Chapter 3

Reusing Strategies for Decision Support in Disaster Management – A Case-based High-level Petri Net Approach

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3.1. Introduction

Disasters are characterized by serious disruptions of society's functionality involving human, material, economic, and/or environmental losses, and particularly by exceeding society's capacity to cope with its own resources [1]. Disaster management is "the organization, planning and application of measures preparing for, responding to and recovering from disasters" [2]. There are several models that explain the key elements of disaster management from different points of view. The most common approach is the division into the four phases 'mitigation', 'preparedness', 'response', and 'recovery' [3]. This research is dedicated to the 'preparedness' phase which aims at facilitating response and recovery by, for example, developing decision support methods and software solutions or, in general, by promoting readiness. The method presented is mainly elaborated through nuclear emergencies.

Decision-making in the event of a disaster is complicated by various factors such as the uncertainty on what is happening and the limited time frame available to identify appropriate strategies for countering such events. A *strategy* is understood as a combination of several measures aiming at specific objectives. In the case of nuclear accidents, for instance, objectives are to reduce the level of radiation exposure to humans and, in the longer term, to return to normal living conditions.

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Computerized support for disaster management is a vital research topic which is reflected, for example, by the annually held Conference on Information Systems for Crisis Response and Management [4] or the various knowledge management systems developed over the last decades [5]. When explicitly looking for decision-supporting solutions for disaster management, the focus varies from scheduling [6] to mobile support [7] to humanitarian relief [8]. Furthermore, different event types such as floods [9] or environmental [10] and technological emergencies [11] have been investigated.

In respect of nuclear emergencies, JRodos [12], Argos [13] or the NARAC [14] system are among the well-known and operationally used decision support systems. These systems prepare decisive information for constructing a strategy with each new event, e.g., projections of the radiological situation, and analyses of the effectiveness of combined measures. However, as regards emergency management, there are still some issues that became particularly apparent during the Fukushima Daiichi Nuclear Power Plant Accident and that have been discussed in several reports and papers (e.g. International Atomic Energy Agency (IAEA), 2015; Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company, 2012; The Fukushima Nuclear Accident Independent Investigation Commission, 2012). Some of these are: (i) Uncertainty in respect of initial information and simulation results; (ii) Complexity of strategy building. Above all, there is a lack of practical experience with regard to appropriate strategies and their implementation, especially in the long-term. (iii) Preparedness and, above all, the structured integration of existing knowledge and experience in the decision process. Mainly with regard to (ii), preparing scenarios and strategies in advance of an accident would help to save time and avoid mistakes in the event of an incident. We suggest a case-based decision support method that identifies strategies for response and recovery on the basis of experience and expert knowledge and in particular prepared strategies that are adaptable to the current circumstances. Here, the strategies are subject to a High-level Petri net (HLPN) model to be included in the case-based decision support system. Hence, the suggested strategies are stored in a structured manner and are executable as well as analyzable.

The presented method is independent of the underlying *event* and hence the occurrence of the incident that triggers the necessity of building and implementing a strategy. However, the concrete implementation of the case-based decision support method requires an in-depth analysis of the underlying triggering incident. The timely structuring of a nuclear accident taking into account the status of release of radioactive material could not be applied to earthquakes, for example. Information on release is crucial for decision-making in nuclear emergency management and would not be relevant in the case of natural disasters.

Our case-based decision support method particularly addresses issues that became apparent during the Fukushima Daiichi Nuclear Power Plant Accident and aims at complementing existing decision support systems (i) In times of high uncertainty; (ii) By suggesting coherent strategies; (iii) By structuring and storing experience and existing knowledge to be reused in a current event, and especially (iv) By preparing scenarios in advance of an event as well as (v) By promoting computerized strategy support and analysis possibilities. To sum up, the method pursues a different approach than do current decision support systems or methods that are mainly simulation-based or based on multi-criteria decision analysis (e.g. [18]).

Fig. 3.1 illustrates an overview of the decision support method which relies on Case-based Reasoning (CBR), a problem-solving paradigm that utilizes knowledge of previously experienced problematic situations to solve a current problem [19]. Here, the description of a problem, the corresponding strategies for problem solving, their effectiveness, and further decision-supporting information build a case in the case base. Scenarios i.e., fictitious events following the same structure as a historical event, enhance the case base. The idea is to determine different accidents and appropriate strategies in advance to store them in the case base and to make them reusable in the case of a current event.

CBR and especially the decision-supporting method can be described as a cycle process that consists of four phases. After identifying and describing the problem to be solved, the first step is to retrieve the most similar case or cases from a case base. The second step is to reuse the strategies of the similar cases involving possibly the merging of several strategies and the adaptation to current circumstances. Besides numerical adaptations according to effectiveness parameters such as waste or costs, several potentially appropriate strategies should be merged to cover all objects possibly endangered. The suggested solution will be revised by the user and possibly tested or adjusted. Finally, the case base is updated by retaining the new case with its confirmed solution in the case base. In general, each phase involves several tasks with various methods to be realized [19]. Besides the specific knowledge in the cases, general domain-dependent knowledge supports each phase of the CBR cycle.

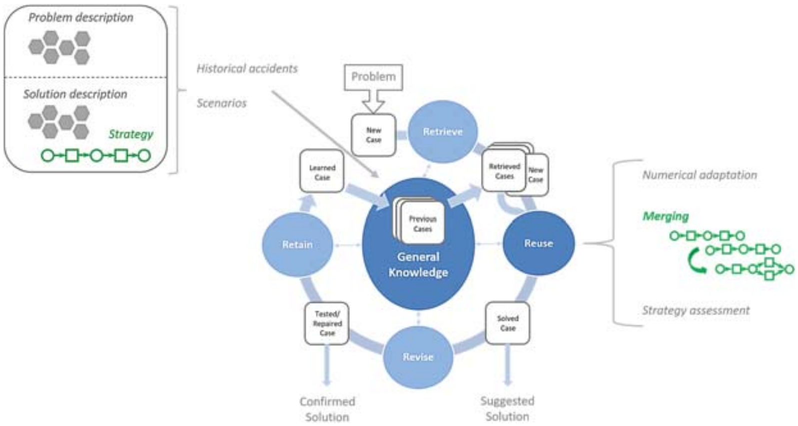

Fig. 3.1. Overview of the decision-supporting method with a special focus on strategy modeling and reuse in the framework of case-based reasoning. The CBR cycle is based on [19].

Research on CBR is manifold (e.g. [20-23]), for example in the context of disaster management as a special field of application (e.g. [24-30]). CBR can be used when solutions are difficult to obtain and when storage makes sense for later reuse. It can also be used in exceptional situations when causal models would reach their limits and in domains that are not fully understood and where the use of similarity offers possibilities to reason [31]. Similar situations may also offer a framework for evaluating solutions and specifically for avoiding mistakes of the past [31] or mistakes that have already been thought through. The latter mainly refers to scenario construction which is part of the method proposed. In general, CBR is intuitively comprehensible and transparent and the proximity to human problem-solving is advantageous in respect of accepting the decision-supporting method.

The strategies stored in the case base are subject to a HLPN model to capture the implementation order, provide analysis possibilities, and support their automated reuse in the course of a current event. Petri nets essentially provide means to describe a course of action formally and unambiguously and are applied successfully in various fields, inter alia in disaster management. The combination with CBR is promising since

(i) Suggestions on strategies are based on experience and expert knowledge; (ii) Strategies are stored in a structured manner and are executable as well as analyzable; and (iii) The approach supports preparedness and provides means to improve by integrating more knowledge.

In Fig. 3.1, the parts of the method presented in the following are highlighted in green. Previous publications particularly focus on the case base and retrieval [32, 33]. First research on the reuse step has already been published [34, 35], and further results are presented in the sections below.

The structure of the book chapter is as follows: First, (high-level) Petri nets are introduced, and their research and benefits in the field of disaster management are discussed. Next, the research questions are presented, and an overview is given of the structure of the entire method, the focus of this publication, and the added value. An introduction to the strategy model is then followed by a presentation of the reuse step and predominantly of the merging of several strategies as well as by examples and a discussion of the Petri net approach and future work.

3.2. Petri Nets and Their Application in Disaster Management

Petri nets are a graphical and mathematical modeling tool useful for describing and analyzing information processing systems as well as for visual communication [36]. They originate from the early work of Carl Adam Petri [37]. A Petri net [36] is a tuple

$$PN = (P, T, F, W, M_0),$$

where:

- P and T are the non-empty finite sets of places and transitions,
- $P \cap T = \emptyset$,
- $F \subseteq (P \times T) \cup (T \times P)$ is called a flow relation of PN. The elements of F are called arcs,
- $W: F \rightarrow \mathbb{N}$ is the weight function,
- $M_0: P \rightarrow \mathbb{N}$ is the initial marking.

Places are represented by circles, transitions by rectangles, and arcs are labeled by weights. The state of the system, which is called a marking $M: P \rightarrow \mathbb{N}$, is reflected by the distribution of tokens, represented by black dots, over places. The input and output places of transitions are defined as follows:

- $\bullet t = \{p | (p, t) \in F\}$ is called the set of input places of transition *t*,

- $t \bullet = \{p | (t, p) \in F\}$ is called the set of output places of transition *t*.

The dynamics of the system can be described by marking changes caused by firing a transition. A transition *t* is enabled if and only if each input place *p* contains at least *w(p,t)* tokens where *w(p,t)* denotes the weight of the arc from *p* to *t*. The firing of *t* removes *w(p,t)* tokens from each input place *p* and adds *w(t,p)* tokens to each output place *p* of *t* where *w(t,p)* is the weight of the arc from *t* to *p*.

There are different types of nets, namely low- and high-level Petri nets. In low-level nets, such as the classical Petri nets introduced above, tokens are indistinguishable. In HLPNs [38], tokens have individual characteristics and therefore can be distinguished. Here, places and transitions are defined with respect to different token types. Further well-known extensions of low-level nets are according to time and hierarchy to structure large models [39]. HLPNs allow for a more compact description than low-level nets and for practical applications, they are preferred to the latter [40].

Petri nets are interesting for a variety of application fields such as performance evaluation, manufacturing/industrial control systems, distributed software systems or decision models [36]. They are used for various emergency management applications: generalized stochastic Petri nets are used e.g. for modeling traffic accident rescue processes [41], and stochastic Petri nets are applied for performance analyses of coal mine emergency processes [42], emergency response decision-making processes [43], and urban response [44]. Colored Petri nets, in particular, are used to model emergency plan business processes [45] and emergency response in the course of chemical accidents with continuous places and transitions [46]. They are used in combination with a queuing system for resource use [47] and in the framework of critical infrastructure protection [48] or for modeling the patients flow in an emergency medical department [49]. Further application examples of Petri nets are emergency management modeling in railway stations [50], modeling of industrial fire management processes [51] or accident modeling [52] where the difficulty is to transfer text into a formal model [53]. Moreover, Petri nets have a huge potential in the field of risk analysis and accident modeling with the possibility of expressing common concepts in Petri net formalisms [54]. Petri nets are particularly used in nuclear power plant emergency management, which aims at reducing the number of false evacuations [55].

The Petri net applications presented so far focus on specific emergency response processes (i.e., in the framework of a specific accident scenario) for performance analysis or for execution support. The research questions addressed in this book chapter have a different focus which will be discussed in the following. The papers by [45-47] are thematically close to our approach. They report on working with HLPNs and distinguishable tokens according to different resource types and the level of the fire state [46]. The application domain of nuclear emergencies can be found in [55] who models a specific emergency management process addressing actions within a nuclear power plant with the help of low-level Petri nets.

3.3. Research Questions

The research presented in this book chapter has a different focus than related work on Petri nets in disaster management. Above all, the following question is addressed: **How can strategies for disaster management be modeled considering following requirements?**

(i) **Independence from the type of event.** This requirement originated from research in the field of natural disasters and analyses of different types of events allowing now to transfer the model to nuclear emergencies as well. The focus on nuclear emergencies originated from the participation in the European project PREPARE [56] where a close collaboration with experts took place providing the possibility of data collection.

(ii) **Capturing the implementation order of measures.** In general, measures cannot be executed in an arbitrary order. Examples in the nuclear field can be found in the Handbook for Assisting in the Management of Contaminated Inhabited Areas in Europe Following a Radiological Emergency [57] where decontamination measures are listed that may have timely or logical constraints with regard to the implementation order.

(iii) **Comprising short- and long-term decisions as well as possible event developments.** Being part of the preparedness phase of disaster management, this work aims at providing support for response and recovery and hence short- and long-term decisions.

(iv) **Capturing the effects of measures.** This requirement is important for the comparability of strategies.

(v) **Capturing crucial factors influencing decisions on measures.** This requirement particularly refers to the learning capability of CBR. The crucial factors are important for identifying similar cases from the case base. Some of them are important for the reuse step as well.

(vi) **Allowing performance analysis**, which is important for the assessment of strategies. Hence, simulation possibilities are of great value.

(vii) **Supporting a graphical representation of strategies** facilitating user understanding. A structured storage and possibilities for automatic processing are of first priority. A graphical presentation would mainly be useful for communication and manual adaptation of strategies, if desired. The latter would be future work.

(viii) **Facilitating automatic processing** which is important for the reuse step of CBR.

(ix) **Allowing easy extensibility.** The modeling capabilities should not be limited. This work does not claim to have integrated all decisive factors but rather focuses on a general model for strategies.

Studies on related work, reports on the flood in 2002 in Germany [58, 59], the German fire department regulation 100 (FwDV 100) [60] dealing with leadership and command in emergency operations command and control systems as well as research within the PREPARE project resulted in the requirements listed so far. The fire department regulations particularly guide situation assessment which is based on locality, time, weather, damage, damaged objects, the extent of damage as well as resources determining the planning process and the resulting measures. In this work, location, context of event or the initial situation are primarily covered by the retrieval step of CBR.

Petri nets are regarded as an appropriate tool answering the research question and meeting the requirements presented before. They allow for a mathematical representation of strategies and provide analysis capabilities of structure and dynamic behavior [61]. Furthermore, they have a good graphical representation. Petri nets are applied successfully in various fields, particularly in the areas of emergency and disaster management as well as accident modeling, as can be seen in the literature review. The modeling of strategies including measures, events, and decisive information leads to various states and an increasing complexity. Hence, HLPNs are preferred over low-level Petri nets allowing for a compact, generic, and clear representation of strategies.

Petri nets are also used in the context of CBR e.g., for establishing a database where case retrieval is based on similarity calculations between markings [62]. In addition, they serve as a means for gaining parameters that can be used in the case retrieval [63] or are used to model cases [64], [65]. Again, specific implementations, purposes, and application domains differ from what is studied and presented in this book chapter. The following section summarizes the structure of the entire method, the focus of this publication, and the added value.

3.4. Case- and HLPN-based Decision Support

The structure of the main components is as follows:

(i) A case of the case base is subject to a case model that consists of a problem and solution model. The solution model includes the strategy model [32]. Strategies are instances of the strategy model.

(ii) The problem model is an n-tuple of attributes where specific attributes are used for the retrieval step of CBR [32]. The strategies of the *k* most similar cases (*k* can be a fixed number or the number of cases whose similarity values exceed a certain threshold) may be reused. Reuse includes numerical adaptation, merging of several strategies, and strategy assessment.

The application domain is disaster management and above all the development of a decision-supporting method for response and recovery promoting the reuse of already compiled knowledge and particularly preparedness. This work builds on previous studies, focusing now on the strategy model and on the reuse step. The strategy model, which is based on HLPNs, allows a structured storage of strategies, automatization of the reuse step of CBR as well as analyses concerning effectiveness parameters. The strategy model is an inherent part of the case model whose graphical representation possibilities may be used to promote user understanding and manual adaptation.

To the best of the authors' knowledge, the above presented integration of HLPNs in a case-based decision-supporting method is new in disaster management. In particular, the authors promote a novel research direction, namely case-based decision support in nuclear emergency management [32], [33], [66-68]. The following section presents the developed strategy model.

3.5. Strategy Model

The strategy model is based on ISO/IEC 15909 [69] with the final published version in 2004 [70]. Moreover, the labeling of transitions [36] is integrated. The strategies in the case base are instances of the strategy model. In consideration of the requirements listed before, the following **assumptions** are made:

(i) The model contains two active components with different behaviors: measures and events.

(ii) Events cause the endangerment of specific objects. In respect of nuclear emergency management, objects may also be surfaces that have been contaminated. Here, 'endangerment' needs to be understood in a wider sense.

(iii) Measures are decided upon and implemented because of an event and its resulting endangered objects.

(iv) Measures reduce the endangerment of the objects and do not create endangerment.

(v) Measures consume resources.

Definition 3.1. HLPN-based strategy model.

The strategy model S is a tuple

$$S = (P, T, Dom, Type, Pre, Post, M_0),$$

where:

(i) P is the finite set of places.

(ii) $T = T_m \cup T_e$ is a finite set of transitions where T_m denotes the set of measures and T_e denotes the set of events. It holds that $P \cap T = \emptyset$. Moreover, there are finite sets of labels for measures Σ_m and events Σ_e and labeling functions

$L_k: T_k \to \Sigma_k, k \in \{m, e\}$,

which assign labels to the transitions from a predefined domain.

(iii) $Dom = \{B \times [0,1], R, \{\cdot\}\}$ is a set of domains where each element of *Dom* is called a type. The first type *B* is a predefined set of endangered objects. The interval [0,1] indicates the degree of endangerment expressed as real number between 0 and 1. With reference to a contaminated surface, 1 indicates 100 % contamination and 0 indicates a successful decontamination[1]. The second type *R* is a predefined set of resources. The type $\{\cdot\}$ does not have any characteristics.

(iv) $Type: P \cup T \to Dom$ is a function used to assign types to places and to determine transition modes. A transition mode is a pair comprising the transition and a value taken from the transition's type.

(v) $Pre, Post: TRANS \to \mu PLACE$ are pre- and post-mappings with

$TRANS = \{(t, m) | t \in T, m \in Type(t)\}$,

$PLACE = \{(p, g) | p \in P, g \in Type(p)\}$,

$\mu PLACE$ is the set of multisets over the set $PLACE$.

(vi) $M_0 \in \mu PLACE$ is the initial marking of the net.

[1] A successful decontamination does not necessarily correspond to a pre-release status but rather to the achievement of specific effectiveness values and the restoration of a worth-living environment

For $(t, m) \in TRANS$, the pre- and post-mappings can be written as symbolic sums of elements of $PLACE$ scaled by their multiplicities:

$$Pre(t, m) = P_\mu = \sum_{x \in PLACE} P_\mu(x)'x, P_\mu \in \mu PLACE,$$

and $Post(t, m)$ respectively. $P_\mu(x)$ denotes the multiplicity of $x \in PLACE$ in the multiset P_μ.

Denote $M \in \mu PLACE$ a marking. A transition mode $(t, m) \in TRANS$ is enabled at a marking M if and only if

$$Pre(t, m) \leq M$$

A finite multiset of transition modes $T_\mu \in \mu TRANS$[1] is enabled at a marking M if and only if

$$Pre(T_\mu) = \sum_{(t,m) \in TRANS} T_\mu(t, m) Pre(t, m) \leq M$$

All transition modes in T_μ are concurrently enabled if T_μ is enabled and there are enough tokens on the input places satisfying the linear combination of the pre-mappings for each transition mode in T_μ. Given that T_μ is enabled at M a step, denoted by $M \overset{T_\mu}{\rightarrow} M'$, may occur resulting in a new marking M'

$$M' = M - Pre(T_\mu) + Post(T_\mu)$$

Let

$$TRANS|T_m = \{(t, m) | t \in T_m, m \in Type(t)\},$$
$$TRANS|T_e = \{(t, m) | t \in T_e, m \in Type(t)\}$$

Assumptions (ii) and (iv) can be formalized as follows:

Let $(t, m) \in TRANS$ with $m = (b, y) \in B \times [0,1]$. For all $\left(p_1, (b, y_{pre})\right) \in Pre(t, m)$ and $\left(p_2, (b, y_{post})\right) \in Post(t, m)$ it holds

$$y_{pre} \leq y_{post} \ if \ (t, m) \in TRANS|T_e, \quad (3.1)$$

$$y_{pre} \geq y_{post} \ if \ (t, m) \in TRANS|T_m \quad (3.2)$$

[1] $\mu TRANS$ is the set of multisets over the set *TRANS*

Note that $\{\cdot\}$ is equivalent to $(p,(b,0))$ and (p,b) for any $p \in P$ and $b \in B$. The first inequality formalizes assumption (ii): events may create endangerment. The second inequality refers to assumption (ii): measures may reduce endangerment.

Assumption (v), which refers to the consumption of resources, can be formalized as follows:

Let $(t,m) \in TRANS|T_m, P_\mu = Pre(t,m)$ and $P_{\tilde{\mu}} = Post(t,m)$. There exists at least one $x = (p,r) \in P_\mu$[1] with $r \in R$ for which it holds that

$$x \in P_{\tilde{\mu}} \text{ and } P_\mu(x) \geq P_{\tilde{\mu}}(x) \text{ or } x \notin P_{\tilde{\mu}} \qquad (3.3)$$

The latter indicates a complete consumption of resources.

The tokens contain information on endangered objects and their endangerment as well as on resources. The implementation of a strategy corresponds to a run of an instance of the strategy model.

3.6. Reuse of Prepared Strategies for Decision Support

Assume that k similar cases are retrieved from the case base to solve a current problem. The specification of k is not a subject of this research. Hence, k strategies are available to be reused. Measures are directed towards specific objects. Hence, the objects are significant when choosing a measure. If a strategy of a retrieved case does not cover all objects currently endangered, another strategy directed towards the missing objects possibly provides additional decision support. The question is how to combine these strategies to cover all endangered objects? Computerized support may facilitate the reuse.

For the sake of clarity, the following **assumptions** are made:

(i) Each net has exactly one initial node and one final node. The initial and final nodes are places of type $\{\cdot\}$.

(ii) Endangerment is produced and reduced completely in each net.

(iii) Resources are completely consumed in each net.

[1] x is a member of the multiset P_μ denoted by $x \in P_\mu$ if $P_\mu(x) > 0$

In the course of merging, we mainly focus on the following situations starting with two strategies to be merged. We assume a joint event resulting in endangered objects:

(i) Both strategies in each case cover disjoint subsets of endangered objects.

   a. They do not have any measures in common. This case particularly would result in concurrently implemented measures.

   b. They share the same measure. This case enhances the set of transition modes and essentially refers to the case when a measure is directed towards different endangered objects. The demanded resources rise accordingly.

(ii) Both strategies are directed towards the same endangered objects. The strategies do not have any measure in common resulting in a choice of measures for specific objects.

These cases may be combined and generalized arbitrarily. The purpose of merging is to identify possible strategies in case a single strategy would only cover part of the problem. The latter primarily refers to the objects currently endangered. Furthermore, in case the addressed objects are the same but different strategies are available, the choice of measures should be identified. Hence, *merging* of two strategies and hence two Petri nets is conducted at their common equally labeled transitions including corresponding pre- and post-mappings and may result in an extension of place types and transition modes.

The way of merging depends on the application context and the intention behind e.g., merging business processes due to organization merging [71] via specific merge points (places). Bottom-up process synthesis is another related research area (see [72] for a literature review) where systems are composed of incomplete sub-systems (modules) with the prominent application area of manufacturing systems [73]. For synthesis, places are merged [74, 75] as well as common transitions, places and paths [76]. Petri nets are synthesized from modules that are modeled by strongly connected state machines [77], colored Petri nets [78], generalized Petri nets [79], labeled partial orders/scenarios [80, 81] or state-based models [73]. [81, 82] particularly embed process synthesis in the disaster response field by modeling adaptive disaster response processes, in which the behavior is synthesized by scenarios at run-time.

Here, transitions (places) are merged if they are labeled equally and have equally labeled predecessors. In general, synthesis techniques may be susceptible to a possible loss of control in behavior of the composed system [72]. A further related research area is the composition of Petri nets [83-86] either via common places, transitions, and arcs or specific nodes. The literature review is intentionally restricted to Petri nets as modeling language. Furthermore, research on pre-merging activities such as identifying correspondences between processes is excluded as well. A wider literature review can be found in [35].

Merging in our context focuses on (i) combining several strategies that cover subsets of objects currently endangered, (ii) providing runs taking into account newly combined endangered objects, and (iii) preserving the original runs of the nets.

Let S_1 and S_2 be two strategies

$$S_i = \left(P_i, T_i, Dom_i, Type_i, Pre_i, Post_i, M_{0,i}\right)$$

with

$$Pre_i, Post_i: TRANS_i \to \mu PLACE_i,$$

and $L_{m,i}$, $L_{e,i}$ the labeling functions of $S_i, i \in \{1,2\}$. In the following, transitions are referred to by their labels

$$T_i \coloneqq \{L_{k,i}(t) | t \in T_i, k \in \{m, e\}\}, i \in \{1,2\}$$

Denote $start \in P_i$ and $end \in P_i, i \in \{1,2\}$ the start and end nodes of the nets.

The merging of the two nets is based on merging the transitions with the same labels, the nodes *start* and *end*, and places that are involved in the pre-and post-mappings of the merged transitions. In the following, the merging of two transitions is investigated further, especially the merged places involved.

Let $t_1 \in T_1$ and $t_2 \in T_2$ with $t_1 = t_2$. Denote

$$TRANS|t_i = \{(t_i, m) | m \in Type(t_i)\}, i \in \{1,2\},$$

$$\tilde{P}_i^{pre} = \{p \in P_i | (p, Type(p)) \in Pre(TRANS|t_i)\},$$

and

$$\tilde{P}_i^{post} = \{p \in P_i | (p, Type(p)) \in Post(TRANS|t_i)\}, i \in \{1,2\},$$

the places involved in the pre- and post-mappings of t_1 and t_2. Two places $p_1 \in \tilde{P}_1^{pre}$ and $p_2 \in \tilde{P}_2^{pre}$ are merged if *Type*(p_1) and *Type*(p_2) both belong either to the endangered objects and their endangerment, resources or do not have any characteristics. The merging generates a new place $p \in P^M$ which denotes the set of all new places originating from merging a place of P_1 with a place of P_2. The same applies to places that belong to $\tilde{P}_i^{post}, i \in \{1,2\}$. *Start* and *end* nodes are always merged.

Let

$$I: P_1 \times P_2 \to P^M,$$

a bijective function assigning places $p_1 \in P_1$ and $p_2 \in P_2$ to a place $p \in P^M$. Denote

$$\pi_i: P_1 \times P_2 \to P_i,$$

the i-th projection mapping, $i \in \{1,2\}$, and

$$\tilde{P}_i = \{p \in P_i | \exists \bar{p} \in P^M: \pi_i(I^{-1}(\bar{p})) = p\}, i \in \{1,2\},$$

the places of S_1 and S_2 that are merged.

Definition 3.2. Merged nets.

Let S_1 and S_2 be two strategies with

$$S_i = (P_i, T_i, Dom_i, Type_i, Pre_i, Post_i, M_{0,i}), i \in \{1,2\}$$

The merged nets result in

$$S = (P, T, Dom, Type, Pre, Post, M_0),$$

where:

(i) $P = (P_1 \cup P_2 \cup P^M) \backslash (\tilde{P}_1 \cup \tilde{P}_2)$,

(ii) $T = T_1 \cup T_2$,

(iii) $Dom = Dom_1 \cup Dom_2$,

(iv) $Type(p) =$

$$= \begin{cases} Type_i(p), p \in P_i \backslash \tilde{P}_i, i \in \{1,2\} \\ Type_1(\pi_1(I^{-1}(p))) \cup Type_2(\pi_2(I^{-1}(p))), p \in P^M \end{cases},$$

(v) $Type(t) = \begin{cases} Type_i(t), t \in T_i, t \notin T_1 \cap T_2, i \in \{1,2\} \\ Type_1(t) \cup Type_2(t), t \in T_1 \cap T_2 \end{cases},$

(vi) $TRANS = TRANS_1 \cup TRANS_2$,

(vii) $Pre, Post: TRANS \to \mu PLACE$ with

$$PLACE = \{(p,g) | p \in P, g \in Type(g)\},$$

and for $(t,m) \in TRANS \backslash TRANS_j$

$$Pre(t,m) = \widetilde{Pre}_i(t,m), \tag{3.4}$$

$i \neq j, i, j \in \{1,2\}$ with

$$\widetilde{Pre}_i(t,m) = \sum_{\substack{(p,g) \in PLACE \\ p \notin P^M}} P_\mu^i(p,g)'(p,g) +$$

$$+ \sum_{\substack{(p,g) \in PLACE \\ p \in P^M}} P_\mu^i\big(\pi_i\big(I^{-1}(p)\big), g\big)'(p,g),$$

with $P_\mu^i = Pre_i(t,m)$ and for $(t,m) \in TRANS_1 \cap TRANS_2$

$$Pre(t,m) = Pre_1(t,m) \vee Pre_2(t,m) \tag{3.5}$$

The same applies to *Post*, respectively.

(viii) $M_0 = M_{0,1} + M_{0,2}$

3.7. Example

For illustrating the merging approach, CPN Tools[1], a modeling and simulation tool for Colored Petri Nets (CPNs), is used. CPNs belong to

[1] http://cpntools.org/

the class of HLPNs and is characterized by the combination of PNs and programming languages [87]. The CPN modeling language particularly conforms to the ISO/IEC standard the definition of the strategy model is based on.

Assume three similar cases retrieved from the case base and hence three strategies available for solving the current problem situation. The first strategy (Fig. 3.2) is targeted towards 'playground' and 'dairy cow', suggesting 'topsoil removal' and 'cover with clean soil' as well as 'clean feeding'. The first two measures can be implemented concurrently to the last measure.

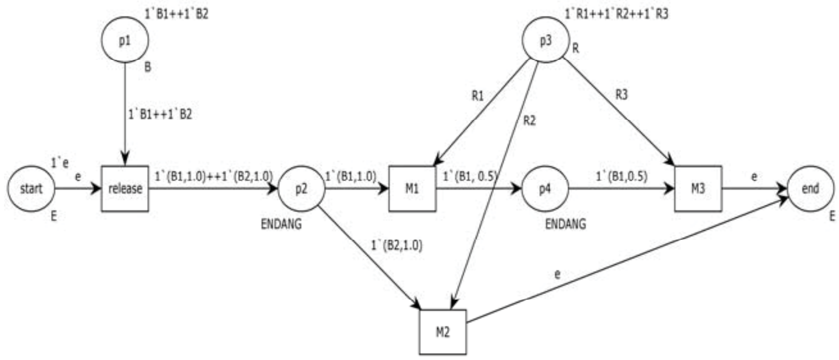

Fig. 3.2. Strategy directed towards *B1* = playground and *B2* = dairy cow. *M1* = topsoil removal, *M2* = clean feeding, *M3* = cover with clean soil. *E = {e}, B = {B1, B2}, DEG = [0,1], ENDANG = B × DEG, R = {R1, R2, R3}.*

The second strategy (Fig. 3.3) suggests 'topsoil removal' and 'plant and shrub removal' to decontaminate the playground. Both measures are implemented sequentially.

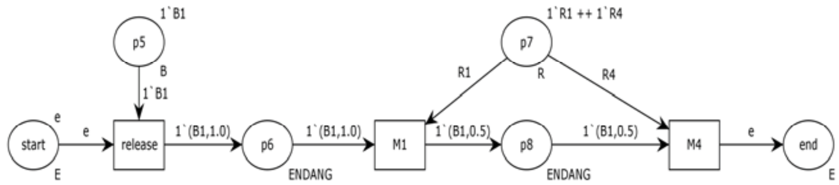

Fig. 3.3. Strategy directed towards *B1* = playground. *M1* = topsoil removal, *M4* = plant and shrub removal. *E = {e}, B = {B1, B2}, DEG = [0,1], ENDANG = B × DEG, R = {R1, R4}.*

The third strategy (Fig. 3.4) is directed towards 'park' and suggests 'ploughing' and 'cover with clean soil', both implemented sequentially.

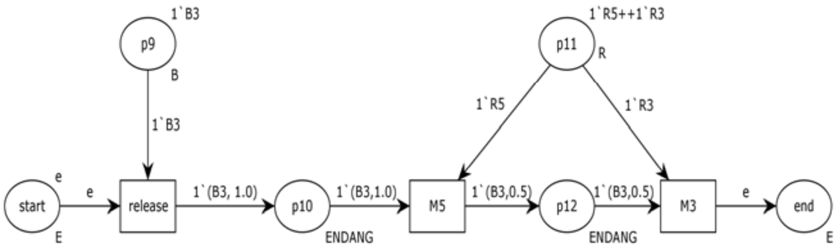

Fig. 3.4. Strategy directed towards 'park'. *M5* = ploughing, *M3* = cover with clean soil. *E = {e}, B = {B3}, DEG = [0,1], ENDANG = B × DEG, R = {R5, R3}.*

To begin with, the first two strategies are merged (Fig. 3.5).

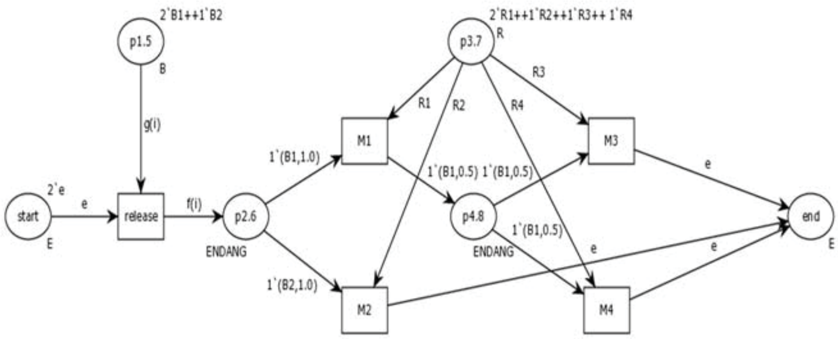

Fig. 3.5. Merging of strategies illustrated in Figs. 3.2 and 3.3 based on common transitions 'release' and *M1*. *B1* = playground, *B2* = dairy cows, *M1* = topsoil removal, *M2* = clean feeding, *M3* = cover with clean soil, *M4* = tree and shrub removal. *E = {e}, B = {B1, B2}, DEG = [0,1], ENDANG = B × DEG, R = {R1, R2, R3, R4}.*

The common transitions are 'release' and *M1* = topsoil removal. Hence the places involved in the pre- and post-mapping are merged accordingly. The resulting strategy offers a choice of measures with regard to the endangered object 'playground'. After topsoil removal (*M1*), either 'cover with clean soil' or 'plant and shrub removal' can be implemented. The set of endangered objects is not extended in the course of merging and hence there is no new combination of endangered objects. The functions *g* and *f* with *B1* = playground and *B2* = dairy cow reflect the possible runs:

$$g(i) = \begin{cases} 1`B1 + 1`B2, i = 1 \\ 1`B1, i = 2 \end{cases}$$

$$f(i) = \begin{cases} 1`(B1,1.0) + 1`(B2,1.0), i = 1 \\ 1`(B1,1.0), i = 2 \end{cases}$$

Fig. 3.6 illustrates the final merged net and merging the net of Fig. 3.5 and Fig. 3.4, respectively.

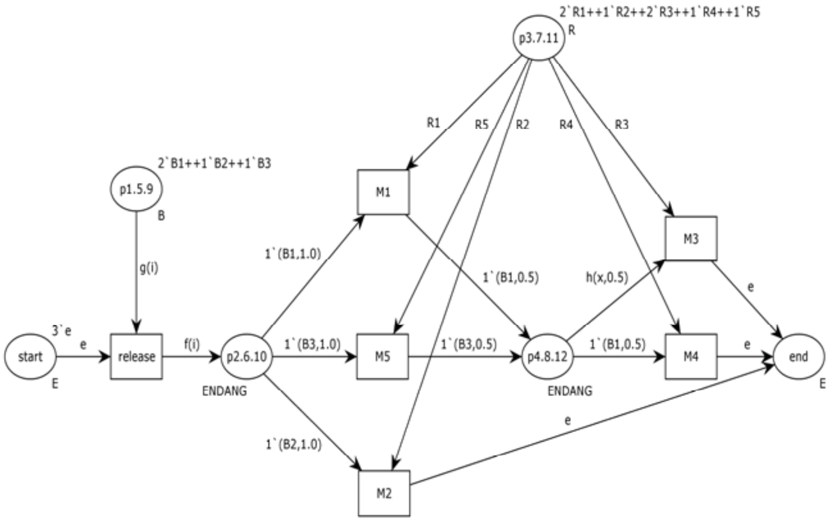

Fig. 3.6. Net resulting from merging nets illustrated in Figs. 3.5 and 3.4 and hence all three strategies available. Merging is based on merging 'release', *M1*, and *M3*. *B1* = playground, *B2* = dairy cows, *B3* = park, *M1* = topsoil removal, *M2* = clean feeding, *M3* = cover with clean soil, *M4* = tree and shrub removal, *M5* = ploughing. *E = {e}*, *B = {B1, B2, B3}*, *DEG = [0,1]*, *ENDANG = B × DEG*, *R = {R1, R2, R3, R4, R5}*.

The merging is based on the common transitions ‘release’, *M1* and *M3*. The set of endangered objects is enhanced by *B3* = park where new combinations of endangered objects are possible now:

$$g(i) = \begin{cases} 1`B1 + 1`B2, i = 1, \\ 1`B1, i = 2, \\ 1`B3, i = 3, \\ 1`B1 + 1`B2 + 1`B3, i = 4, \\ 1`B1 + 1`B3, i = 5, \end{cases}$$

$$f(i) = \begin{cases} 1`(B1,1.0) + 1`(B2,1.0), i = 1, \\ 1`(B1,1.0), i = 2, \\ 1`(B3,1.0), i = 3, \\ 1`(B1,1.0) + 1`(B2,1.0) + 1`(B3,1.0), i = 4, \\ 1`(B1,1.0) + 1`(B3,1.0), i = 5 \end{cases}$$

The measure *M3* is directed towards ‘playground’ and ‘park’ and hence the user may choose between *M3* and *M4* with regard to ‘playground’:

$$h(x, 0.5) = \begin{cases} 1`(B1,0.5), x = B1, \\ 1`(B3,0.5), x = B3 \end{cases}$$

3.8. Discussion and Future Work

This chapter presents the reuse step of a case-based decision support method for disaster management. A case of the case base is subject to a case model that consists of a problem and solution model. The solution model includes a strategy model which is the subject of this publication and which is particularly based on High-level Petri nets. Strategies stored in the cases are instances of the strategy model.

Basically, the strategy model includes two types of transitions which are events that trigger the endangerment of objects and measures that reduce the endangerment. The tokens contain information on the object endangered and its degree of endangerment. The latter is modified during a run. This chapter above all focuses on the semantic model to present the basic ideas. In the example section, a possible graphical representation is introduced.

The strategies of the *k* most similar cases (*k* can be a fixed number or the number of cases whose similarity values exceed a certain threshold) may be reused. Reuse includes numerical adaptation, merging of several strategies, and strategy assessment. The merging is particularly presented in this chapter, in case each strategy retrieved only covers part of the problem description of the query and a subset of the current endangered objects, respectively. Merging aims at identifying strategies that cover all endangered objects specified in the query. The basic ideas are to merge the common transitions and their pre- and post-mappings. We specifically assume a predefined set of transition labels. The merging preserves the original runs of the Petri nets and identifies possible new runs for newly combined endangered objects.

Process-oriented approaches are very promising for disaster management although many requirements of this specific application field have not been addressed so far, among others a lack of disaster response management-related elements in the modeling languages [88]. Other research gaps refer to methods and tools for process analysis and simulation at design time, tools to transform models into executable process specifications, integration of resource management during process enactment, adaptation of processes at runtime, and evaluation [88].

Processes are often used to model emergency management measures and plans e.g., by event-driven process chains [89] or workflow management systems [90-94], particularly with business process model and notation [95]. The latter publication mainly emphasizes the need for domain-specific adaptation e.g., different types of resources, their usage, states, spatial allocation, and interdependencies. [96, 97] pursue an activity-centric approach to coordinate disaster response activities and develop a collaborative disaster response process management system. The authors specifically state that business process management technology is not suitable for disaster response processes mainly focusing on event-driven process chains. They essentially argue that "Disaster response processes do not have information dependencies between the activities, but temporal dependencies, which need a different kind of treatment."([96] p. 62). The authors' focus differ from ours and concentrate on an ad-hoc activity management system for different parties involved, specifically on the intra- and inter-organizational levels. We aim at a generic strategy model to be applied to different kinds of disasters, especially for storing strategies in the case base to be reused in the course of a new event. Hence, besides storing a strategy in a structured and unambiguous manner, an automatized further use is demanded. High-level Petri nets are regarded as being suitable to meet these requirements due to their mathematical representation and great expressiveness. Furthermore, they have analysis capabilities of structure and dynamic behavior and allow for analyses of effectiveness parameters. The latter is particularly interesting if two strategies are available for selection.

The model and merging mechanism presented are generic since they are neither linked to a specific event nor measure type. So far, the model takes into account two decisive factors for measure selection i.e., the objects endangered and the resources needed for implementation. Note that further decisive factors such as the area affected as well as relevant information in respect of release, are considered in the similarity calculation. For reuse, we oriented towards the key steps in constructing a strategy (e.g. [57]). A missing factor would be the radionuclides involved. However, the model can be extended according to more decisive factors by including more types. Note that the key steps in selecting and combining measures include the consideration of effectiveness parameters as well, which is partly covered by the degree of endangerment. However, waste produced or costs contribute to the effectiveness of a strategy also. This might be modeled through the post-mappings of the measures, for example.

In general, Petri nets offer various possibilities for enhancement such as the duration of implementing a measure or the probability of the occurrence of an event. The duration of implementing a measure might be uncertain and endowed with a probability distribution as well. Note that the merging step may result in a choice of several strategies making a subsequent strategy assessment necessary. In respect of the latter, multi-criteria assessment according to certain effectiveness parameters such as reduction of contamination, cost, and waste are possible. In addition, performance analyses related to the duration of a whole strategy as well as resource utilization may be used in the assessment as well providing the user a wide decision basis.

Furthermore, performance analyses offer possibilities to improve strategies according to resources and the implementation order of measures. Assume concurrently implemented measures of different durations resulting in waiting resources because both measures need to be finished before another measure can be implemented. A change in the distribution of resources or timely change in the implementation of measures may improve the performance of the entire strategy.

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