the papers listed here as a starting point for patterns which need to be supported by *Configurable Declare*. Note that all patterns listed in these papers reason about process models specified in an imperative language. Therefore, we cannot apply the patterns directly to *Configurable Declare*. Within each table, we have presented some intuition on how to support the different patterns if they can already be encoded in *Declare*. Each pattern, which we want to support or is already supported, is considered in more detail in the next section.

4 Configurable Declare

Configurable process models have been defined for some of the imperative modelling languages. However, as mentioned in the introduction, we do not yet have configurable process models for declarative languages. Therefore, we define *Configurable Declare* which is explained in this section.

Prior to defining *Configurable Declare*, we list the patterns identified in Section 3 which are already supported by *Declare* (Section 4.1). In general, these patterns are supported by the flexibility which a *Declare* model already offers. For example, with the *inter-relationship* pattern, we want to introduce correlation between the execution of activities A and B which is supported by either a *co-existence* or a *not co-existence* between A and B.

After defining the supported patterns, we extend *Declare* to *Configurable Declare*. We, furthermore, list the different types of configuration patterns we allow. Then, we list how to configure a *Configurable Declare* model. Finally, we list how we support the patterns identified in Section 3 but which are not supported by *Declare*.

4.1 Patterns supported in Declare

The following patterns are already present as a construct in *Declare*. We list how the different patterns can be supported using the constructs.

Inter-relationship

Inter-relationship means that the execution of a task A depends on the execution of a task B and vice versa. According to [DRvdA+06], we have two types of inter-relationship, mutually dependent and mutually exclusive. With mutually dependent, we have that either A and B occur together or they do not occur at all. This can be modelled with a *co-existence* between A and B. When we have a mutually exclusive relation between A and B, this means that A and B cannot occur together. We can model this by having a *not co-existence* between A and B.

Interleaved parallel routing

We want to choose in which order a set of tasks is executed with the interleaved parallel routing pattern. Let the set of tasks be the tasks $A_1, \cdots A_n$. By using the *precedence* constraint between a number of events, the user can choose which events should occur before which other events by simply switching the *precedence* constraint on or off. If we want to support all possible orders of events, we need to add the *precedence* constraint between all pairs of events. Assume we want that the tasks are execute based on their indices, i.e. A_i is executed before A_{i+1}, then we add a *precedence* constraint between two consecutive tasks. This *precedence* constraint enforces that we can only execute the tasks in a certain order.

The aforementioned approach only works the first time the tasks are executed, i.e. after A_i has been executed we can do any number of A_{i+1} independent of A_i. When we strengthen the *precedence* constraints, i.e. substitute them by *alternate precedence* constraints, we can enforce that the order of execution is always maintained after the first execution of the events. With the *alternate precedence* constraint, A_{i+1} cannot happen twice in a row without the execution of A_i.

When we want to strengthen the previous model even further, by stating that the first task cannot execute another time before the last task has been executed, we have to add *alternate succession* between all pairs of tasks. This means we have *alternate succession*(A_i, A_j) for all pairs i and j for which $i < j$.

Parallel split

Within this pattern, we want to choose a subset of the set of tasks consisting of $A_1, \cdots A_n$. We can construct this pattern by using the *choice*(1 of n) constraint between the tasks, this constraint states that we need to do at least one task and we can do at most n tasks, i.e. all of them. If we combine this constraint with the *optionality* pattern for greater flexibility, i.e. in some cases one does not want to consider some tasks, we can express the parallel split pattern as described in [DRvdA$^+$06].

Exclusive choice

Within *Declare*, we have the *exclusive choice*(1 of n) which expresses that we want to have exclusively 1 task out of the n tasks. Using the *optionality* pattern in a similar way as for the *parallel split*, we can support the *exclusive choice* pattern.

Multi choice

The *multi choice* can be translated in a *parallel split*, an *exclusive choice* and an *and-split*. Both the *parallel split* and the *exclusive choice* can be made in the same way as described before. The *and-split* can be made by using the *choice*(n of n) constraint which states that all n tasks should be executed. Again, we can use the *optionality* pattern to remove some tasks.

Aggregation

With the *aggregation* pattern, one wants to combine two events into a single event. Assume these two events are event A and event B, we can aggregate them by placing a *chain succession* between A and B, i.e. every A is directly followed by a B and every B is directly preceded by an A. Using this construction, one can see A and B as a single event, i.e. no other event can occur between A and B.

Preservation

The *preservation* pattern denotes which patterns can be applied on a certain part of the model. Within *Configurable Declare*, each event and constraint is augmented with a boolean stating whether it can be removed, and each constraint has a list associated with it denoting in which other constraints it can be altered. In this sense, the *preservation* pattern is already encoded in the model.

(optional) Blocking

Optional *blocking* gives the user the option to prevent the execution of a particular branch in an imperative model. When we block an activity in *Declare*, i.e. prevent it from executing, we only block activities dependant on the execution of this blocked activity, e.g. via *response* or *precedence* constraints in which, if we want to execute the non-blocked activity, we also need to execute the blocked activity. In this sense, we do not block a particular branch from executing but a set of activities dependant on the execution this activity. We can use the $absence_1$ to encode that a particular activity is blocked, i.e. it does not occur once. If we also make this $absence_1$ constraint optional, we can encode the (optional) blocking.

4.2 Extending *Declare* to ***Configurable Declare***

Configurable Declare is a true extension to *Declare* in the sense that it only annotates the events and constraints in the model with extra information. We can express a multitude of models in *Configurable Declare* with the use of these annotations. However, a *Configurable Declare* model is not executable and operates on a level higher than *Declare*.

We introduce three types of configuration patterns: (1) the removal of an event, (2) the removal of a constraint, and (3) the alteration of a constraint into a different constraint. In the meta-model for *Configurable Declare*, depicted in Figure 60 (Appendix A), the events and constraints have been substituted by configurable events and configurable constraints, identifiable by the prefix C. Each configurable event and configurable constraint has an attribute *omit* which denotes whether this event or constraint can be omitted, i.e. removed from the model. Furthermore, each configurable constraint has a, possibly empty, list associated with it containing all the constraints to which it can be changed to.

4.3 Configuring ***Configurable Declare***

After the design phase of the configurable model, we transform the configurable model in a configuration model. A configuration model is a configurable model which can be annotated, or configured, by the user to model her processes. I.e. in the configuration model the user sets which events and constraints she wants to keep in the model and to which constraints the configurable constraints are changed to. The meta-model for the configuration model is depicted in Figure 61 (Appendix A).

When the user has finished configuring the configuration model, i.e. changed the configuration model in such a way that it resembles, as much as possible, the users processes, it will be transformed into a *Declare* model. These transformations are listed in Section 4.4, and the implementation of these transformations is summarised in Section 6. The different steps are depicted in Figure 7.

In order to clarify the difference between configurable, configuration and a *Declare* model, we use the analogy with a multiple choice test. The configurable model can be viewed as a multiple choice test in which the teacher specifies which options can be chosen for certain questions, events and constraints in our case. The student receives the multiple choice test with the possibility to select which answers she thinks are correct, the configuration model. After

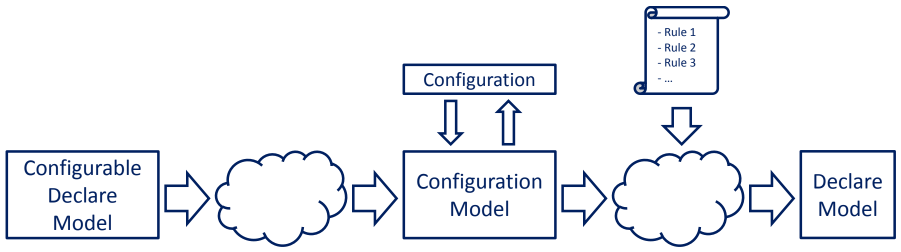


Figure 7: The different transformation when transforming a *Configurable Declare* model into a *Declare* model

completing the multiple choice test, i.e. setting all of the configuration options in the configuration model, the teacher transforms the filled in test to a grade, or a *Declare* model in our case, which takes the selected options into account.

4.4 Patterns supported in Configurable Declare

In the remainder of this section, we elaborate on the patterns we were not able to support within *Declare* but which we can support in *Configurable Declare*.

Optionality pattern

The *optionality* pattern allows the user to configure whether one does want to include an event or one does not want to include an event in the model. We have to define some conversions from the old set of constraints to a new set of constraints in order to remove an event.

We have to define these conversions such that the implicit constraints between events are preserved, e.g. if we have that B and C do not occur together and A and B always occur together, we implicitly have that also A and C do not occur together. In the configured model, we would like to have those implicit constraints since in this way we have a new model which stays, with respect to the allowed behaviour between A and C, close to the configurable model.

We first look at the different *existence* templates and their implication on the other events when we remove an event. Afterwards, we explain how we deal with the *relation* templates such that the implicit constraints still hold between the remaining events. We then show how the different *negative relation* templates are handled, and finally, the conversions of the *choice* templates are mentioned.

At the end of this section, we show how to solve the implicit constraints for models which contain branched constraints. We, furthermore, present problems which have not been solved in this thesis but we present solutions to those problems in the future work section (Section 8).

Shorthand notations Within this section, we use shorthand notation to denote certain sets of templates, e.g. we write $\Diamond B \Rightarrow \Diamond A$ for the set of templates which denote that if we have a B in a trace we also have an A in that trace. In Table 10, a full list is presented with the shorthand notations used in this section. Furthermore, the meaning of the shorthand notation, and the list of templates which are associated with that shorthand notation are listed in that table. Note that if we do not denote the order of the arguments of a template, we assume it is (A, B), e.g. when we write *chain succession* we mean *chain succession*(A, B). We use some shorthand notations identified by [DAC99].

Abbreviation	Meaning	Templates
$\#A \leq \#B$	Means that the total amount of times A is executed does not exceed the total amount of times B is executed	*alternate response*, *alternate precedence*(B, A), *alternate succession*, *chain response*, *chain precedence*(B, A), *chain succession*
$\#A \geq \#B$	Means that the total amount of times A is executed is at least the total amount of times B is executed	*alternate response*(B, A), *alternate precedence*, *alternate succession*, *chain response*(B, A), *chain precedence*, *chain succession*
$\#A = \#B$	Means that the total amount of times A is executed is equal to the total amount of times B is executed	*alternate succession*, *chain succession*
$\Diamond A \Rightarrow \Diamond B$	Means that if there is an A in the trace, there is also a B in the trace	*responded existence*, *co-existence*, *response*, *precedence*(B, A), *succession*, *alternate response*, *alternate precedence*(B, A), *alternate succession*, *chain response*, *chain precedence*(B, A), *chain succession*
$\Diamond A \Leftrightarrow \Diamond B$	Means that if there is an A in the trace, there is also a B in the trace and vice versa	*co-existence*, *succession*, *alternate succession*, *chain succession*
$\neg B W A$	B can only happen after an A has happened	*precedence*, *succession*, *alternate precedence*, *alternate succession*, *chain precedence*, *chain succession*
$\Box(A \Rightarrow \bigcirc(\neg A U B))$	Means that if there is an A in the trace, it is eventually succeeded by a B and there is no other A between these A and B	*alternate response*, *alternate succession*, *chain response*, *chain succession*

Table 10 continues on the next page

Abbreviation	Meaning	Templates
$\neg B\,W A \wedge \Box(B \Rightarrow \bigcirc(\neg B\,W A))$	Every B is preceded by an A and there is no B between these A and B	*alternate precedence*, *alternate succession*, *chain precedence*, *chain succession*
$\Box(A \Rightarrow \Diamond B)$	Means that if there is an A in the trace, it will eventually be followed by a B	*response*, *succession*, *alternate response*, *alternate succession*, *chain response*, *chain succession*
$\Box(A \Rightarrow \bigcirc B)$	Means that every A is directly followed by B	*chain response*, *chain succession*
$\Box(\bigcirc A \Rightarrow B)$	Means that every A is directly preceded by B	*chain precedence*, *chain succession*

Table 10: Shorthand notation for sets of constraints

In the remainder of this subsection, we list how to deal with the different templates. For each template, we have identified the cases where implicit templates occur. Each case consists of a combination of two templates, or classes of templates denoted by the shorthand notation, which are in the model, and, if applicable, a template which should be added after the removal of the event. When we write an LTL like formula, e.g. $\Diamond A \Rightarrow \Diamond B$, we mean the set of templates associated with this formula. We write the name of a template, e.g. *not succession*, when we want a particular template.

Existence templates Within the existence templates, we consider two events, A and B, and we want to remove one of the events (B). A can then be in two different positions with respect to B: it is either in front or after event B. We consider both cases separately. The position of an event A w.r.t. the position of event B is based on the templates between A and B. If A is in front of B, we mean that either after the execution of A we need to have a B, e.g. *response*, or prior to executing a B we need to have executed an A, e.g. *precedence*. A similar reasoning holds when we consider the case in which A is after B.

The relation between A and B can either be a template or a set of templates based on the shorthand notation. If a rule holds for a set of templates, this means that we can apply this rule for each template in that set of templates.

A **in front of** B We have the case as depicted in Figure 8, note that n_1 and n_2 are conjunctions of non-contradictory *existence* templates, e.g. n_1 is *init* and *existence*$_3$ but not that n_2 is *exactly*$_5$ and *absence*$_4$.

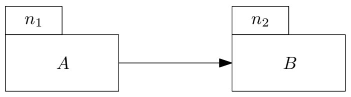


Figure 8: Part of the model if we want to remove event B

In Table 11, all conversions are presented with n_1 consisting of different templates and the relation between A and B. In the last column, the templates are listed which need to be added to n_1 after the removal of event B such that the implicit templates on event A still hold. Note that we have split the *exactly* into its *existence* and *absence* parts, e.g. instead of considering *exactly*$(5, A)$ we consider the rules for *existence*$(5, A)$ and *absence*$(6, A)$.

n_2	Relation A B	Add to n_1
$existence_m$	$\Diamond B \Rightarrow \Diamond A$	$existence_1$
$existence_m$	$\#A \geq \#B$	$existence_m$
$existence_m$	$\Diamond B \Rightarrow \neg\Diamond A$	*absence*
$absence_m$	$\#A \leq \#B$	$absence_m$

Table 11: Steps for removing event B

A **after** B We have the case as depicted in Figure 9, note that n_1 and n_2 are, again, conjunctions of non-contradictory *existence* templates.

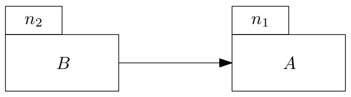


Figure 9: Part of the model if we want to remove event B

In Table 12, the different steps are presented to maintain the implicit templates. Note that we have split the *exactly* into its *existence* and *absence* parts.

n_2	Relation B A	Add to n_1
$existence_m$	$\#B \leq \#A$	$existence_m$
$existence_m$	$\Diamond B \Rightarrow \Diamond A$	$existence_1$
$existence_m$	$\Diamond B \Rightarrow \neg\Diamond A$	*absence*
$absence_m$	$\#B \geq \#A$	$absence_m$
init	$\Box(B \Rightarrow \bigcirc A)$	*init*

Table 12: Steps for removing event B

Relational templates We have three events: A, B, and C, and we want to remove event B from the model. There are three cases: A and C in front of B, A in front of B and C after B, and A and C after B. Each of these cases is treated in isolation. We use the same notion of before and after, similar to the *existence* templates. Furthermore, whenever we use an LTL-like formula we use it to denote the shorthand notation, when we mean a particular template we denote this by using the template name, e.g. *chain response*.

A **and** C **in front of** B We have a part of the model as depicted in Figure 10, note that x and y are *relation* templates.

When we have that event A is always followed by event B and event B is always directly preceded by event C, we have the implicit template that event A is followed by event C. In Table 13, a full list of rules is presented. Note that we have a symmetric case when x and y are swapped. We will not list this symmetric case, however, note that the templates will be inverted, i.e. if we have *precedence*(C, A), swapping x and y yields *precedence*(A, C).

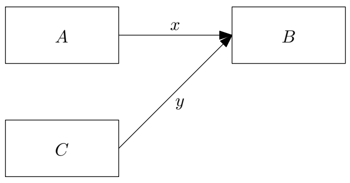


Figure 10: Part of the model if we want to remove event B

We only need to consider combinations of templates in which A implies the existence of B and B implies the existence of C. In these cases, we have that A implies the existence of C by transitivity. This reasoning also needs to be applied in the opposite direction, i.e. C implies B and B implies A then we have that C implies A.

x	y	Between C and A
chain response	*precedence*	*precedence*
chain response	*succession*	*precedence*
chain response	*alternate precedence*	*alternate precedence*
chain response	*alternate succession*	*alternate precedence*
chain precedence	*response*	*response*
chain precedence	*succession*	*response*
chain precedence	*alternate response*	*alternate response*
chain precedence	*alternate succession*	*alternate response*
chain succession	*response*	*response*
chain succession	*precedence*	*precedence*
chain succession	*succession*	*succession*
chain succession	*alternate response*	*alternate response*
chain succession	*alternate precedence*	*alternate precedence*
chain succession	*alternate succession*	*alternate succession*
$\Diamond A \Rightarrow \Diamond B$	$\Diamond B \Rightarrow \Diamond C$	*responded existence*(A, C)
$\Diamond A \Leftrightarrow \Diamond B$	$\Diamond B \Leftrightarrow \Diamond C$	*co-existence*

Table 13: Steps for removing event B

A in front and C after B We have the situation as depicted in Figure 11, we again have that x and y are *relation* templates.

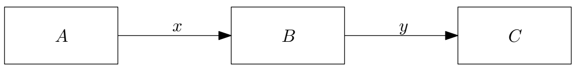


Figure 11: Part of the model if we want to remove event B

When x and y are both *relation* templates, the obtained model has a relation z between A and C, where $z = \min(x, y)$, if x and y are comparable, i.e. x is weaker/stronger than y, for instance, when x is *response* and y is *alternate response*. We do not have a relation, i.e. no template, between A and C if x and y are incomparable, for instance, x is *chain response* and y is *precedence*. In Figure 12, the weaker/stronger relation is depicted. When we have an arrow between x and y, this means x is stronger than y. To compute $\min(x, y)$, we take the strongest template which is implied by both x and y, e.g. $\min($*chain response*, *alternate succession*$)$ is *alternate response*, $\min($*succession*, *succession*$)$ is *succession*, and $\min($*response*, *precedence*$)$ yields *no template*.

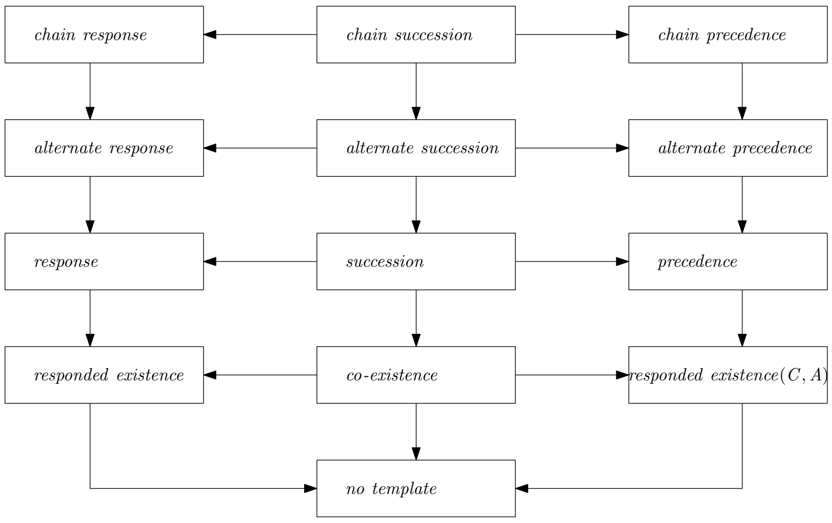


Figure 12: The order between the *relation* templates in *Declare*

When we have the case as depicted in Figure 13 and we remove event B from the model, we do not have all possible execution paths when we apply the aforementioned approach. In the original model, the execution of $ABACBC$ is possible while, if we remove event B from the model, we want to obtain a new model in which $AACC$ is a valid execution. Unfortunately, when we apply our approach, this allows only executions of AC.

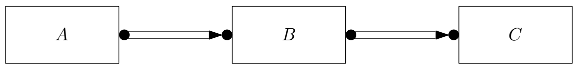


Figure 13: A model in which, after the removal of B, our approach only allows a subset of executions

This problem is more fundamental than meets the eye, consider the model in Figure 14. If we omit all B_is from the model, we need to have a model which supports the traces A^nC^n which is a non-regular language. Our approach only allows the traces AC. We propose to extend *Declare* with a new template to support these reductions, we elaborate on this extension in Section 8.

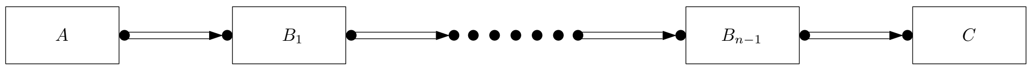


Figure 14: A model in which, after the removal of all B_is, our approach only allows the trace AC

We only have this problem when we combine two *alternate* templates, i.e. *alternate response*, *alternate succession*, or *alternate precedence*, into a single *alternate* template. We classify these rules as *strong* rules, i.e. they allow for less behaviour of the new model compared to the behaviour allowed in the original model.

A **and** *C* **after** *B* We have the partial model as depicted in Figure 15, with x and y being *relation* templates.

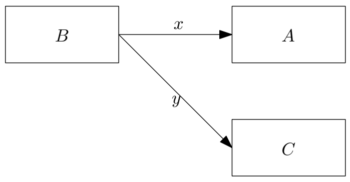


Figure 15: Part of the model if we want to remove event B

For example, when we have that event A is always preceded by event B and event B is always directly succeeded by event C, we implicitly have that event A is always preceded by event C. In Table 14, a full list of combinations is presented. Note that, similar to the case in which A and C are in front of B, we have a symmetric case when we swap x and y as explained earlier.

x	y	Between A and C
chain response	*precedence*	*precedence*
chain response	*succession*	*precedence*
chain response	*alternate precedence*	*alternate precedence*
chain response	*alternate succession*	*alternate precedence*
chain precedence	*response*	*response*
chain precedence	*succession*	*response*
chain precedence	*alternate response*	*alternate response*
chain precedence	*alternate succession*	*alternate response*
chain succession	*response*	*response*
chain succession	*precedence*	*precedence*
chain succession	*succession*	*succession*
chain succession	*alternate response*	*alternate response*
chain succession	*alternate precedence*	*alternate precedence*
chain succession	*alternate succession*	*alternate succession*
$\Diamond A \Rightarrow \Diamond B$	$\Diamond B \Rightarrow \Diamond C$	*responded existence*
$\Diamond A \Leftrightarrow \Diamond B$	$\Diamond B \Leftrightarrow \Diamond C$	*co-existence*

Table 14: Steps for removing event B

Negative relation templates For the *negative relation* templates, we have the same cases as for the *relation* templates. We, furthermore, have the same figures as with the *relation* templates.

A **and** *C* **in front of** *B* We have the case as depicted in Figure 10, note that x or y are now *negative relation* templates. In Table 15, the conversions are listed, note that we have symmetric cases when we swap x and y similar to the symmetric cases for the *relation* templates.

x	y	Relation A and C
not co-existence	$\Diamond C \Rightarrow \Diamond B$	*not co-existence*
not succession	$\Box(C \Rightarrow \Diamond B)$	*not succession*

Table 15: Steps for removing event B

The combinations listed are inspired by transitivity, for instance, the *not succession* between A and B. When we also have that every C is eventually followed by B, i.e. succeeded by B, we do not want to have a C after we have seen an A. A similar reasoning hold for the *not co-existence* between A and B, we now want to consider templates in which C implies the existence of B.

A in front and C after B In Figure 11, this case is depicted. Note that again x or y are *negative relation* templates. The conversions are listed in Table 16.

x	y	Relation A and C
not co-existence	$\Diamond C \Rightarrow \Diamond B$	*not co-existence*
$\Diamond A \Rightarrow \Diamond B$	*not co-existence*	*not co-existence*
not succession	$\neg C W B \wedge \Box(C \Rightarrow \bigcirc(\neg C W B))$	*not succession*
$\Box(A \Rightarrow \bigcirc(\neg A U B))$	*not succession*	*not succession*
not chain succession	$\Box(\bigcirc C \Rightarrow B)$	*not chain succession*
$\Box(A \Rightarrow \bigcirc B)$	*not chain succession*	*not chain succession*

Table 16: Steps for removing event B

Similar to the previous case, i.e. A and C in front of B, we are searching for combinations of templates in which A prevents the execution of B and C demands the execution of B. When we have two templates which fulfill the aforementioned conditions, we know we have to create a template between A and C.

A and C after B This case is depicted in Figure 15 with again x or y being *negative relation* templates. Table 17 contains the conversions. The symmetric case can easily be obtained in a similar way as with the *relation* templates.

x	y	Relation A and C
not co-existence	$\Diamond C \Rightarrow \Diamond B$	*not co-existence*(A, C)
not succession	$\neg C W B$	*not succession*(C, A)

Table 17: Steps for removing event B

The rules identified are very similar to the rules identified when A and C are in front of B. This is mainly because we have a symmetric cases for the first rule, for the second rule we need to have a template between B and C in the opposite direction, i.e. C followed by B versus C preceded by B.

Choice Templates With the *choice* templates, we encounter a problem when we want straightforward deduction rules. Consider the model depicted in Figure 16 from which we want to remove event B. We can deduce that B will always be executed, hence we need to keep the *choice* construct, and $m-1$ out of the $n-1$ events need to be executed. Although, we can deduce that B will always be executed, we need to follow a chain of *response* templates to deduce it. This is, however, undesirable from the viewpoint of the user configuring the model since she needs to observe a large portion of the model. This approach is also error prone because one might miss a *response* template.

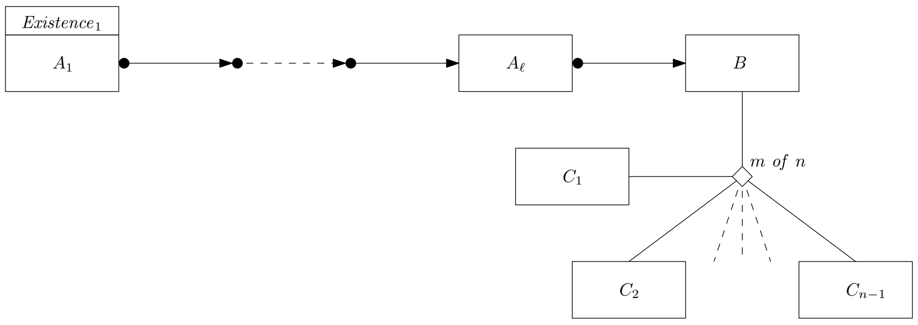


Figure 16: Example in which we need to consider a large portion of the model

The best way of solving the problem is to assume that either event B is always executed or event B is never executed independent of the model, i.e. in the example of Figure 16 we might still assume that event B is never executed, although this is not the case. The main reason is that we want a deterministic approach for dealing with choices based on the local properties. The user of the configurable model can then adjust the m attribute of the *choice* template to reflect the semantics of the model without event B while the user does not need to considering the entire model to find out whether event B will always or never be executed.

We assume event B is never executed; this has the advantage that the user of the configurable model can set the m of the choice and it will not be changed, i.e. it denotes the minimal amount of events needed to be executed with respect to the choice after removing the omitted events. If we would assume that event B is always executed, we would have updated the m and the n. In this case, the user would have to set the m at such a value that after the removal of the omitted events the m has the right value, which is obviously harder.

Supporting branched templates In order to apply the rules defined earlier on branched templates, we need to extend the language. Consider the example in Figure 17 and we want to remove the events B_1, B_2, and B_3.

The implicit template which holds after the removal of the B_is is depicted in Figure 18. Although, this kind of template is not part of *Declare*, *Declare* can be extended with it. We elaborate more on this extension in the future work section (Section 8).

We can solve this problem when we only compare the same templates, e.g. only *response* templates with *response* templates. Consider the model in Figure 19 where, after the removal of B_2, we can deduce and express the implicit templates in *Declare*. These implicit templates are *response*$(\{A\},\{B_1,C\})$ and *response*$(\{B_3\}\{C\})$.

When we have composed templates, i.e. templates which consist of the conjunction of other templates, for instance, *succession* and *co-existence*, we

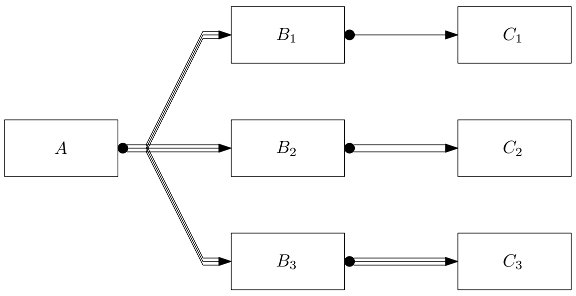


Figure 17: A model in which we cannot express the implicit templates

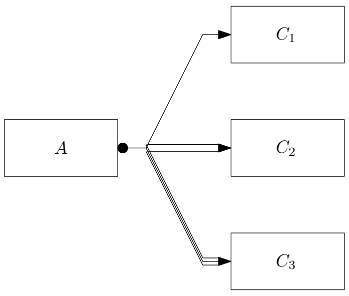


Figure 18: The implicit templates after the removal of the B_is in Figure 17

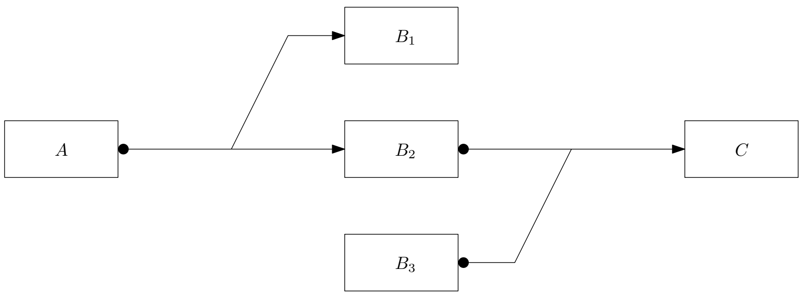


Figure 19: Model in which, after the removal of B_2, we have partial implicit templates

only consider the templates in the conjunction. Consider the model in Figure 20. When we compute the implicit templates, we have the model as depicted in Figure 21 in which we do not have a single *succession* template.

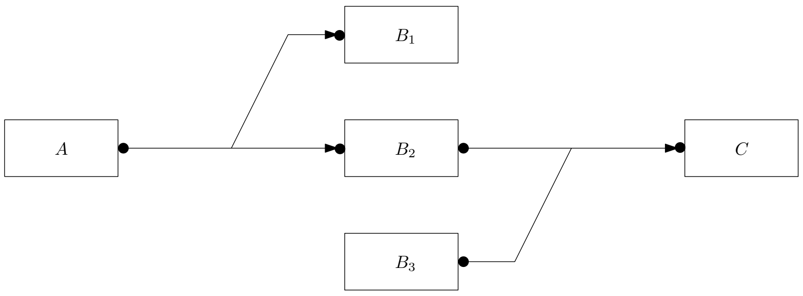


Figure 20: Model in which after the removal of B_2 we do not have implicit succession templates

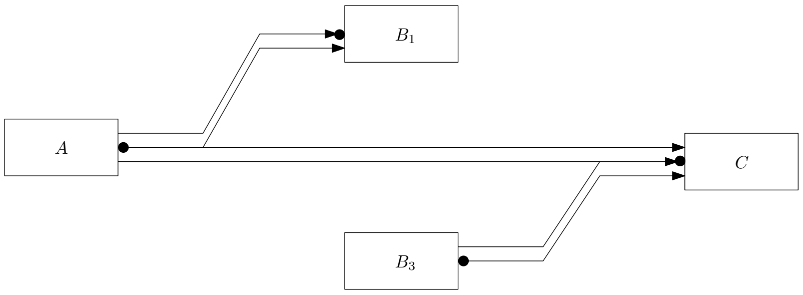


Figure 21: Figure 20 with the implicit templates after the removal of B_2

We can be slightly more permissive than only comparing the same templates. In general, when we have that A places a constraint on B, e.g. $\mathit{response}(A, B)$, and B places a constraint on C, e.g. $\mathit{precedence}(C, B)$, we have implicitly that A places a constraint on C. With branched constraints, we have two sets B^1 and B^2 instead of a single B, i.e. $\mathit{response}(A, B^1)$ and $\mathit{precedence}(C, B^2)$, A can only place a constraint on C if all event in B^1 are omitted and B^1 is a subset of B^2. We want that B^1 is a subset of B^2 such that we know that A only places a constraint on C. If B^1 is not a subset of B^2, A might also place a constraint on another event such that we cannot conclude anything about its relation with C. Both cases, i.e. $B^1 \not\subseteq B^2$ and $B^1 \subseteq B^2$, are depicted in Figure 22. In the left model, we have that A can be followed by B_1. When A is followed by B_1, we do not have a constraint on C. If A is followed by B_2, we do have a constraint on C, this means that A cannot place a constraint on C. In the right model, it does not matter whether we perform B_1 or B_2 after A because we always know that C will be executed, hence A places a constraint on C.

We can be even more permissive when A is in front of B and C is after B, we now do not need that B^1 is a subset of B^2. In this case it is sufficient that the template between A and B^1 is not stronger than the template between B^2 and C, in the case A places a constraint on C. When C places a constraint on A, we need to have that the template between C and B^2 is not stronger than

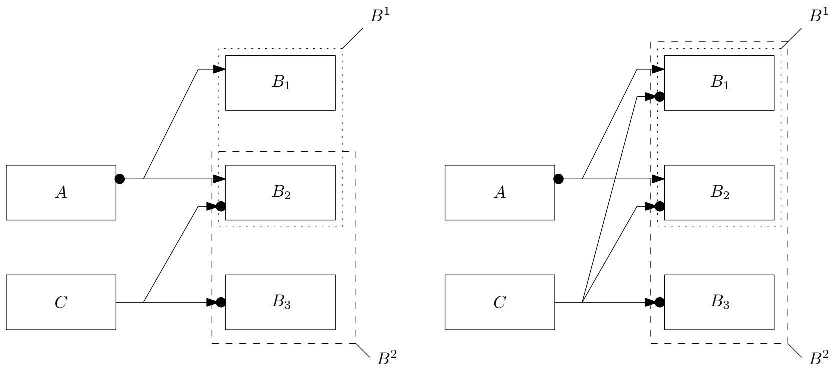


Figure 22: In the left model, A does not pose a constraint on C, but in the right model A does pose a constraint on C

the template between B^1 and A. Consider, for instance, Figure 23, if B_1 and B_2 are omitted, A still posses a constraint on C_1, C_2, and C_3, although, B^1 is not a subset of B^2.

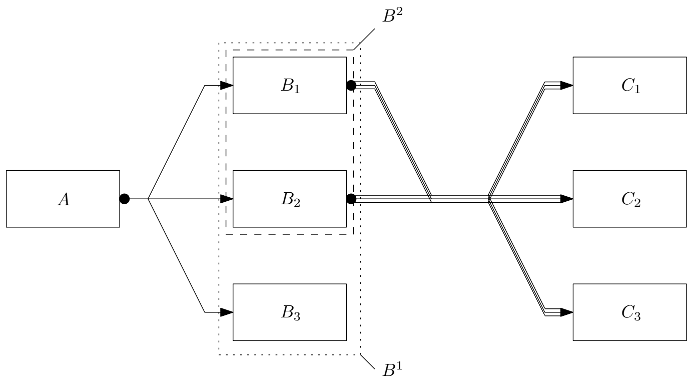


Figure 23: A poses a constraint on C although, B^1 is not a subset of B^2

All unidirectional templates, i.e. one set of events constrain the other set of events and not vice versa, can be split on one of their arguments. For instance, *response*$(\{A_1, A_2\}, B)$ is equivalent to *response*(A_1, B) in conjunction with *response*(A_2, B), and *precedence*$(A, \{B_1, B_2\})$ is equivalent to *precedence*(A, B_1) in conjunction with *precedence*(A, B_2). This allows us to combine templates and split templates. The templates which can be split on their first argument are: *responded existence*, *response*, *alternate response*, *chain response*, *not succession*, and *not chain succession*, the templates which can be split on their second argument are: *precedence*, *alternate precedence*, and *chain precedence*. The *co-existence*, *succession*, *alternate succession*, and *chain succession* templates cannot be split straightforward but we can substitute them by their conjuncts, i.e. *succession* consists of the conjunction of *response* and *precedence*. Finally, the *not co-existence* can be split on either its first argument or its second argument but not on both at the same time.

The aforementioned equivalence can be used to create the subset relation.

Let B^1 be the set of events which needs to be a subset of B^2, we can try to decrease the size of B^1 or increase the size of B^2 by combining or splitting templates.

A similar problem, w.r.t. implicit templates which cannot be expressed, occurs when we consider the *existence* templates. In Figure 24, we cannot deduce what implicit templates hold on B_1, B_2, and B_3 after the removal of A_2. If A_1 and A_3 only occur 4 times, or less, we know any of the B_is have to occur at least once. Also this template cannot be expressed in *Declare*, but we have opted for an extension to *Declare* to support these cases in Section 8.

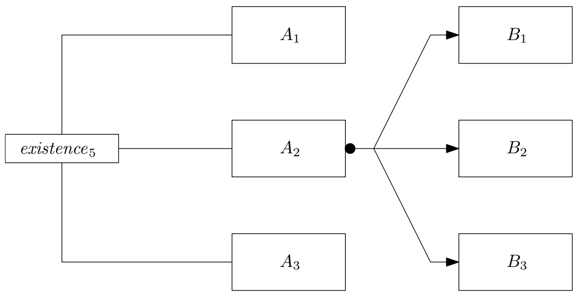


Figure 24: We cannot express the implicit templates after the removal of A_2

Not all *existence* templates are problematic. Consider the model in Figure 25. If we remove A_1, A_2, and A_3, we know B_1, B_2, or B_3 has to occur at least once. This yields for the following decision, w.r.t. application of a rule: if an *existence* template is between a subset of events of the connected *relation* template and all events connected to the *existence* template are omitted, i.e. *isOmitted* is set to true, we can apply the rule.

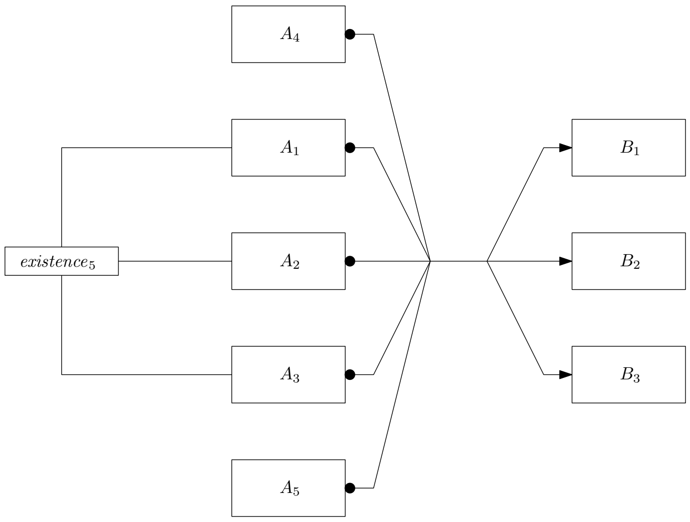


Figure 25: We can deduce the implicit templates after the removal of A_1, A_2, and A_3

When we have *existence*$(5, \{A_1, A_2, A_3\})$ and we omit A_2, we cannot deduce anything about how many times A_1 and A_3 have to be executed. With the *absence*$(5, \{A_1, A_2, A_3\})$, where we omit A_2, we can deduce that A_1 and A_3 cannot happen more than 5 times. Therefore, we can keep the *absence* template but we cannot keep the *existence* template when one of the events is omitted.

Removing a constraint We have seen how to handle the deletion of an event from the model. The deletion of a constraint is straightforward, we simply remove the constraint from the model. We do not need to take anything else into account since the removal of a constraint c also means we want to remove the implicit constraints with respect to c. This holds automatically after the removal of c.

Alteration pattern

We can change constraints into different constraints, or into a similar constraint but with different attribute values, e.g. $existence_5$ instead of $existence_7$. The alteration is straightforward since we only need to remove the old constraint and add the new constraint connected to the same sets of events.

4.5 Running example

We have listed all of the different rules identified to change a *Configurable Declare* model into a *Declare* model. We present an example from the case study (Section 7) in which we demonstrate the application of the different rules. Consider model A (Figure 26) in which filled red crosses denote that we want to remove that event or constraint.

First, we remove the events which do not yield any implicit constraints, e.g. Send to department in mailbox, and the constraints which need to be remove, i.e. *exclusive choice* between Inform customer via telephone or e-mail and Produce extract and sign it. This yields the model in Figure 27.

We remove the events which are inside a blue or green square. The events in a blue square can be removed straightforward by applying the non-branched rules. Removing Inform customer via telephone or e-mail entails more steps. First, this constraint is split into a *response* and a *precedence*. We can update the *precedence* constraint by removing the Inform customer via telephone or e-mail, however, we cannot remove this event from the *response* constraint. We, therefore, remove the *response* constraint. The newly acquired model is depicted in Figure 29.

We have annotated the previous output model with blue squares denoting which events are removed in this step. All events can be removed straightforward without any extra computations, note that we remove the duplicate *succession*, between Send to DMS department and Produce extract and sign it, prior to deducing any implicit constraints. The model obtained after the removal of the events in blue is depicted in Figure 30.

Figure 30 is annotated with which events will be removed in the next iteration. In the next iteration, the duplicate *succession*, between Process payment and Produce extract and sign it, is removed. The obtained model is depicted in Figure 31 which is also annotated with which events will be removed in the next iteration.

The output model (Figure 32) does not contain any duplicate constraints. Since there are no events which need to be removed, i.e. *isOmitted* is true, we know we are done with applying the rules.

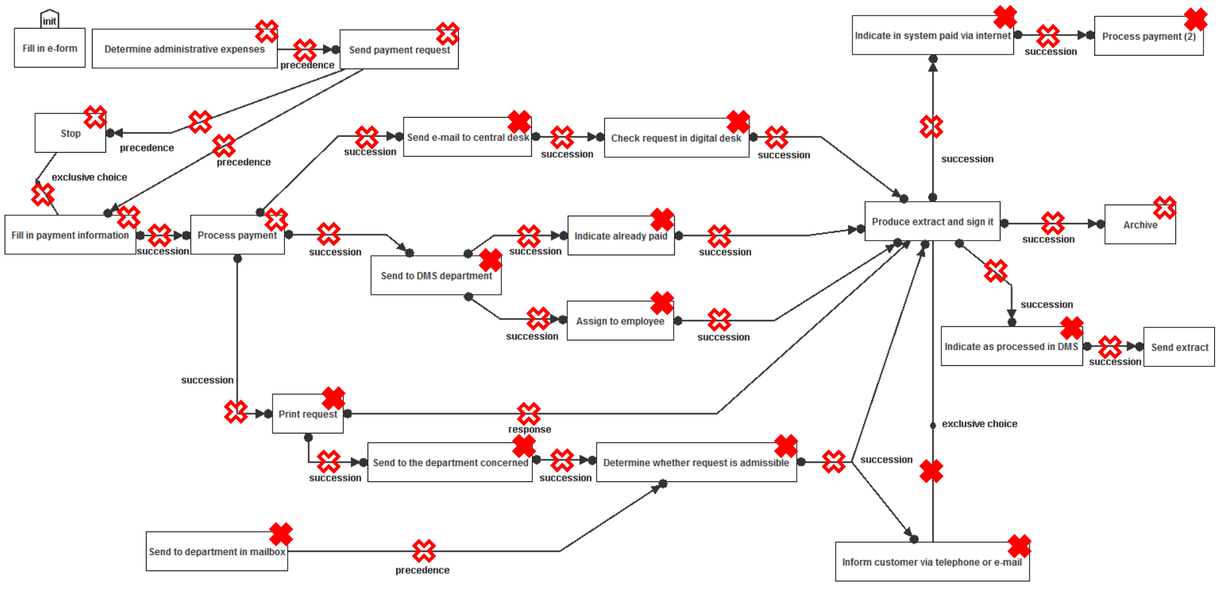


Figure 26: The input model for applying the different rules

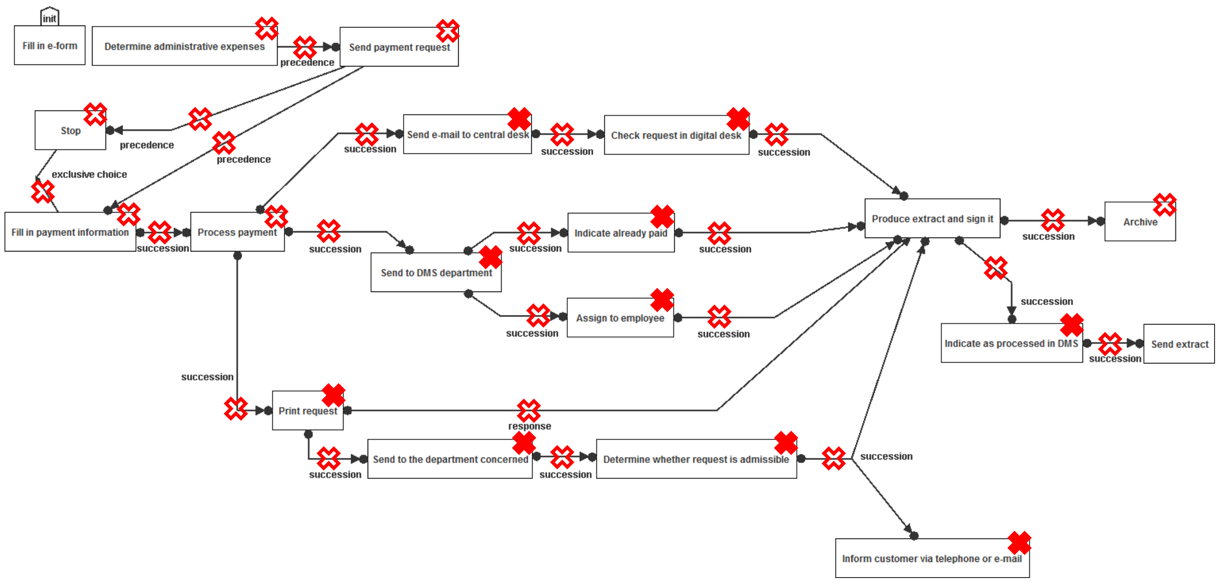


Figure 27: The model after removing all omitted constraints and event which do not yield any implicit constraints

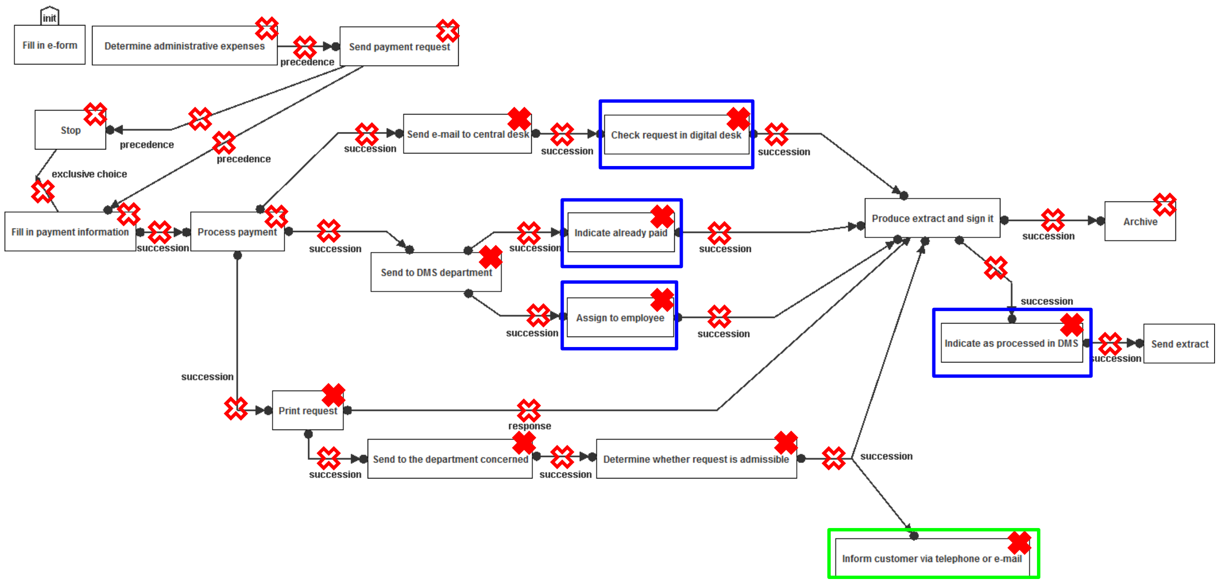


Figure 28: The model from Figure 27 annotated with which events will be removed in the following step

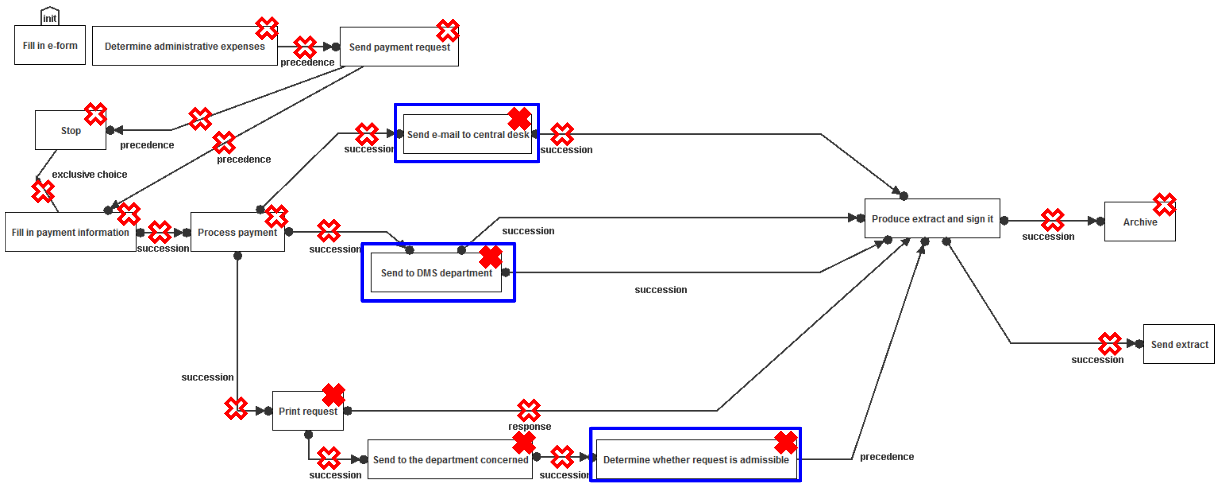


Figure 29: The model obtained after the previous step annotated with which events will be removed in the following step

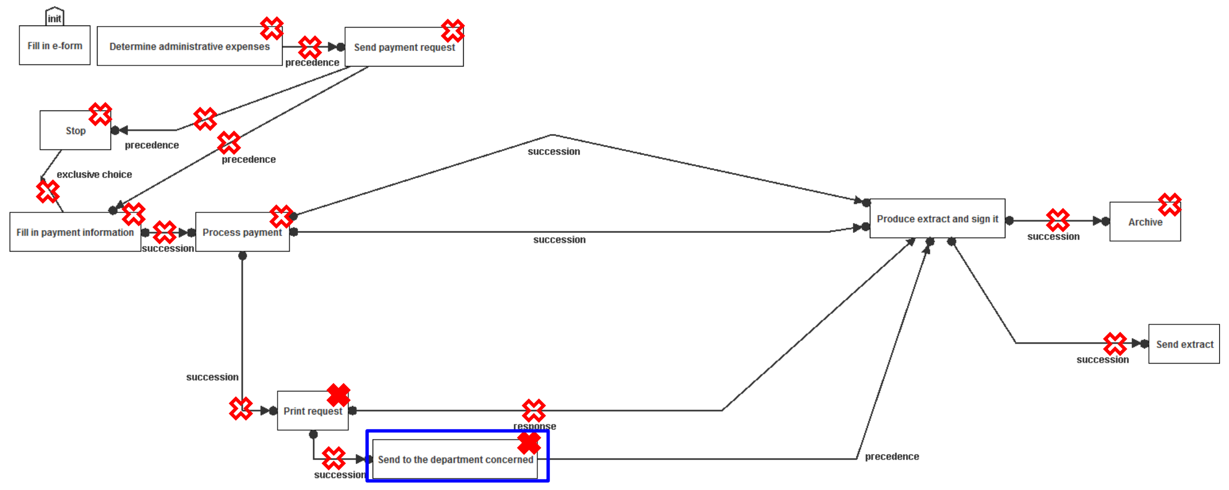


Figure 30: The model obtained after the previous step annotated with which events will be removed in the following step

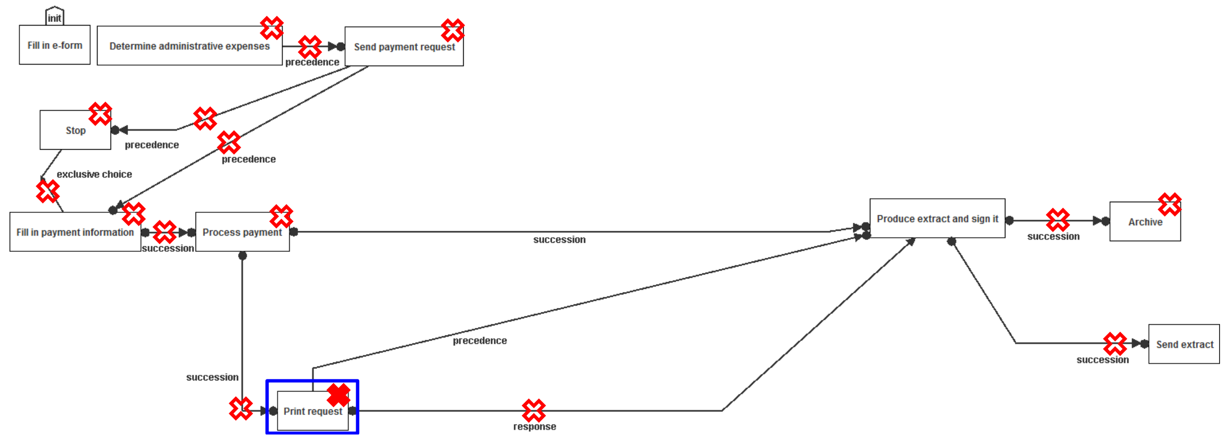


Figure 31: The model obtained after the previous step annotated with which events will be removed in the following step

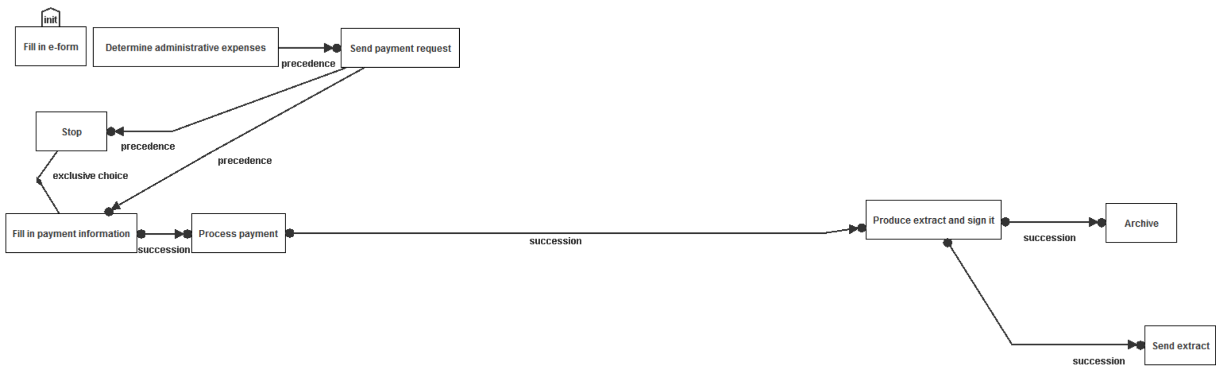


Figure 32: The output model

5 Combining models

When an organisation wants to apply *Configurable Declare* to increase the maintainability and flexibility of their process models, they have to design this *Configurable Declare* model from scratch. Designing this *Configurable Declare* model is difficult, i.e. it has to support all the different *Declare* models, and it is costly. Therefore, we present a conversion in the opposite direction, i.e. instead of going from a *Configurable Declare* model to a *Declare* model, we are now given a set of *Declare* models and we want to create a *Configurable Declare* from which all of those *Declare* models can be deduced from (Figure 33).

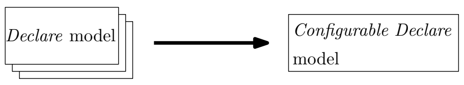


Figure 33: The combining of different *Declare* models into a single *Configurable Declare* model

We first show the straightforward approach in which we simply include everything which is in the *Declare* models. This means that although a constraint can be deduced from the current set of constraints in the *Configurable Declare* model, it will be added if it is present in one of the *Declare* models. For instance, assume we have that every A is eventually followed by a B and every B is eventually followed by a C, then we also have implicitly that every A is eventually followed by a C. When a *Declare* model contains the constraint that every A is eventually followed by a C, this constraint will be made explicit in the *Configurable Declare* model, although, this might already be encoded.

After the straightforward approach, we define heuristics to reduce the amount of constraints in the *Configurable Declare* model as well as how to deal with *choice* and *exclusive choice* templates. Finally, we go step by step through the merger of two models from the case study.

5.1 Combining the models

We have a set of *Declare* models which we want to merge. For these *Declare* models, we create a single *Configurable Declare* model. The different constructs, events and constraints, are dealt with in the following sections.

Event

All of the *Event*s are converted to *CEvent*s with the same name. If an *Event* appears in all *Model*s, i.e. an *Event* with the same name is present in all *Model*s, we add the corresponding *CEvent* to the *CModel* with the *CEvent*'s attribute *omit* set to *false*. If an *Event* appears only in some *Model*s, we add the corresponding *CEvent* to the *CModel* with the *CEvent*'s attribute *omit* set to *true*.

Constraint

Every *Constraint* is converted to a *CConstraint* with the same name, and the *canBeChangedTo* attribute is set to the *Constraint* which we are transforming.

If a *Constraint* appears in all *Model*s, i.e. every *Model* has the same constraint between the same set of *Event*s, its *omit* attribute is set to *false*. If a *Constraint* does not appear in all *Model*s, we set the *omit* to *true*.

We check whether a *Constraint* appears in all *Model*s independent of all events which it constrains are present in the models. If we would take this into account, i.e. a *Constraint* $c(A, B)$ can be omitted if and only if there is a model in which c does not occur and all events in A and B are present in that model, we would not be able to deduce all models. Consider, for instance, the models depicted in Figure 34, since B occurs always with the *succession* constraints (*succession*(A, B) and *succession*(B, C)), we cannot omit the *succession* constraints. This prevents us from deducing the bottom model since, after the removal of B, we always have a *succession* between A and C.

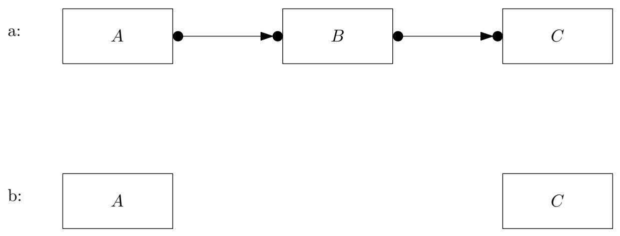


Figure 34: Two models for which it must hold, after combining them, that all constraints can be omitted, although, B does not occur in all models

After initialising the *name* and the *omit* attributes, the *from* and *to* attributes have to be set. We want to have a mapping which, after applying it, yields the same set of constraints but now on the set of *CEvent*s. Figure 35 depicts the conversion from *Constraint* to *CConstraint* w.r.t. the *from* and *to* attributes. Here, c is a *Constraint*, c' is de conversion from c to a *CConstraint* where the *name* and *omit* attributes have been set. When we apply χ to an *Event*, we transform it to a *CEvent* in the aforementioned way.

5.2 Removing redundant constraints

When we have combined all models, we might have redundant constraints in our model. We can use the rules defined in Section 4.4 to compute the redundant constraints in our model. The main difference is that we keep all events in the model instead of removing events.

We cannot apply the rules naively, i.e. if we can omit an event we can apply the rules to deduce implicit constraints. Consider the example in Figure 36, if we combine all three models, we have a *response* between A and B, between B and C, and between A and C. The *response* between A and C is redundant since we can obtain this constraint by removing B and applying the rules. However, if we remove the *response* between A and C, we cannot deduce model c.

Therefore, we need to take into account which events are present in a certain model prior to applying the rules. If an event B and a constraint c are both present in at least one model, we cannot apply rules which state that, after the removal of B from the model, we can deduce constraint c.

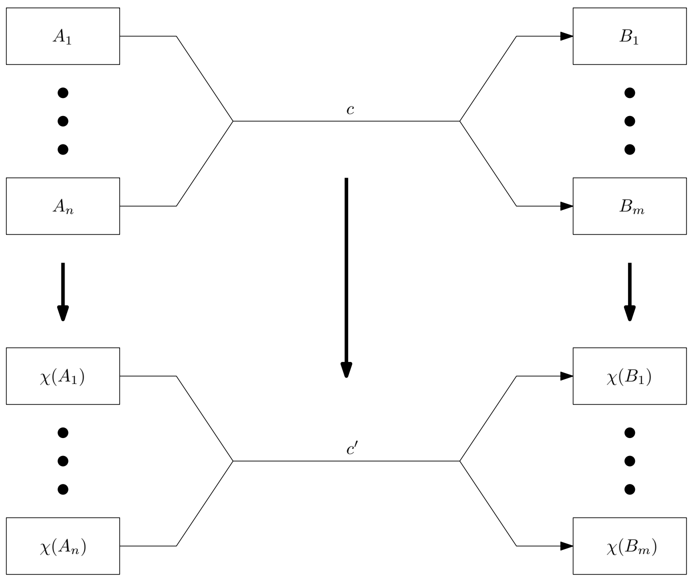


Figure 35: The conversion from a *Constraint* to a *CConstraint*

We also have to take into account that two rules can deduce each other. Consider the model in Figure 37, where we can deduce both *precedence* constraint by applying deduction rules on the other two constraints, the *chain succession* and the *precedence*. We want to have one *precedence* in the model to be able to deduce the original set of input models, therefore, we need to take into account which constraints can be deduced by which other constraints. This way we can easily deduce when two constraint deduce each other and hence, one needs to remain in the model.

Choice templates

We have seen with the conversion from a *Configurable Declare* model to a *Declare* model that we are not able to convert the *choice* templates straightforward. We have a similar problem when we combine two models. Consider the two models depicted in Figure 38.

When we combine both models, we can have both resulting models as depicted in Figure 39. For the *choice* templates, we choose the right resulting model. We choose this model since it allows the same traces as the combination of the traces of the input models. E.g. the trace *CD* is allowed in the input models and also in the right combined model, but not in the left combined model.

5.3 Running example

In order to get some more intuition for the model combiner, we combine two models used for the case study. Assume we have the models depicted in Figures 40 and 41 (models D and F of the case study).

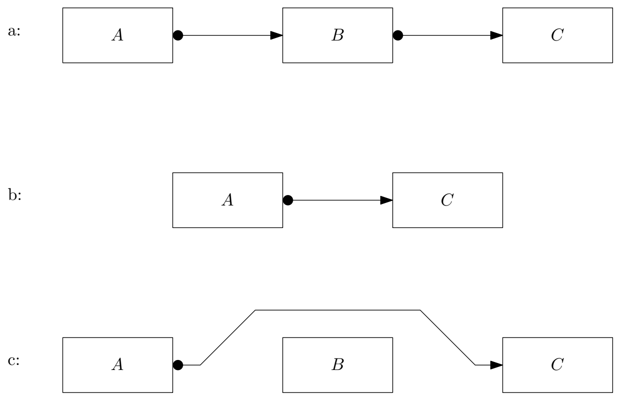


Figure 36: Three models from which, after combining them, we cannot remove any implicit constraints

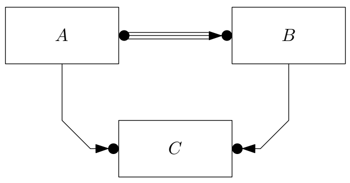


Figure 37: An example of a model in which both *precedence* constraints can be deduced from the other *precedence* and *chain succession* constraint

We first need to check which events and constraints are present in both the models. We apply the decision making mentioned earlier, i.e. if an event or constraint is present in all models we set *omit* to false else we set it to true, furthermore, an open red cross means that *omit* is set to true. We now combine all events and constraints into a single model which is depicted in Figure 42.

When we apply the rules identified in Section 4.4, we obtain the minimal *Configurable Declare* model depicted in Figure 43.

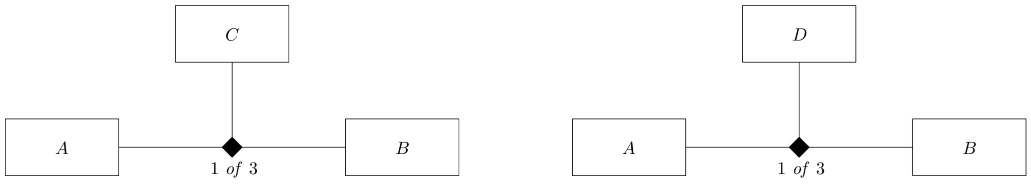


Figure 38: Two input models

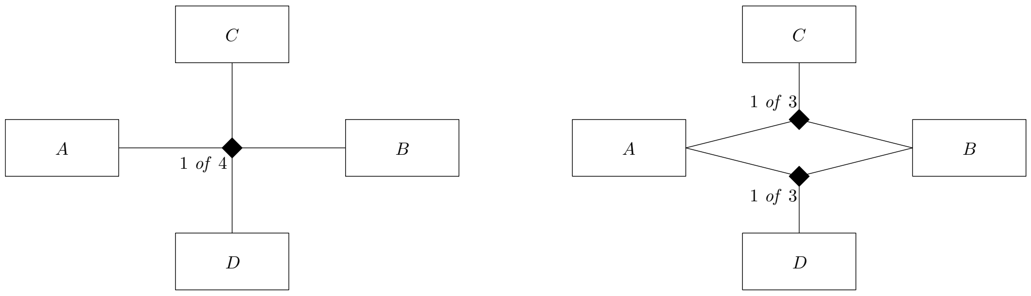


Figure 39: Two possible output models

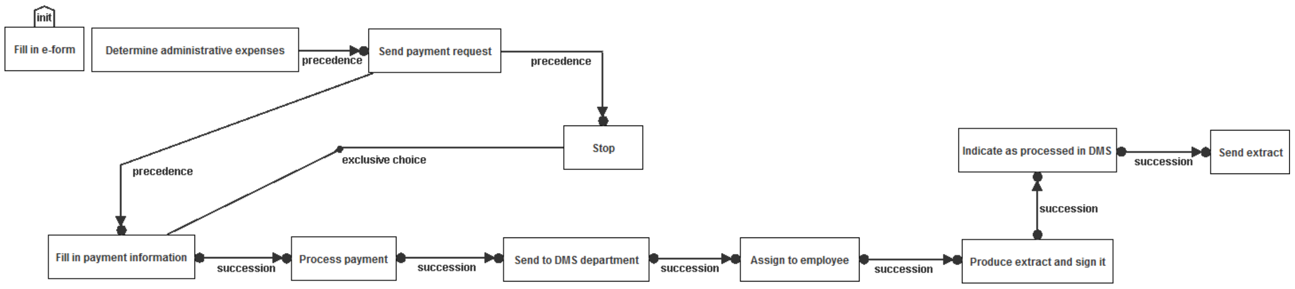


Figure 40: Input model D

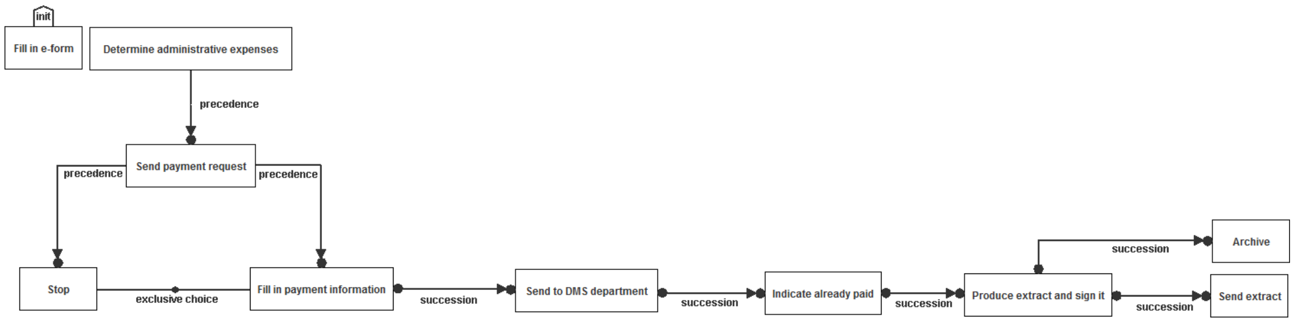


Figure 41: Input model F

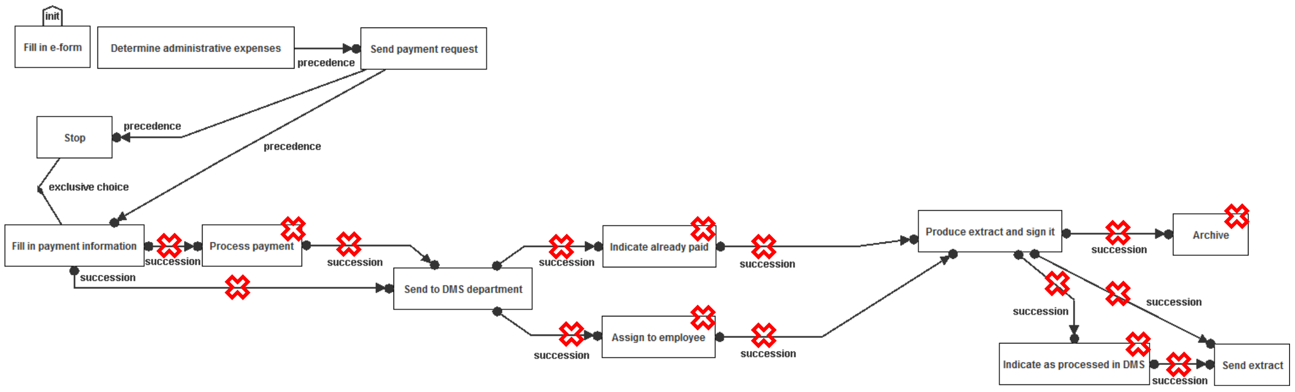


Figure 42: The configurable declare model of the models D and F with the *omit* attributes set

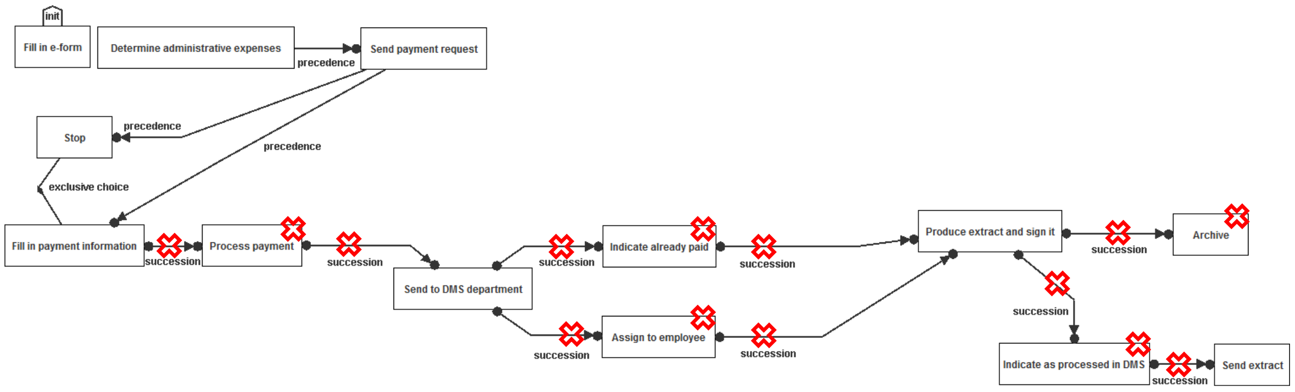


Figure 43: The minimal configurable declare model of the models D and F

6 Implementation

We have implemented both directions mentioned in the previous sections, i.e. going from a *Configurable Declare* model via a *Configuration* model to a *Declare* model, and combining a set of *Declare* models into a single *Configurable Declare* model. This implementation is used in the case study to show that *Configurable Declare* can be applied to real life models.

The implementation is done in Java and Figure 44 depicts the architecture and the communication between the different parts of the code. The *Main* class is the orchestrator of the code, it takes care that the input models, arguments, and rules are read, and that the output models are written. Based on the arguments it either performs one of the four conversions: (1) *Configurable Declare* $\rightarrow$ *Configuration*, (2) *Configuration* $\rightarrow$ *Declare*, (3) *Declare* $\rightarrow$ *Configurable Declare*, and (4) *Declare* + *Configurable Declare* $\rightarrow$ *Configurable Declare*. Each of these conversion either belongs to *Configurable Declare* $\rightarrow$ *Declare* or to the *Model Combiner*. We elaborate on the two different directions in the following sections as well as explain the rule engine which is used in both directions. Note that we do not fully support *Branched Declare* since *Declare* does not yet allow all constructs necessarily. When the implementation is applied on cases which are not covered, we cannot guarantee anything about the output of the conversions.

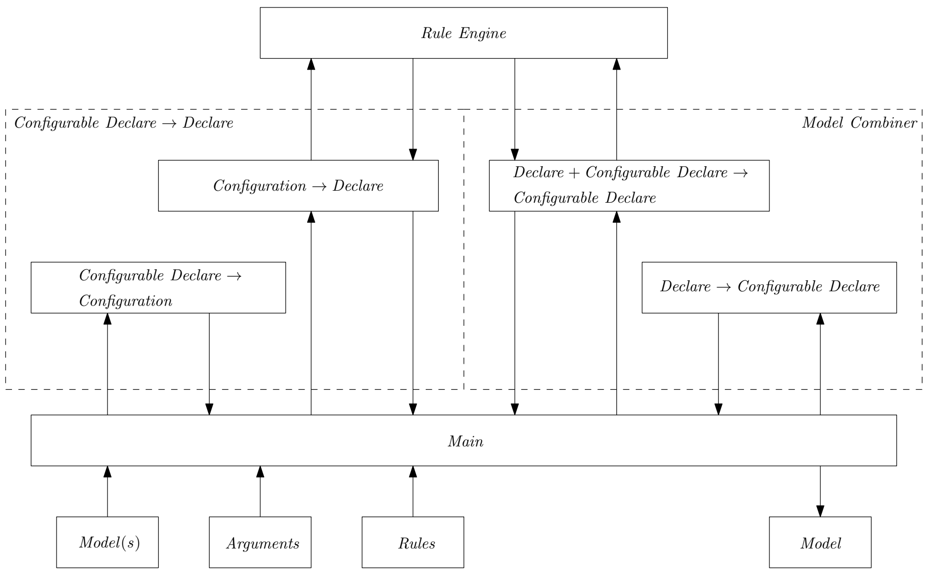

Rule Engine
Configurable Declare → Declare
Model Combiner
Configuration → Declare
Declare + Configurable Declare → Configurable Declare
Configurable Declare → Configuration
Declare → Configurable Declare
Main
Model(s)
Arguments
Rules
Model

Figure 44: The architecture for the different conversions

6.1 Configurable Declare to Declare

Transforming a *Configurable Declare* model into a *Declare* model entails two steps: (1) going from a *Configurable Declare* model to a *Configuration* model and (2) going from a configured *Configuration* model to a *Declare* model. The conversion from a *Configurable Declare* model to a *Configuration* model is straightforward, i.e. we only need to initialise an extra attribute, *isOmitted* which is

Attribute	*Configurable Declare*	*Configuration*	*Declare*
name	*name*	*name*	*name*
omit	*omit*	*omit*	✗
isOmitted	✗	*omit*	✗
from	$A_1, \cdots, A_n$	$\phi(A_1), \cdots, \phi(A_n)$	$\psi(\phi(A_1)), \cdots, \psi(\phi(A_n))$
to	$B_1, \cdots, B_m$	$\phi(B_1), \cdots, \phi(B_m)$	$\psi(\phi(B_1)), \cdots, \psi(\phi(B_m))$
canBeChangedTo	*canBeChangedTo*	*canBeChangedTo*	✗
isChangedTo	✗		✗

Table 18: The initialisation of the different attributes in the different conversions

set to the value of the *omit* attribute, and change the types of the different constructs, e.g. a *CConstraint* is changed into a *ConfConstraint*.

In Table 18, the different value for the different conversions are listed. Note that $\phi(A_i)$ means the conversion from a *CEvent* to a *ConfEvent*, and $\psi(A_i)$ means the conversion from a *ConfEvent* to an *Event*.

The conversion from a *Configuration* model to a *Declare* model entails more work. Apart from converting the different constructs, we also have to apply the rules as defined in Section 4.4. We only mention the conversion from a *Configuration* model to a *Declare* model, the application of the rules is described in detail in Section 6.3.

Prior to applying the rules, we need to perform some preprocessing. We first have to remove all constraints which are omitted, i.e. the *isOmitted* attribute is set to true. We, furthermore, need to substitute constraints, when the *isChangedTo* attribute is set, to the intended constraint.

When our model contains composed constraints, we need to split this composition on the different constraints. Consider, for instance, a *succession*(A, B), this constraint is composed of *response*(A, B) and *precedence*(A, B), but also *co-existence*(A, B) is a composed constraint consisting of *responded existence*(A, B) and *responded existence*(B, A). We need to split the constraints on their composition to support *Branched Declare*. Note that we duplicate the *not co-existence* constraint, i.e. when we have *not co-existence*(A, B), we also add *not co-existence*(B, A) to the model, such that we can split on both arguments.

We now apply the rule engine on the remaining set of constraints to compute all the implicit constraints. After having computed the implicit constraints, we need to remove the omitted events and all constraints, implicit and explicit, connected to those events. Finally, we map weaker constraints to stronger constraints, e.g. when we have *response*(A, B) and *alternate response*(A, B), we remove the *response* and keep the *alternate response*.

6.2 Combining Declare models

Combining a set of *Declare* models is implemented as an iterative approach. We first transform a *Declare* model into a *Configurable Declare* model, and then, we add the remaining *Declare* models, one-by-one, to obtain every time a new *Configurable Declare* model.

Using an iterative approach increases the flexibility but it reduces the minimality of the model, i.e. the model becomes bigger. The increased flexibility is achieved by only considering a *Configurable Declare* model and a *Declare* model without considering all *Declare* models which lead to the *Configurable Declare* model. In Figure 45, we have an example in which combining the models in a certain order does not yield a minimal model.

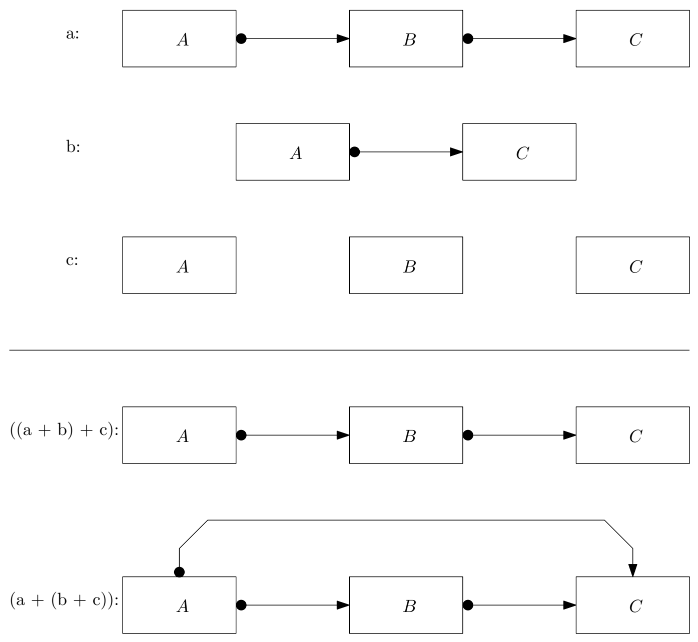


Figure 45: Combining three different models in two different ways.

As mentioned before, combining the *Declare* models consists of two phases: (1) transform a *Declare* model into a *Configurable Declare* model (initialisation), and (2) combining a *Declare* model with a *Configurable Declare* model (iterative step). We explain both steps in isolation in the following sections.

Initialisation

We transform a *Declare* model (*Model*) into a *Configurable Declare* model (*CModel*) by transforming the different constructs, i.e. constraints and events. We list per construct the steps taken to transform it. Prior to transforming the events and constraints, we first create a new *CModel* with its name equal to the name of the *Model*. Afterwards, we transform the *Event*s into *CEvent*s where the name of the *CEvent* is equal to the name of the *Event* and the *omit* attribute is set to false.

The different initialisations are summarised in Table 19, note that we can use the initialisation for both the *CEvent*s and *CConstraint*s, e.g. we keep the *name* the same for both the *CEvent* and the *CConstraint*. When we write $\chi(A_i)$, we mean the transformation from *Event* A_i to a *CEvent*. Prior to applying these transformation, we first split composed constraints, similar to the conversion from a *Configuration* model to a *Declare* model, we also duplicate the *not co-existence*.

Attribute	*Declare*	*Configurable Declare*
name	*name*	*name*
omit	✗	*false*
from	$A_1, \cdots, A_n$	$\chi(A_1), \cdots, \chi(A_n)$
to	$B_1, \cdots, B_m$	$\chi(B_1), \cdots, \chi(B_m)$
canBeChangedTo	✗	

Table 19: The initialisation of the different attributes when transforming a *Declare* model into a *Configurable Declare* model

Iterative step

In the iterative step, we need to do some more work apart from simply converting a *Declare* model into a *Configurable Declare* model and combine this with the original *Configurable Declare* model. The first step in the iterative approach is setting the *omit* attributes correct. For each *CEvent*, we check whether there is an *Event* in the *Declare* model with the same name. If we cannot find an *Event* with the same name, we set the *omit* attribute of the *CEvent* to true else we do not change the value.

We apply a similar approach for the *CConstraint*s, of which first the composed constraints are split, and all *not co-existence* are duplicated. If there is not a semantically equivalent *Constraint* present in the *Model*, we set the *omit* attribute of the *CConstraint* to true. Semantical equivalence between a *CConstraint* and a *Constraint* means that they both represent the same constraint on the same set of events, e.g. $Succession(A, B)$ is semantically equivalent to the $CSuccession(A, B)$.

After having set all of the *omit* attributes of the events and constraints already in the *Configurable Declare* model, we can add the events and constraints not in the *Configurable Declare* model, but which are in the *Declare* model, to the *Configurable Declare* model. We convert each event and constraint in the same way as we did in the initialisation step. The main difference with the initialisation step is that the *omit* attribute is set to true instead of false.

We use the rule engine to deduce all implicit constraints which can be obtained by considering the events not present in both models as being omitted. For each constraint, we store from which other constraints it can be deduced from (children) and which constraint it deduces (parents). Consider, for instance, the model in Figure 46, here, c_1 and c_2 are the children of c_3, i.e. c_3 can be deduce from c_1 and c_2 using the rules and c_3 is a parent of c_1 and a parent of c_2.

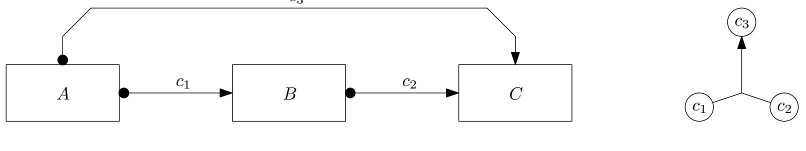


Figure 46: The parent child relation for a model

The output of the rule engine is a directed graph denoting which constraints can be deduced from which other constraints. Each constraint c can be part of any of the following classes:

- Explicit: c cannot be deduced or it occurs in all models, i.e. *omit* is false
- Implicit: c can be deduced and c does not occur in all models
- Deducible: c is either explicit or it has a pair of children and both children are deducible

We want that all constraints are deducible which means that our model covers all constraints. When some constraints are not deducible, this means that some behaviour is allowed which should not be allowed, i.e. some constraints are in the complete and naive model but are not in the reduced model.

We use Algorithm 1 to compute which constraints should remain in our model. Let $\mathcal{S}_c$ denote the set of constraints we want to keep, note that we only include constraints which are present in at least one model, this to prevent the algorithm to choose and add implicit, and thus redundant, constraints to the model.

Algorithm 1: The pseudo code for choosing which constraints to include in the model

```
chooseConstraints()
(1)  $\mathcal{S}_c \leftarrow \emptyset$
(2)  **foreach** constraint $c$ which is present in all models
(3)      add $c$ to $\mathcal{S}_c$
(4)  **foreach** constraint $c$ which cannot be deduced from
     any constraint
(5)      add $c$ to $\mathcal{S}_c$
(6)  **while** there are constraints not yet deducible from the
     constraints in $\mathcal{S}_c$
(7)      Let constraint $c$ be a constraint not yet deducible
         by the constraints in $\mathcal{S}_c$ and $c$ is present in at least
         one model
(8)      add $c$ to $\mathcal{S}_c$
```

6.3 Rule engine

We have created a rule engine which is used in both directions, i.e. going from a *Configuration* model to a *Declare* model and going from a *Declare* model and a *Configurable Declare* model to a *Configurable Declare* model. The rule engine consists of four different functionalities: (1) a *rule container* which is a wrapper for the different rules as defined in Section 4.4, (2) a *rule referee* which determines whether we can apply a certain rule in a certain case, (3) the *closure* takes care of the actual application of the rules on the set of constraints, and (4) a *cleaner* maps equivalent constraints on top of each other.

The rule container mainly consists of the following functionality: given two constraints and the position of the to-be-removed event, i.e. the cases we identified in Section 4.4, which constraint holds implicitly between the remaining events. We use the rule referee to query when we may apply a certain rule on a pair of constraints, e.g. when we transform a *Configuration* model to a *Declare* model we only compute an implicit constraint for two constraints if they share an omitted event.

The application of the rules is done similar to Algorithm 2 which computes the closure. We have included the handling of a single rule, A in front and C after B, in Algorithm 3. Each of the functions is dealt with in isolation.

CalculateClosure Within the calculation of the closure, we keep iterating through the list of constraints until we reach a fixpoint. This fixpoint is defined to be the maximal length a constraint can have, where the length of a constraint is recursively defined as the length of the constraints from which it is deduced. When a constraint is not deduced from any other constraints, we assume the length of this constraint to be one.

The constraints in the ℓ_c are traversed and, for every constraint c_i, we check whether we can apply a certain set of rules. For instance, if c_i is an *existence* constraint, we know we cannot apply the rules for the *choice* templates. If we can apply a certain rule, we pass the constraint to a function to try and apply the rules on this constraint.

After each iteration of the computation of the closure, we clean the set of constraints we have computed so far. This cleaning entail mapping pairs of constraints on top of each other. Consider Figure 47 where c_{12} can be deduced from c_1 and c_2, and c_{34} can be deduced from c_3 and c_4. Obviously, we do not want to keep both c_{12} and c_{34} inside of the model. We, therefore, map c_{34} on top of c_{12} which means that we remove c_{34} from the model, add c_3 and c_4 as a pair of children to c_{12}, and make c_{12} the parent of c_3 and of c_4.

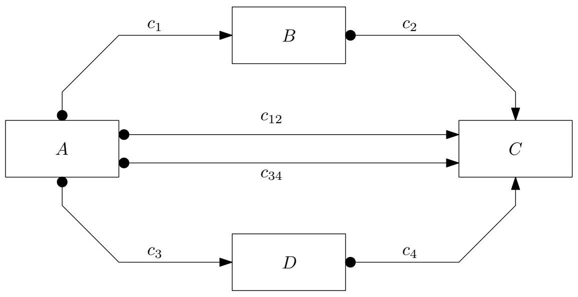


Figure 47: A model in which the cleaner maps c_{34} on top on c_{12}

Algorithm 2: The pseudo code for computing the closure

```
CalculateClosure()
(1)   while We have not yet arrived at a fixpoint
(2)       copy the constraints to a temporal list $\ell_c$
(3)       foreach $c_i \in \ell_c$: we want to consider $c_i$
(4)           if the rule referee allows us to apply the existence
              set of rules on $c_i$ then
(5)               ⋮
(6)           if the rule referee allows us to apply the relation
              or negative relation set of rules on $c_i$ then
(7)               applyRulesABC($\ell_c$, $c_i$)
(8)               applyRulesACB($\ell_c$, $c_i$)
(9)               applyRulesBAC($\ell_c$, $c_i$)
(10)          if the rule referee allows us to apply the choice
              set of rules on $c_1$ then
(11)              ⋮
(12)      Clean the constraints using the cleaner
```

ApplyRulesABC When we possibly can apply a rule, we try a constraint (c_i) with all possible other constraints ($c_j \in \ell_c$). If the rule referee allows us to combine two constraints, we apply the rules and obtain a new constraint c'. We set the *from* and *to* relation of c', note that we assume that c_i is between A and B and c_j is between B and C, if this is not the case, we do not allow the application of this rule.

Similar to the examples in Section 4.4 and in particular Figure 23, we either need to combine the *from* or *to* events of the new constraint with the *from* or *to* of c_i or c_j. If all constraints are *response* type of constraints, i.e. they can be split on their first argument, we need to add $c_i.to$ to the $c'.to$. We need to add this since the events which are between c_i and c_j which are omitted are now substituted by the events in $c_j.to$.

If all constraints are *precedence* type of constraints, i.e. they can be split on their second argument, we know that the events which are between c_i and c_j, which are omitted, are now substituted by the events in $c_i.from$. But, we still have to maintain the events which were already in $c_j.from$.

Consider, for instance, the model in Figure 48 from which we want to remove B_2. $c'.from$ is equal to the $c_i.from$, and $c'.to$ is equal to the union of $c_j.to$ and $c_i.to$. In other words, event B_2 is substituted, in c_i, by C_1 and C_2, and c' now represents this constraint.

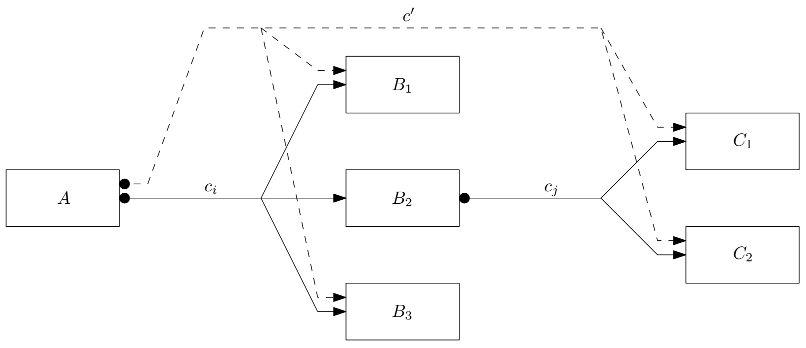


Figure 48: A model in which both the $c_i.to$, and $c_j.to$ have to be added to $c'.to$

Algorithm 3: The pseudo code for applying the ABC type of rules
applyRulesABC(ℓ_c, c_i)
Input: ℓ_c a list of constraints, c_i a constraint
Output:

```
(1)   foreach $c_j \in \ell_c$: $c_i \neq c_j$
(2)       if the rule referee allows us to apply a rule on $c_i$ and $c_j$ then
(3)           $c'$ ← the constraint after applying the rules, on $c_i$ and $c_j$
(4)           $c'.from \leftarrow c_i.from$
(5)           $c'.to \leftarrow c_j.to$
(6)           if $c_i$, $c_j$, and $c'$ are response type of constraints then
(7)               $c'.to \leftarrow c'.to \cup c_i.to$
(8)           if $c_i$, $c_j$, and $c'$ are precedence type of constraints then
(9)               $c'.from \leftarrow c'.from \cup c_j.from$
(10)          add $c'$ to the ConfigurationModel
```

7 Case Study

In order to validate the applicability of *Configurable Declare* to real life models, we have performed a case study. We performed our case study on models obtained by interviewing different municipalities. These interviews yielded imperative models from which we have deduced the *Declare* models. The different models entail the request for an excerpt from the civil registration. The different municipalities model this process in different, but very similar, ways.

All models include the following three activities: (1) Fill in e-form in which the customer fills in her credentials on an e-form in order to obtain an excerpt. (2) Produce extract and sign it in this step the municipality produces the excerpt and signs it denoting that this is an official excerpt. (3) Send extract denotes that the excerpt is sent to the customer.

We want to show with this case study that we can combine the *Declare* models from the municipalities into a *Configurable Declare* model and configure the *Configurable Declare* model such that we can obtain all original models.

7.1 Combining the models

We have combined the different input models, depicted in Appendix B, in alphabetical order, i.e. first model A with model B, then the combined model AB with model C, etc. The output model is depicted in Figure 49. Combining the models is done in the same way as explained in Section 5.

The output model is minimal in the sense that we do not have any redundant constraints. Using the model combiner, we were able to remove three redundant constraints. The *succession* between Process payment and Produce extract and sign it, for instance in model A, has been removed when we added model C to the combined model. Between Fill in payment information and Send to DMS department, we have a *succession* in model F, this constraint was never added since we already had an implicit *succession* from model D. Finally, we had a *succession* between Produce extract and sign it and Send extract, for instance, in model B, but this *succession* is implicit in model D and has been removed.

We can also see why we need to split the *succession* constraints in *response* and *precedence* constraints. Instead of a *succession* between Print request and Produce extract and sign it, we have a *response*. The reason we have a *response* is because the *precedence* between Print request and Produce extract and sign it can be deduced via Determine whether request is admissible and Send to the department concerned.

7.2 Configuring the models

We use two different crosses to denote the different reasons for removing a constraint. A complete red cross denotes that we have to remove this constraint to obtain a model which allows all desired behaviour. Red crosses filled with green denote that we remove a constraint to remove redundant constraints, note that, when we transform a *Configuration* model to a *Declare* model, we do not consider other implicit constraints already in the model.

In order to obtain the input models, we first set the *isOmitted* attribute of the activities not in the input model to true. When we have an *exclusive choice* consisting of only one activity, e.g. when we want to remove Inform customer

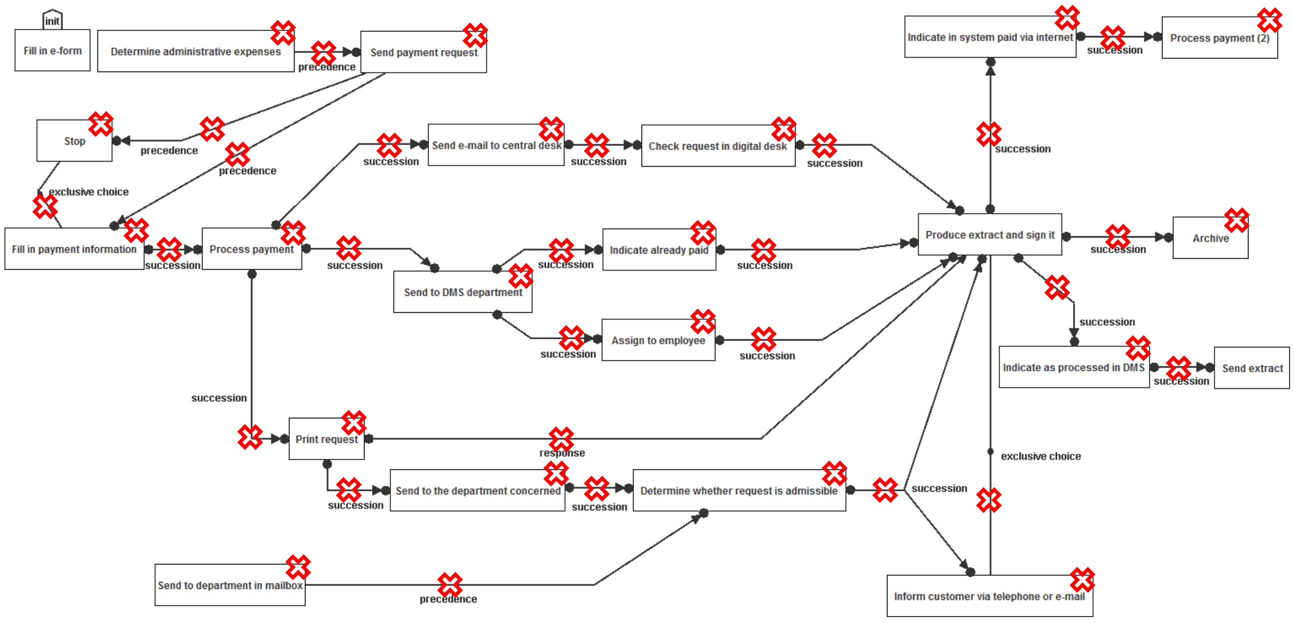


Figure 49: The configurable *Declare* model

via telephone or e-mail, we also remove the *exclusive choice*. If we would not remove this *exclusive choice*, it would mean that the other activity is always executed. In some cases we need to remove some constraints from the model to prevent unwanted implicit constraints, e.g. to obtain model E we need to remove, amongst other constraints, the *succession* between Process payment and Send e-mail to central desk, if we would keep this constraint it would need to hold that every Process payment is eventually followed by a Produce extract and sign it while the user might want to choose to execute activity Inform customer via telephone or e-mail.

After all activities and constraints which need to be removed have been removed, we choose to remove some extra constraints from the model. By removing these extra constraints, we prevent the deduction of redundant constraints on the models. Consider, for instance, model C, if we would keep the *succession* constraint between Process payment and Send to DMS department, we can deduce that we have a *succession* between Process payment and Produce extract and sign it. Although, this is not incorrect, it is redundant since we already have this *succession* implicit via the activities: Send e-mail to central desk and Check request in digital desk.

7.3 Running example

We have seen how we combined the models D and F in Section 5. We now elaborate on how to configure the *Configurable Declare* model such that we obtain the original models again.

Model D, and the configuration for model D, are depicted in Figure 50 and Figure 51 respectively. We first need to set the *isOmitted* attribute of all events not present in the original model to true.

The *exclusive choice* between Produce extract and sign it and Inform customer via telephone or e-mail has to be removed. After the removal of Inform customer via telephone or e-mail, *exclusive choice* demands that we always execute Produce extract and sign it, although, the user might have chosen to execute Stop after the execution of Send payment request such that we cannot execute Produce extract and sign it.

We remove the *succession*(Process payment, Send e-mail to central desk), *succession*(Process payment, Print request), and *succession*(Send to DMS department, Indicate already paid) to prevent the deduction of redundant implicit constraints.

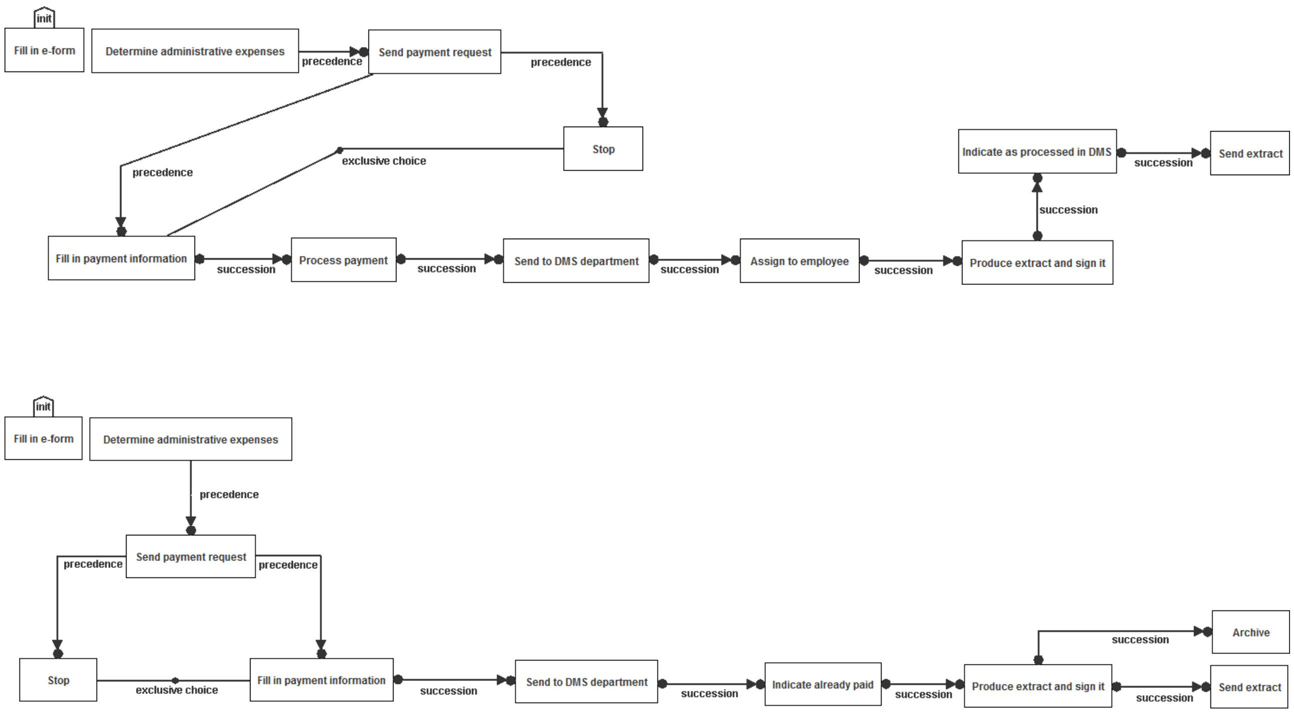


Figure 50: Top: model D, bottom: model F

Figure 50 contains model F and Figure 51 contains the configuration for model F. Similar to model D, we first set the *isOmitted* attribute for the event not present in model F to true. We, furthermore, remove the *exclusive choice* between Produce extract and sign it and Inform customer via telephone or e-mail to prevent the model from demanding that Produce extract and sign it is always executed. Finally, similar to the configuration of model D, we have to remove some *succession* constraints from the model in order to prevent the deduction of redundant implicit constraints.

7.4 Comparing the models

We cannot find any difference between the input and output models after combining and configuring the models in the way described above. We wanted to show that we can combine a set of *Declare* models into a *Configurable Declare* model and by configuring this *Configurable Declare* model we wanted to obtain the input models. This is shown by the case study.

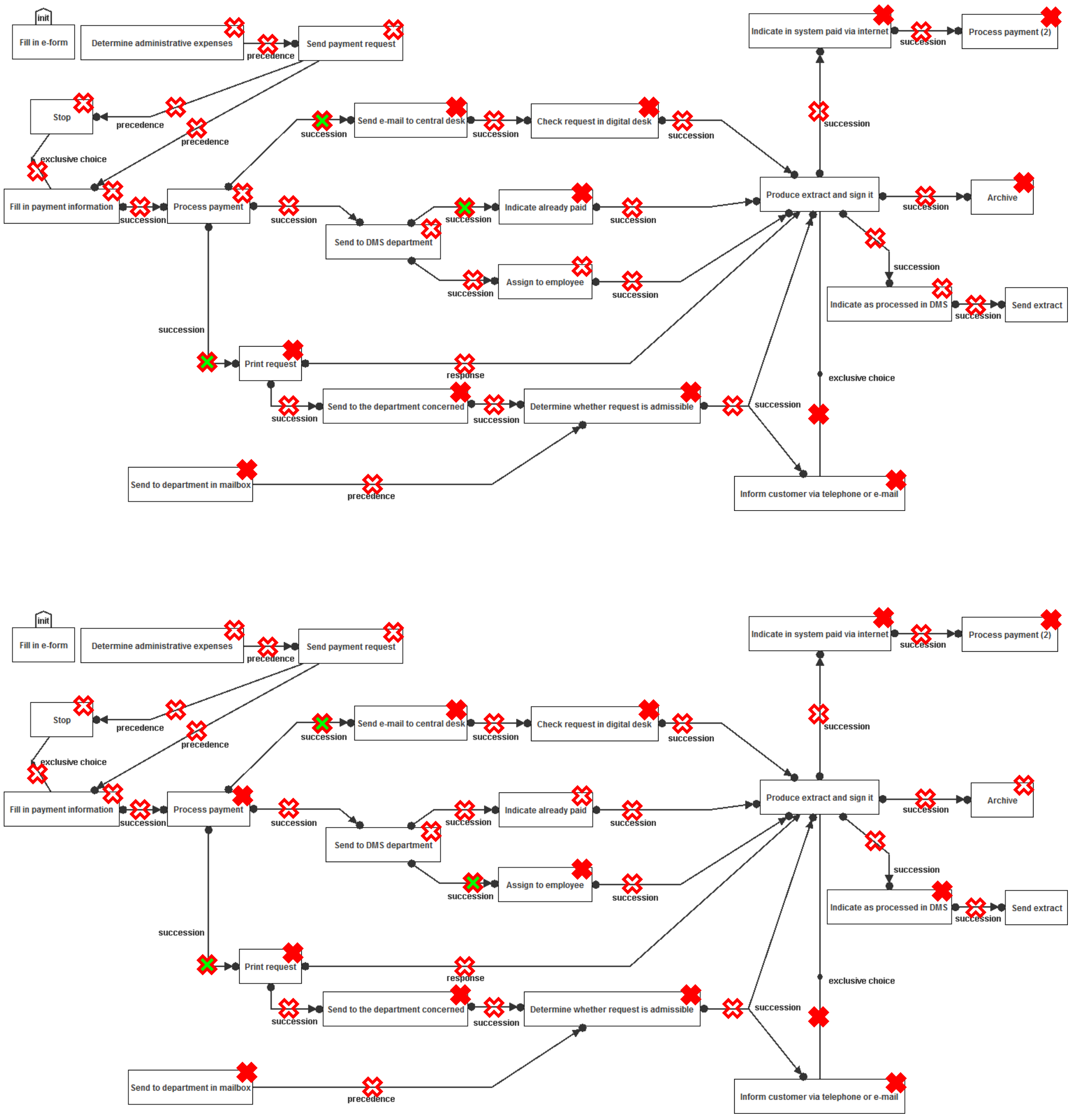


Figure 51: Top: configuration for model D, bottom: configuration for model F

8 Future work

Here, we identify a number of direction in which we can extend *Configurable Declare*. For each direction, we list the benefits when extending *Configurable Declare* with this extension but also, if applicable, possible problems one might encounter when exploring this direction.

Meta-constraints

We do not guide the user in configuring its *Configurable Declare* model, i.e. the user can configure a *Configurable Declare* model in such a way that it cannot be executed. Therefore, we want to extend *Configurable Declare* with meta-constraints. Meta-constraints are constraints between constraints or between tasks and constraints. These meta-constraints would allow the designer to restrict the configurability of a model such that the user can only model valid *Declare* models.

Consider, for instance, the model depicted in Figure 52 in which we have a *not co-existence* between task B and *response*(A, C) denoting that if task B is present, we do not have *response*(A, C) in our model.

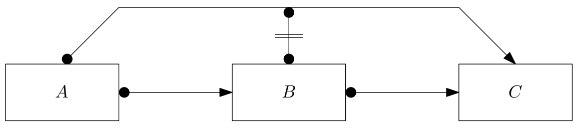


Figure 52: Example of a model with a meta-constraint

Automatic rule discovery

The rules defined in Section 4.4 are defined both manually and automatically. Ideally one has an approach to deduce all rules in an automated fashion which is based on some formal notion. This automated approach can then later on be applied when one decides to extend *Declare* with new constraints.

One can design this automated approach in such a way that it automatically satisfies the soundness, completeness, and confluence properties. Soundness means that all rules are correct, while completeness means that we have discovered all of the rules. Finally, when the confluence property holds, this means that we can apply the rules in any order.

The main problem with automatic rule discovery is that it is far from trivial, consider, for instance, the model depicted in Figure 53. We have the following LTL formula to denote this model (*chain response*(A, B) and *chain response*(B, C)):

$$\Box(A \Rightarrow \bigcirc(B)) \wedge \Box(B \Rightarrow \bigcirc(C)) \ .$$

We want to obtain the following formula denoting that whenever we execute an A we immediately execute a C afterwards.

$$\Box(A \Rightarrow \bigcirc(C))$$

This means we have to find an approach which can remove the next operator from the LTL formula and obtain a formula no longer equivalent to the original formula, i.e. in the original formula we have the relation that if we execute an A, we first execute something else (B) and then execute C ($\Box(A \Rightarrow \bigcirc(\bigcirc(C)))$).

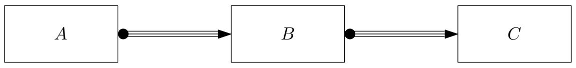


Figure 53: Problematic model for automatic rule discovery

Solving alternate problem

As mentioned before, we have a non-regular language when we apply the rules with the *alternate* templates, e.g. *alternate succession*. We can solve this problem by introducing a new binary constraint denoting what the maximal difference in executions can be. Assume we have two activities, A and B, and the maximal difference between the amount of executions of A and B is five. Then A can never happen six times in a row without a B in between.

In Figure 54, we would add the constraint that A can have at most a difference of two w.r.t. C. This means that after we have executed A two times we need to execute a C. We can encode this in LTL with the following formula: $\Box(A \Rightarrow \bigcirc((\neg A U C) \vee ((A \Rightarrow \bigcirc(\neg A U C)) U (C \wedge \bigcirc(\neg A U C)))))$. Intuitively, whenever we have an A we either do not perform A until we perform C, or if we perform a second A, we do not perform an A until we perform a C and we keep on doing this until we encounter two Cs without an A in between.

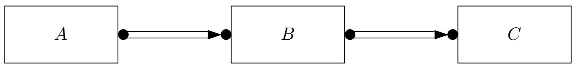


Figure 54: A model in which A cannot execute three times without the execution of C

This approach only works in a non-branched setting: consider, for instance, the model in Figure 55. Within this model, after the removal of B_2, we allow, amongst other, the traces: AAB_1C, $AACB_1$, $AACC$ but not the trace AAB_1B_1. Therefore, we need to create *distance equivalence* classes, i.e. two events are in the same *distance equivalence* class if the same number of *alternate response* constraints are between A and the events. In our example, B_1 is at distance one, and C is at distance two.

When an event is in a certain *distance equivalence*, it can respond to an amount of As proportional to its distance to A without the execution of a new A. B_1 can respond to at most one A, while C can respond to two As. Basically, we are counting the amount of times an event from a *distance equivalence* class can happen to validate this constraint. Before A can happen a next time, we have to make sure that A did not happen more often than the events at the maximal distance to A, in the example two times. Furthermore, if A happened five times and afterwards the events in the *distance equivalence* class at distance one also happened five times, we still need to observe four times events from different *distance equivalence* classes.

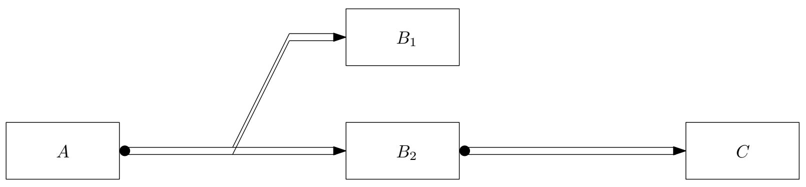


Figure 55: A model in which, after the removal of B_2, we cannot pose the same constraint between A and B_1 and between A and C

Full support for branched constraints

We have seen in Section 4.4 that we have a problem when we have the case as depicted in Figure 56. We could solve it by allowing constraints similar to the constraint in Figure 57.

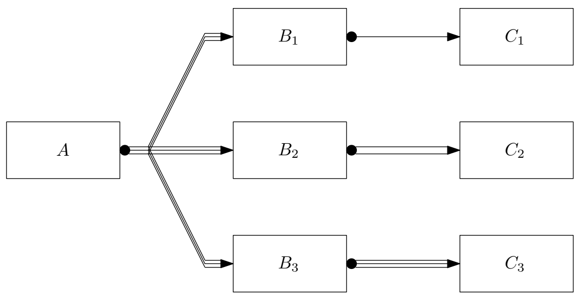


Figure 56: A model in which we cannot express the implicit constraints

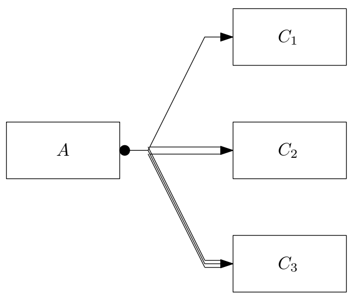


Figure 57: The implicit constraints after the removal of the Bs in Figure 56

We have the following LTL formulas for the different constraints, where $A = \{a_1, \cdots, a_n\}$ and $B = \{b_1, \cdots, b_m\}$ are sets of events: *response*$(A, B) = \Box((a_1 \vee \cdots \vee a_n) \Rightarrow \Diamond(b_1 \vee \cdots b_m))$, *alternate response*$(A, B) = \Box((a_1 \vee \cdots \vee a_n) \Rightarrow (\neg(a_1 \vee \cdots \vee a_n) U (b_1 \vee \cdots b_m)))$, and *chain response*$(A, B) = \Box((a_1 \vee \cdots \vee a_n) \Rightarrow \bigcirc(b_1 \vee \cdots b_m))$. The different formulas only differ on the righthand side of the implication. We can support the new branched constraint by taking the disjunction of the righthand sides, this yields as LTL formula for the new constraint: $\Box((a_1 \vee \cdots \vee a_n) \Rightarrow (\Diamond(b_1 \vee \cdots b_m) \vee \neg(a_1 \vee \cdots \vee a_n) U (b_1 \vee \cdots b_m) \vee \bigcirc(b_1 \vee \cdots b_m)))$.

The second problem we identified was the problem depicted in Figure 58. We needed a constraints between A_1, A_3 and the Bs denoting that if A_1 or A_3 occurred less than 5 times we needed to execute a B.

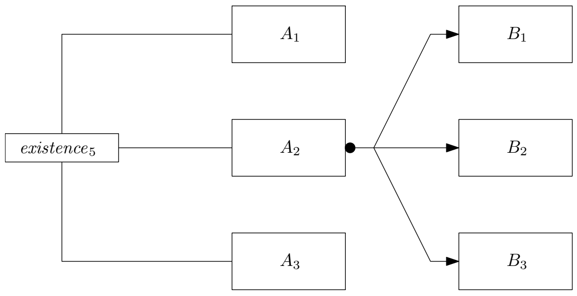


Figure 58: We cannot express the implicit constraints after the removal of A_2

We can extend the *existence* templates with a new template which takes four arguments, basically consisting of the amount of times the events in a certain set of events should occur. When we write $\mathit{existence}'(nr, A, nr', B)$, this means that the events in A should occur at least nr times or the events in B should occur at least nr' times.

In the aforementioned problem, we can encode the implicit constraint as $\mathit{existence}'(5, \{A_1, A_3\}, 1, \{B_1, B_2, B_3\}) = \Diamond(B_1 \vee B_2 \vee B_3) \vee (\Diamond((A_1 \vee A_3) \wedge \bigcirc(\mathit{existence}'(4, \{A_1, A_3\}, 1, \{B_1, B_2, B_3\}))))$. In which $\mathit{existence}'$ is recursively defined similar to the *existence* template.

Support for more configuration patterns

When we operate in a *Branched Declare* setting, we also want to extend the possibilities for configuring the models. One may think of removing a branch from a constraint instead of removing the entire constraint. If we extend *Declare* such that the different branches can have different semantics, one also wants to be able to change the semantics of some branches, similar to substituting a constraint in the non-branched *Declare* setting.

Extending the code

Within the case study, we had to remove constraints not because they had to be removed but because this yielded nicer models. In the future, we will not only compute implicit constraints between omitted activities but also between activities which remain in the model. When we have computed all implicit constraints between activities, we can remove the redundant explicit constraints still in the model.

We currently have a command line program which, using command line arguments, performs the different conversions, e.g. from *Configurable Declare* to a *Configuration*. We use the Eclipse Modelling Framework (EMF) [Fra11] to generate the eXtensible Markup Language (XML) documents representing the models. We want to add a Graphical User Interface (GUI) to the program such that the users can use the GUI to design and configure their models similar to the *Declare* designer[Des11]. Within this GUI, it also should be possible to define new constraints and rules.

Perform multiple case studies

We have used *Configurable Declare* in a single case study where the models shared a large number of similarities. In order to see the full potential of *Configurable Declare*, we want to apply this approach to less homogeneous models. To apply *Configurable Declare* to those less homogeneous models, we first need to solve most of the problems addressed in this section, since less homogeneity means that we want to combine different constraints into a single constraint.

Apart from simply combining different models and then configuring them so that we obtain the original models again, we also want to apply our approach within a real organisation. This will allow us to observe how *Configurable Declare* would be used by people who are not familiar with *Configurable Declare*. Then, we can optimise *Configurable Declare* to better suit their needs and also remove bottlenecks if they exist.

Automatically configuring the model based on a log

[SMS11] presents an approach to automatically validate, given a log and a model, which constraints hold non-vacuously. Non-vacuous satisfaction means that the value, i.e. true or false, of some subformulas of a formula does not change the validity of the entire formula. Consider, for instance, $\mathit{response}(A, B)$ which means that every A is eventually followed by a B. In logs where A does not occur, this formula is always valid, i.e. every A is followed by a B.

We can take our *Configurable Declare* model and a log from an organisation and deduce which constraints hold non-vacuously on the log and should be kept in the model. The approach by [SMS11] also takes into account whether certain events are present in the log, hence we can use this to automatically configure the events in the *Configurable Declare* model.

Automatic configuration to obtain a given model

To obtain the *Declare* models, used in the "combining models" algorithm, the user has to manually define the configurations on the *Configurable Declare* model. We want to define these configurations automatically, so given a *Configurable Declare*$_0$ model and a *Declare* model, we want to obtain the configuration (if it exists) of the *Configurable Declare*$_0$ model, which yields the given *Declare* model.

We first need to check whether the tasks in the *Declare* model are all present in the *Configurable Declare*$_0$ model. If this is the case, we need to validate that all tasks not present in the *Declare* model can be configured to be omitted in the *Configurable Declare*$_0$ model. We remove all tasks not in the *Declare* model from the *Configurable Declare*$_0$ model using the rules defined earlier and obtain the *Configurable Declare*$_1$ model. After we have validated whether the tasks can be omitted, we need to validate that the constraints can be configured as needed w.r.t. the constraints of the *Declare* model.

We compute all implicit constraints on the *Configurable Declare*$_1$ model and the *Declare* model. If the (implicit) constraints of the *Declare* model are not a subset of the (implicit) constraints on the *Configurable Declare*$_1$ model, we know some constraints are present in the *Declare* model but not in the *Configurable Declare*$_1$ model. This means that we cannot define a configuration.

If the constraints of the *Declare* model are a subset of the constraints in the *Configurable Declare*$_1$ model, we remove all constraints in the *Configurable Declare*$_1$ model not present in the *Declare* model and which can be removed, i.e. *omit* is true. After removing these constraints from *Configurable Declare*$_1$, we obtain *Configurable Declare*$_2$.

By removing the constraints from the *Configurable Declare*$_1$ model not present in the *Declare* model, we might also remove constraints necessarily to deduce implicit constraints present in the *Declare* model. In order to ensure that we did not remove an explicit constraint needed for this deduction, we recompute the implicit constraints on the *Configurable Declare*$_2$ model and obtain the *Configurable Declare*$_3$ model. Consider, for instance, the *Declare* and *Configurable Declare*$_1$ model in Figure 59. If we remove the constraints not in the *Declare* model from the *Configurable Declare*$_1$ model, we also remove the implicit *responded existence* between C and B which is explicit in the *Declare* model.

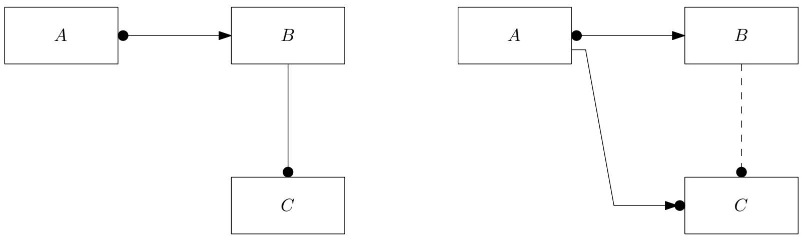


Figure 59: Left: *Declare* model, right: *Configurable Declare*$_1$ model

Instead of a subset relation, we want to have an equivalence between the constraints, implicit and explicit, of the *Configurable Declare*$_3$ model and the constraints, implicit and explicit, in the *Declare* model. If we have an equivalence, we also have the configuration, i.e. all tasks which are not in the *Declare* model have to be removed and all constraints not in the *Declare* model (either implicit or explicit) have to be removed. In case we do not have an equivalence, we cannot deduce a configuration, i.e. there are constraints in the *Declare* model which are not in the *Configurable Declare*$_3$ model.

Configuring the model based on a questionnaire

In [LRLS$^+$07], the authors propose an approach to configure a model by means of a questionnaire. Each question of the questionnaire is linked to a set of decision point and each decision point has a set of questions associated with it. A decision point is a construct of the language which can be altered, i.e. similar to the alteration of constraints.

We want to use such a questionnaire-based approach for *Configurable Declare*. This would allow the user of *Configurable Declare* to configure the model without any knowledge of *Configurable Declare*, and it would allow the designer of the *Configurable Declare* model to limit possible configurations. By limiting possible configurations, the designer can forbid configurations which lead to non-executable *Declare* models or which lead to *Declare* models which invalidate a legislation.

9 Conclusion

We have presented a solution to extend *Declare* to *Configurable Declare*. *Configurable Declare* allows for flexibility within a process model, i.e. everything is allowed unless stated otherwise. *Configurable Declare* also allows for flexibility of the process model itself, i.e. the process model can be changed to better cope with the environment in which it will be applied. This means that as well as having flexibility at run-time we also have flexibility at configuration-time, i.e. between design-time and run-time. After the process model has been designed but before the process model is used, we can adapt the process model towards company's needs.

By supporting both notions of flexibility, we developed a process modelling language which is the preferred choice to be applied in environments with high variability. The application of *Configurable Declare* is not limited to environments with high variability. In every environment where rules or legislation must be obeyed, *Configurable Declare* is a candidate worth considering.

All the configuration patterns identified in literature, which are useful to consider, are supported by *Configurable Declare*. Unfortunately, we were not able to address all problems which occur when moving to *Branched Declare*. In the future work section (Section 8), we show that most of the issues which still exist can be easily addressed. Most of the patterns which are difficult to incorporate in imperative languages are almost trivial to support in *Configurable Declare*, especially the patterns which entail the flexibility within the process model.

Considering that *Configurable Declare* takes implicit constraints into account, we can use it to encode legislation. If the legislation is non-configurable, we know that, after transforming this *Configurable Declare* model into a *Declare* model, all legislation is still encoded in the *Declare* model. If the legislation is configurable, we can remove parts of the legislation and we have to be sure that this does not yield incomplete encoded legislation. Therefore, we opt for the creation of a questionnaire to guide the user in configuring the legislation for her organisation. By using this questionnaire, we can guarantee that all legislation is encoded properly in the *Declare* model.

The theoretical design is supported with both an implementation and a case study. With the implementation, we can perform the conversions, described in the thesis, in combination with the application of the rules. Using this implementation, we showed in the case study that our approach can be applied to real life declarative process models, whilst yielding the expected outcome.

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Appendices

A Meta-models

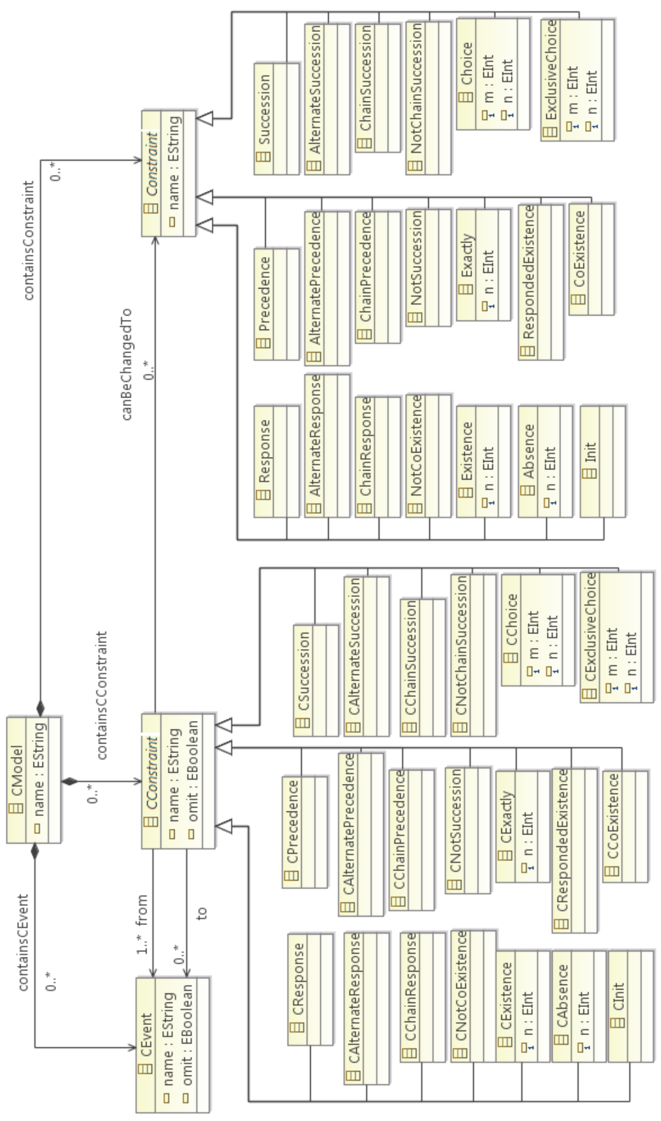


Figure 60: Meta-model of *Configurable Declare*

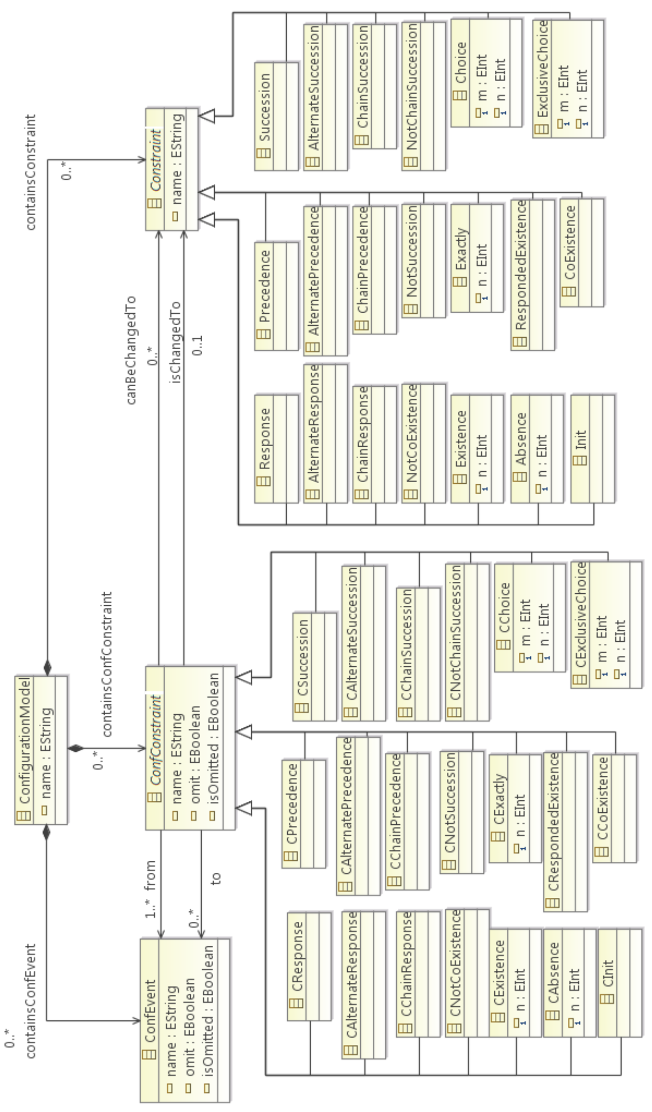


Figure 61: Meta-model of a *Configuration*

B Input models

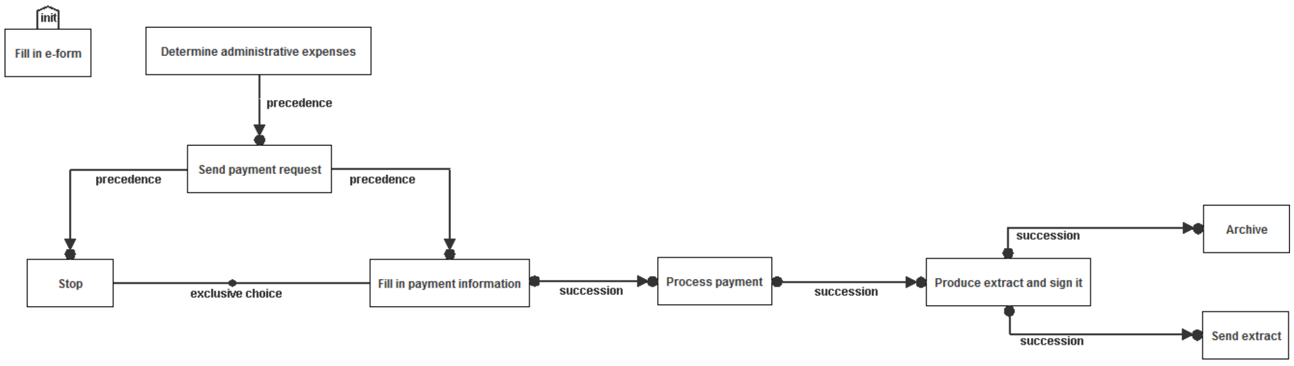
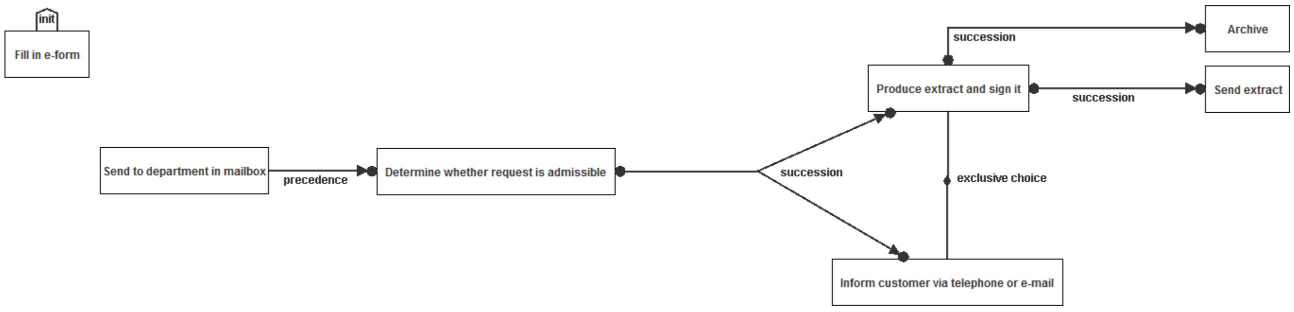


Figure 62: Input model A



init
Fill in e-form
Send to department in mailbox
precedence
Determine whether request is admissible
succession
Produce extract and sign it
succession
Archive
succession
Send extract
exclusive choice
Inform customer via telephone or e-mail

Figure 63: Input model B

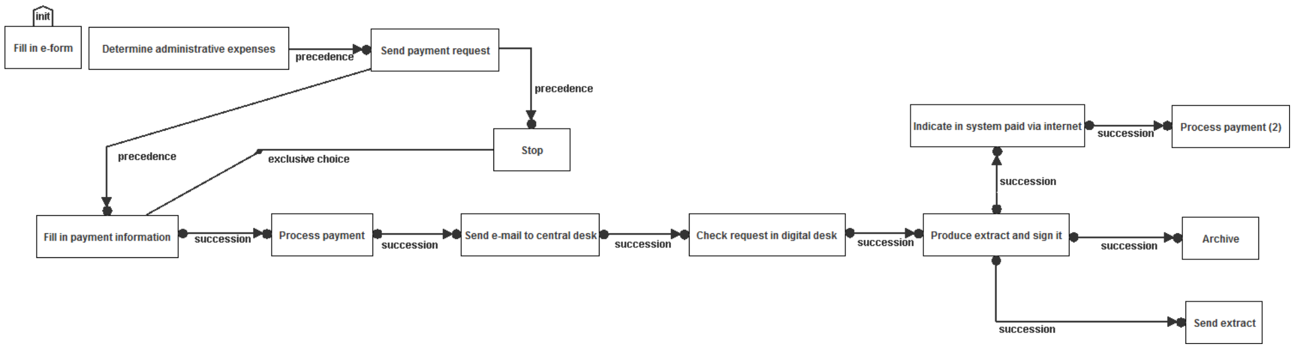


Figure 64: Input model C

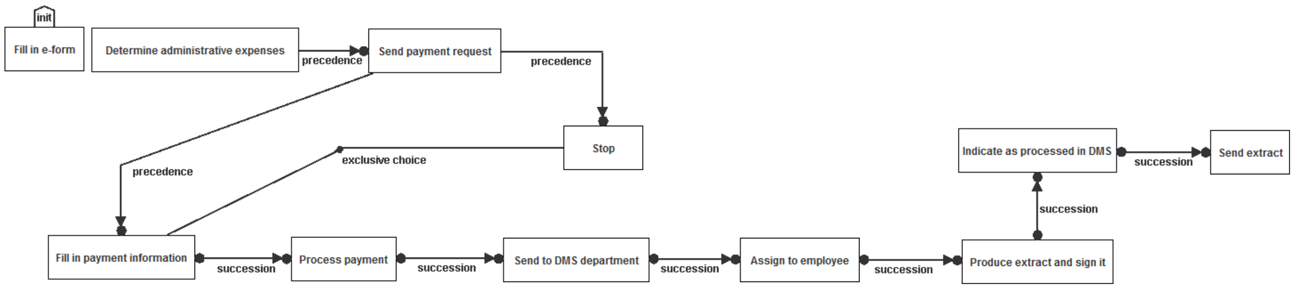


Figure 65: Input model D

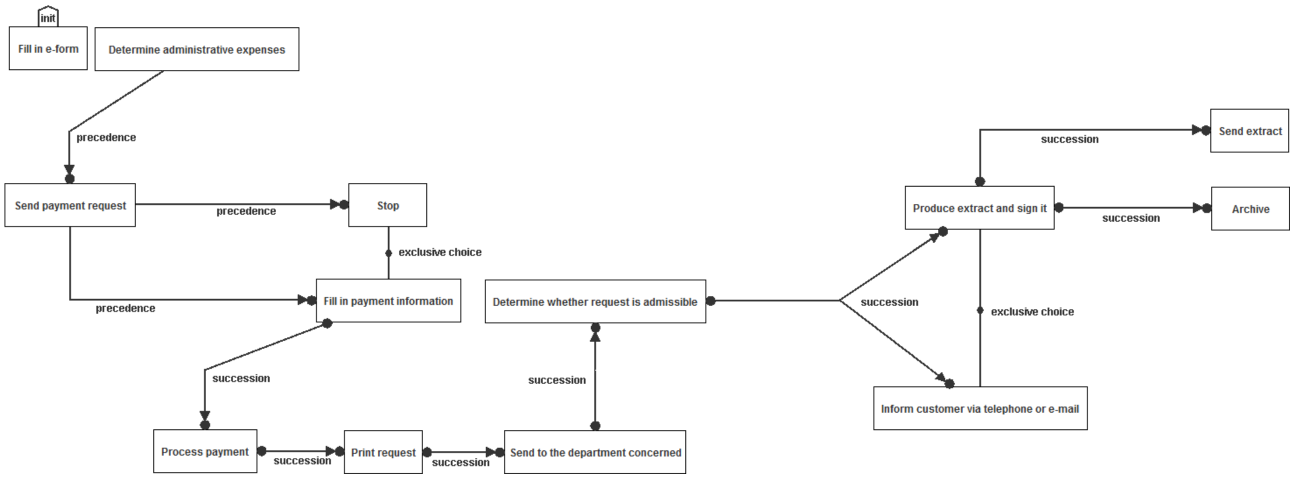


Figure 66: Input model E

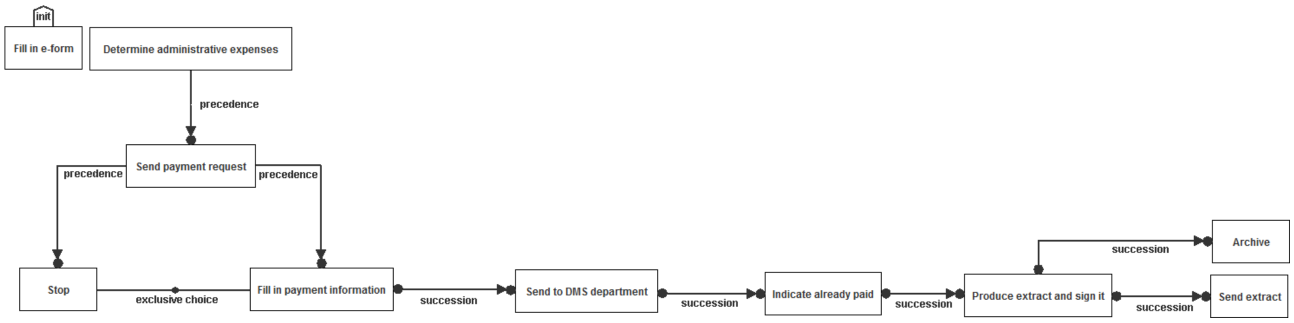


Figure 67: Input model F

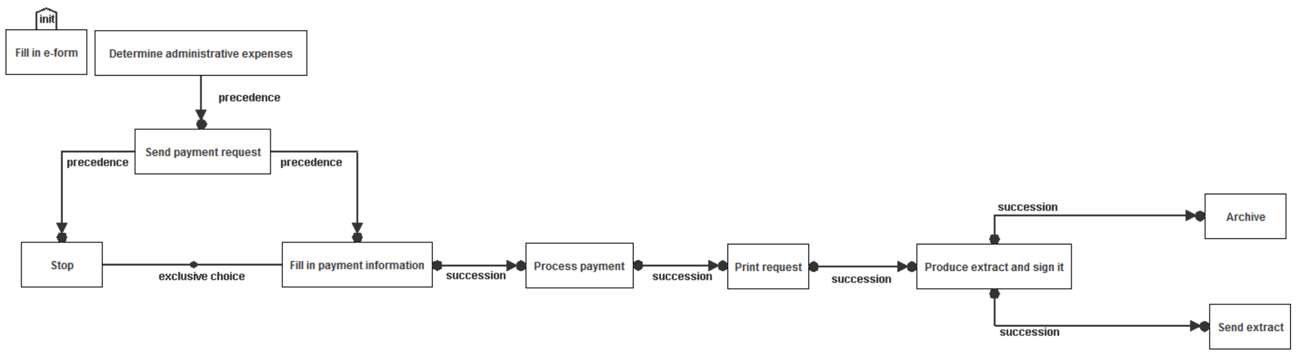


Figure 68: Input model G

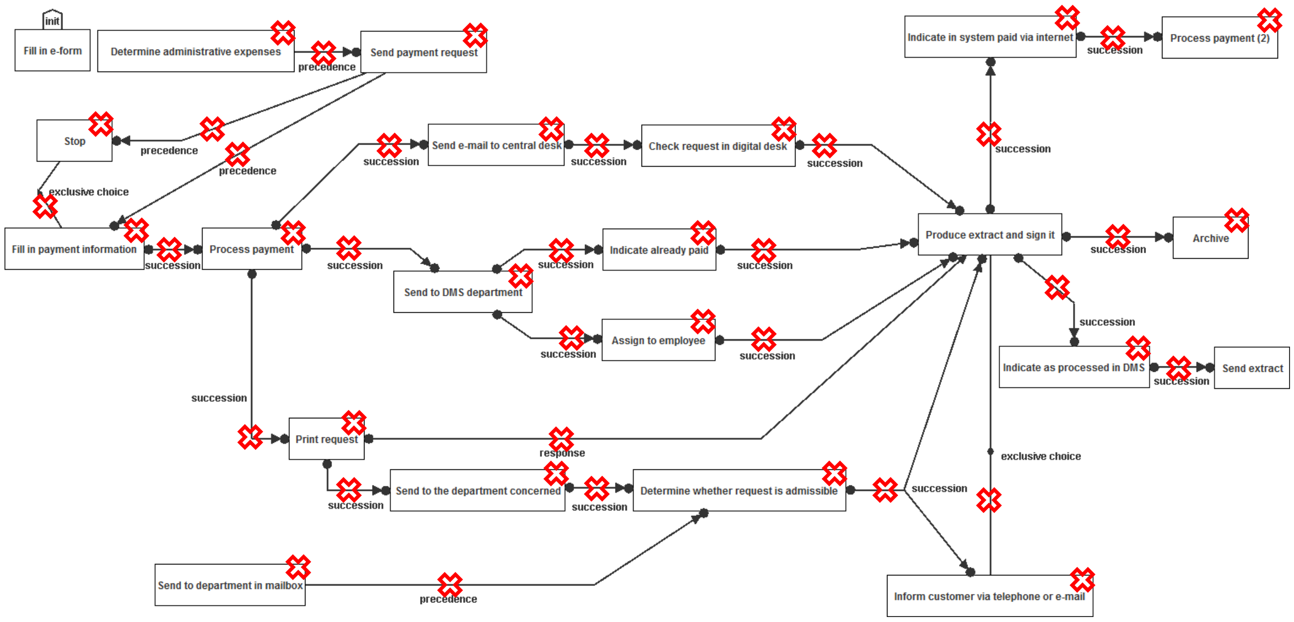


Figure 69: The *Configurable Declare* model

C Configuration models

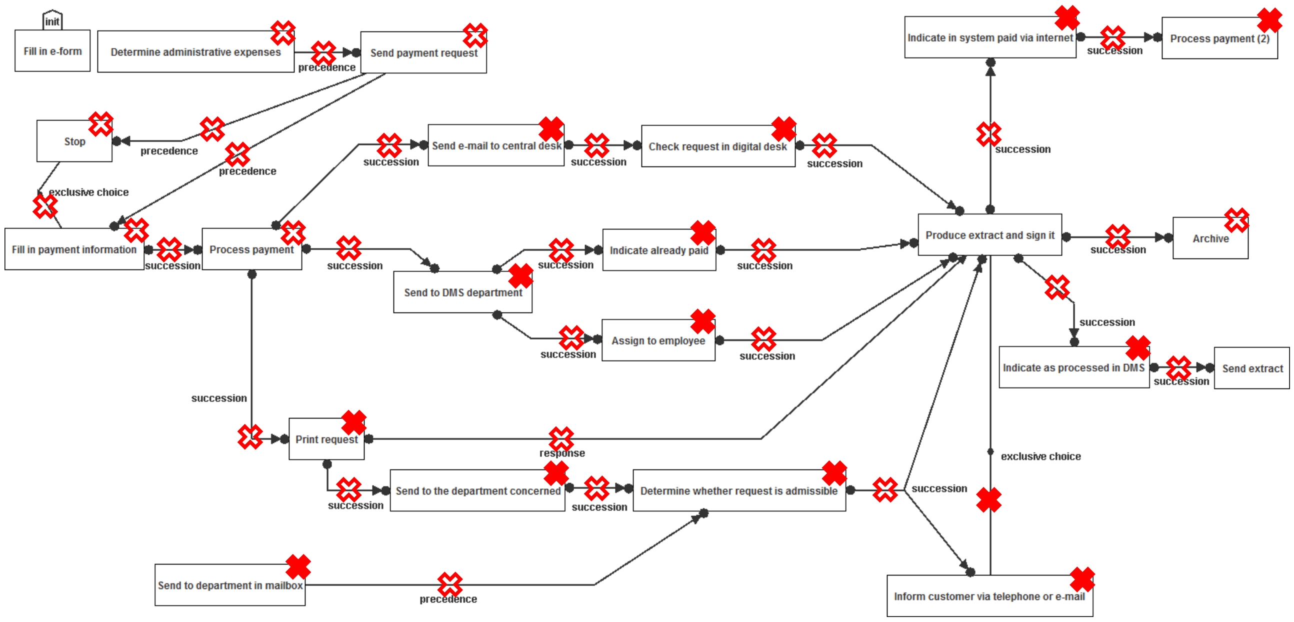


Figure 70: The configuration for model A

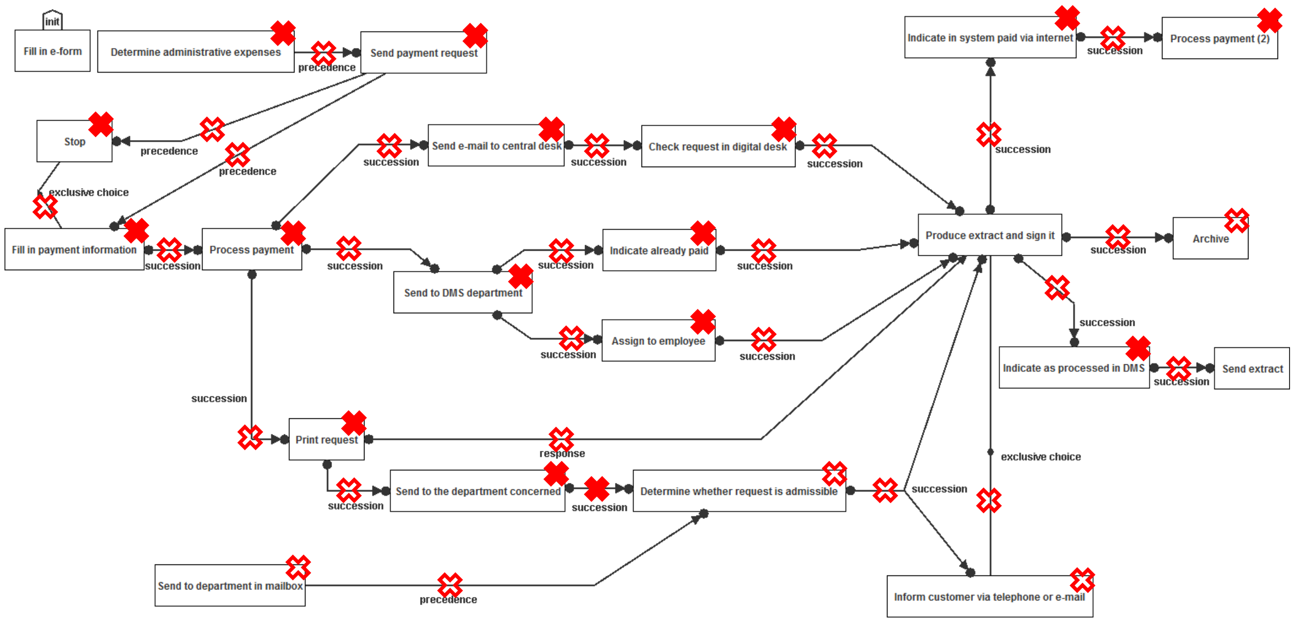


Figure 71: The configuration for model B

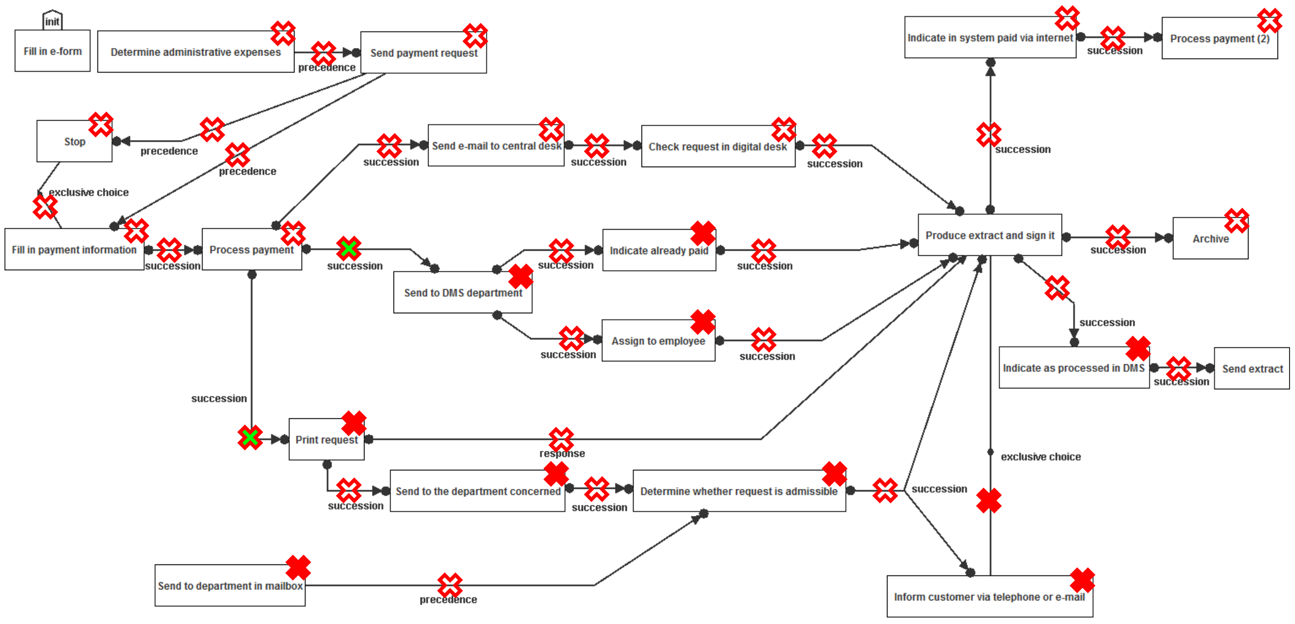


Figure 72: The configuration for model C

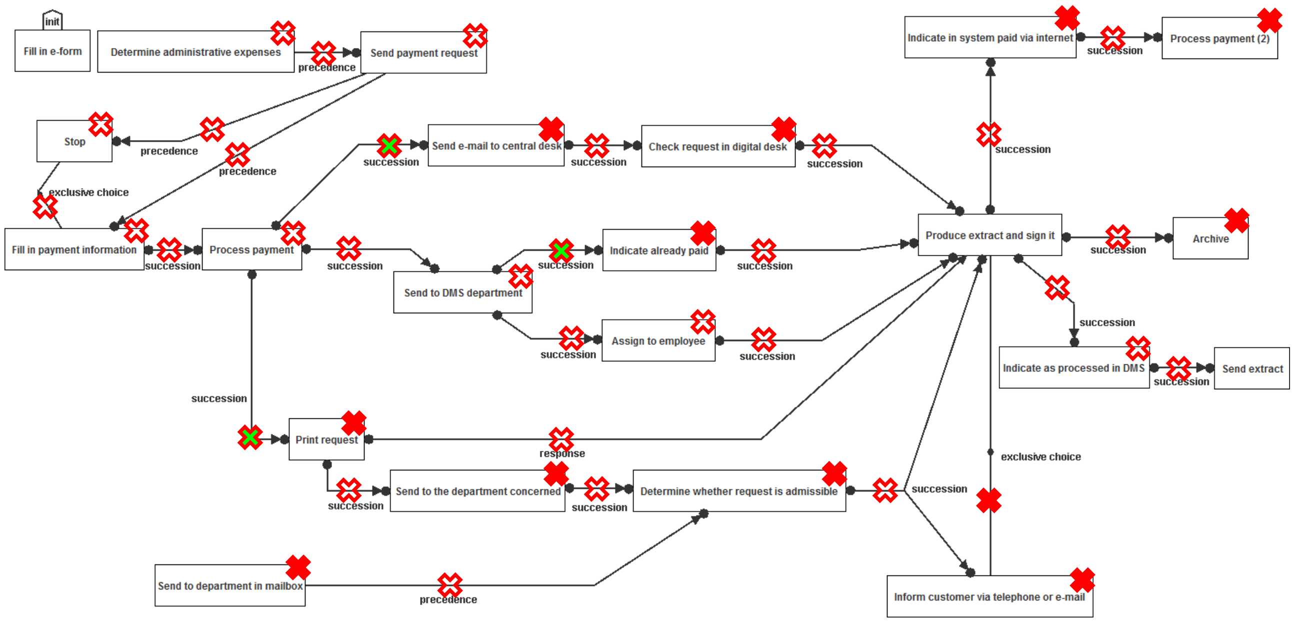


Figure 73: The configuration for model D

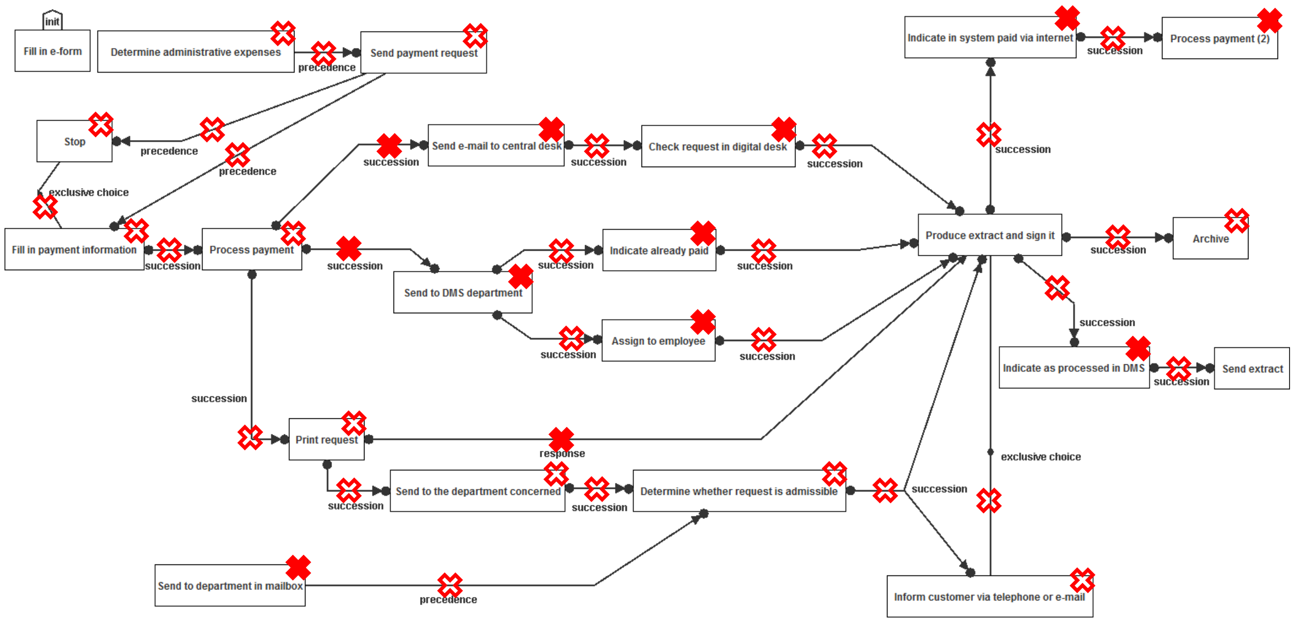


Figure 74: The configuration for model E

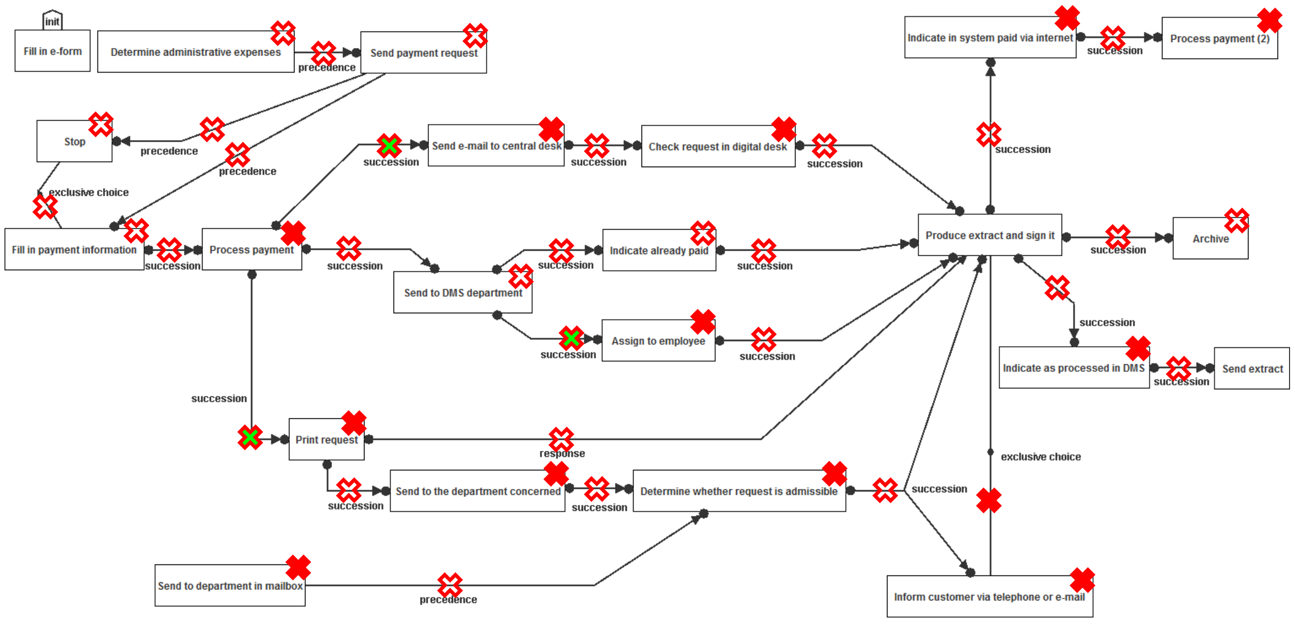


Figure 75: The configuration for model F

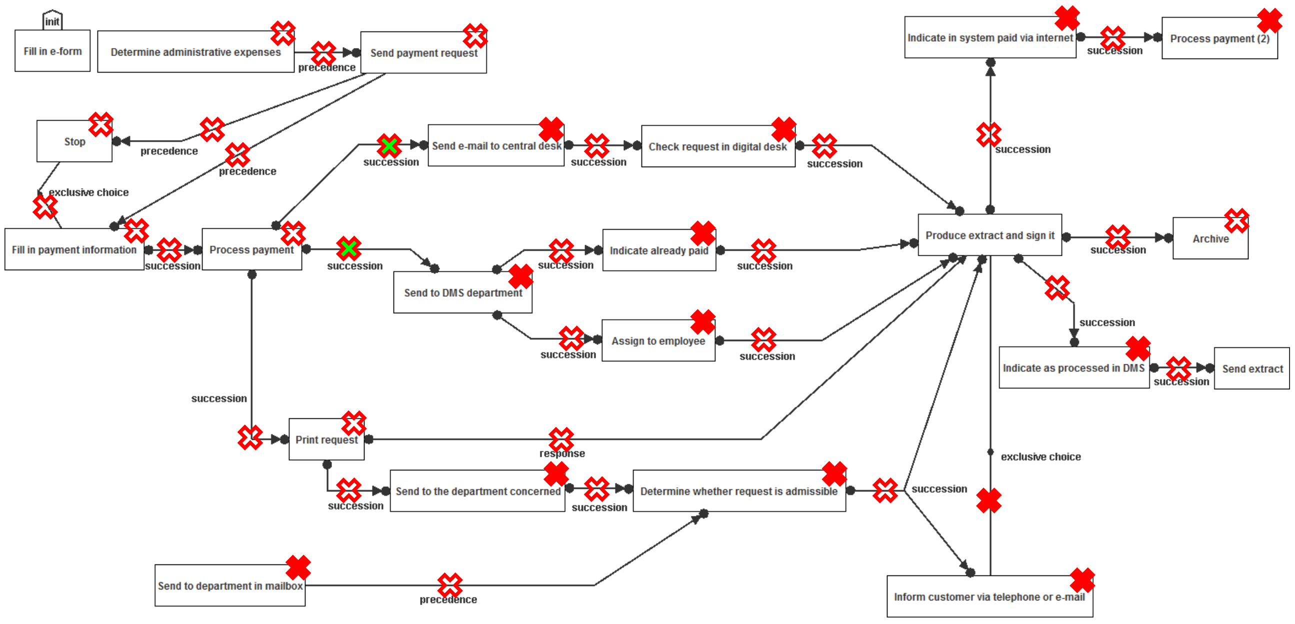


Figure 76: The configuration for model G