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Proposition of a formal model for crisis management in the context of high-speed train networks in border areas

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Abstract

Especially in inter-country areas, Crisis Management (CM) faces several challenges. Thorough preparation and anticipation are crucial organizational tools to address those challenges and enable proper reaction to crises. CM requires the joint effort of various stakeholders from different countries: public authorities, private companies, Non-Governmental Organizations (NGOs), etc. need to collaborate under specific, locally different regulations. The present paper includes a brief introduction to the state of the art of CM of international railways with special regard to the topics partnerships, leadership & communication as well as training. As part of a research project, a survey with international crisis management experts was conducted. Based on the survey results, a handbook containing transnational recommendations regarding the involved stakeholders and their responsibilities is developed. Of course, existing CM concepts of relevant organizations are taken into consideration for the development. The handbook was discussed with end-users in the course of a project workshop.
In addition, when the crisis management is required, the response is coordinated within the framework of the National Crisis Management System (NCMS). The cooperation between these NCMSs leads to the concept of System-of-Systems (SoS). Based on Supervision Control Theory (SCT), we propose a formal model built from decomposition of NCMSs using a multi-model approach. The resulted framework offers a global view of the SoS and resolves problems of system’s dependence and of operating mode management. The proposed model is designed by using the High Level Petri Nets (HLPNs) formalism and is illustrated with a crisis of a railway system. The main result of this paper is the comprehensive knowledge of current crisis management strategies in the context of cross-border incidents. Weaknesses in the existing system are identified and two approaches that seek to enhance CM are introduced.

Keywords: Crisis management; International cooperation; Operating modes; Supervisory control; Petri nets; System-of-Systems.

Nomenclature

CM	Crisis Management
NGO	Non-Governmental Organization
NCMS	National Crises Management System
SoS	System-of-Systems
SCT	Supervision Control Theory
HLPN	High Level Petri Net
UIC	International Union of Railways
CMP	Crisis Management Plan
CI	Critical Infrastructure
PT	Public Transportation
CMT	Crisis Management Team
BSI	British Standards Institution

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1. Introduction

The International Union of Railways (UIC) defines a crisis as a "[…] sudden event or set of circumstances that could significantly affect an organization's ability to carry out its business […]" (UIC (2017)) or events that could negatively impact an organization's reputation, have harmful consequences for the environment or the general public. According to the British Standards Institution (BSI(2014)) CM refers to the "development and application of the organizational capability to deal with […]" – most desirably limit – the negative outcomes of such sudden events. Usually the respective strategies and actions include preparing for possible future events as well as dealing with unforeseen incidents and are documented in a Crisis Management Plan (CMP). The CMP can be considered "[…] a superordinate document [that] provides overall organizational and general procedural guidelines for the management of information, activities, operations and communications during an […] emergency" (UIC (2017)). It thus summarizes all actions and operational procedures that are necessary for dealing with the challenges during crises. Examples for such challenges are high levels of uncertainty, limited time, limited information and limited resources. In border areas or when interorganisational cooperation is required, these challenges are amplified. In his analysis of past EU activities towards natural disaster risk mitigation, Papatheodorouet al. (2014) name, among others, the lack of capacity and resources for cooperation, limited knowledge about cooperating organizations and differences in organizational structures and procedures as recurring issues in cross-border cooperation. These problems have to be resolved because due to a changing threat landscape, transboundary cooperation is increasingly important for crisis management (Boin et al. (2014), Surminski et al. (2017)).

In accordance with the general demand for improved cooperation, the Franco-German joint research project RE(H)STRAIN focused part of its current work on these issues. In the second chapter, the difficulties of crisis management will be outlined. In addition, exemplary recommendations for enhanced response to crisis events in border areas will be given on the basis of existing standards and guidelines, current research projects and a survey amongst crisis management experts carried out in the course of RE(H)STRAIN.

Crisis management is established in all kinds of organizations: Medium-sized enterprises as well as globally operating corporations and state-run departments/authorities as well as NGOs and the general public. In some areas, crisis management is of more significant importance because of the large impact of potentially negative incidents, also on third parties like the environment, other businesses or the public at large. Critical Infrastructure (CI) is one example for such an area. The Federal Ministry of the Interior of Germany (2009) defines CI as infrastructure that is so substantial for the well-being of society that in the case of a breakdown, "[…] sustained supply shortages, significant disruption of public safety and security, or other dramatic consequences" could occur. One example for CI is Public Transportation (PT) – in the context of this paper focusing on passenger railway transportation. PT is comprised of a complex, cross-border network of trains, tracks and stations and plays a major role for the well-being of modern societies (Lévy-Bencheton and Darra (2015)).It is therefore a key interest to ensure the proper functioning of PT under any circumstances – even in crisis situations. If a crisis occurs, it is of utmost importance to be well prepared in order to ensure a timely return to the operating state of the CI. Thus, organizations within the sector of PT should establish their own crisis management.

Best practices suggest that National Crisis Management Systems (NCMSs) cooperate with one another to deal with crises that have caused or have the potential for causing fatalities or injuries and/or major damage. This cooperation leads to the concept of System-of-Systems (SoS) representing an international crisis management system. Jamshidi (2009) defines SoS as a concept offering a high-level viewpoint encompassing the interactions between different cooperating but independent systems. The concept of SoS is applied in a wide range of research areas such as transportation (DeLaurentis (2005)), healthcare (Wickramasinghe et al. (2008)), management (Shenhar et al. (2009) and ship environment (Mahulkar et al. (2009)). In this paper, we propose a formal model offering a global view of the studied SoS, built from decomposition based on High Level Petri Nets (HLPNs). In fact, we adopt a multi-model approach which allows to define separate behavior of each CMS of the SoS. In our case, each behavior is an operating mode representing an emergency plan applied for a type and level of crisis. Emergency plans are ranging in complexity and the crisis level may develop from incidents beginning at a lower level. For each crisis, the switching between emergency plans is controlled due to the operating modes management based on Supervisory Control Theory (SCT).

In the following sections, we present the developed work in its different stages and aspects.

2. Crisis management in public transportation

Oftentimes, in the event of crises, a special organizational structure is required to deal with all resulting challenges in an appropriate and effective manner. The Crisis Management Team (CMT) is often part of this structure (UIC (2017), BSI (2014)). The CMP that comprises fixed procedures to be followed in the event of a crisis usually defines this structure. The precise content of the CMP has to be determined individually as "[…] crisis management varies from organization to organization and sector to sector" (BSI (2014)). Accordingly, all organizations should build their own individual CMP, tailored to their needs. But as there are general requirements to crisis management that are independent of the concerned sector, universal standards can be an important help for developing a CMP. Moreover, standards and guidelines can be used as a source to determine the current best practice of crisis management.
Additionally, two other sources were exploited in order to raise comprehensive information regarding the actual current state of the art of CM in PT focusing on cross-border CM. Current research projects were reviewed and an anonymous international survey was conducted among crisis managers of railway companies. In the following section the sources are introduced and the raised information is briefly examined.

2.1. Standards and guidelines of crisis management

In total, five standards and guidelines, which are widely accepted and have a high relevance according to the authors of this paper, were taken into account in this examination. The BSI (2014) as well as the UIC (2017) publication are addressed in this work. The *National Preparedness Goa*l of the Department of Homeland Security of the U.S., the ISO 22320:2011 *Societal Security – Emergency management*and the *Baustein ÜA4 Krisenmanagement* (Component ÜA4 Crisis Management) of the BundesamtfürVerfassungsschutz (The domestic intelligence service of the Federal Republic of Germany) were valuable sources of information as well but are not explicitly mentioned in this paper.
The BSI (2014) is widely accepted and "[…] intended for any organization, regardless of location, size, type, industry or sector". The document provides precise guidance for understanding crisis management. It helps to establish a crisis management structure, helps to prepare the CMT for the challenges they will have to face and it provides information regarding appropriate communication during crises. Additionally, the issue of training, exercising and learning from crises is addressed explicitly. The UIC standard however, concentrates on giving advice to railway operators to help them, among other things, with developing a CMP, establishing a capable CMT including the definition of key members and their functions, estimating what infrastructure should be provided in order to enable effective crisis management and additionally, instruct operators regarding the basics of crisis communication. Other topics addressed are training, evaluation and updating crisis management structures, setting priorities and establishing alerting levels.
Both standards have rather guiding character, providing practical advice for top management in the case of the BSI and for rail operators in the case of the UIC. It is to note that the UIC standard is slightly more detailed, which is probably due to the fact that it is mainly focused on railway transportation. As both have been quite recently published, they can be used to identify best practices, respectively the supposed current state of the art in crisis management. The elements of both standards are in large parts similar and suggest that the following aspects can be considered as good practice and should be implemented in organizations to ensure effective management of crisis situations:

1. Documented and fixed procedures for managing information, operations, etc. in the event of crises with different escalation levels (develop a CMP),
2. Name persons in charge of the respective operations and clarify the extent of their responsibilities (establish a CMT),
3. Agreeing on communication principles during crises and
4. Conducting training and exercises to practice the above.

To complement the good practice identified in the standards and guidelines, current research projects that deal (at least partly) with crisis management are analysed to identify actual challenges and future recommendations.

2.2. Research projects related to crisis management

Currently, there are multiple research projects that address crisis management. Oftentimes, crisis management is not the research focus but considered as one of many factors that contribute to enhanced resilience or public safety, which is also acknowledged in ISO 22316:2017 by the International Organisation for Standardisation (IOS (2017)). The individual research focus as well as the outcomes of the research projects gives indications regarding the importance of individual components and additionally, indications regarding the weaknesses of crisis management. For the present paper, six research projects (CIPRNet, EPISECC, FORTRESS, PREDICT, PREPARE, START) that are funded by the European Commission, were examined and taken into consideration for the development of recommendations on cross-border crisis management. The projects are only briefly introduced; the examination is not detailed in this paper.

FORTRESS and PREDICT concentrate on cascading effects. FORTRESS proposes recommendations focussed on communication and uniform semantics in cross-border crisis management, PREDICT facilitates the training of crisis managers by different means and enhances self-assessment of end-users. PREDICT concentrates its efforts on supporting organizations in the area of critical infrastructure. EPISECC, CIPRNet and PREPARE mainly emphasize the importance of sharing information. In that context, multiple platforms that seek to facilitate the exchange of information were set up, tools that seek to enhance simulation in order to support decision-makers were developed and databases containing past events and how they were dealt with were established. START contributes to disaster risk reduction by establishing crisis management structures on a regional level.

Besides the briefly introduced research projects, which are predominantly funded by the European Commission, there are numerous other actions seeking to enhance preparedness to disasters or enhanced response by harmonizing procedures and semantics (e.g. Vademecum – Civil Protection), by means of information sharing (e.g. Disaster Risk Management Knowledge Centre - DRMKC, United Nations Space-based information for Disaster Management and Emergency Response – UN-SPIDER) or by providing capacities to coordinate and deploy emergency services (e.g. Emergency Response Coordination Centre – ERCC, European Emergency Response Capacity - EERC). There has been, however, criticism with regard to the coordination capacity and the effectiveness of EU initiatives in the context of transboundary crisis management (Boin et al. (2014)).

Existing standards and current research projects already provide good information regarding the state of the art of crisis management and regarding most prominent challenges in that context. For example, it is obvious that sharing information and communication in general are recurring sources of problems. However, the literature review also shows that there is neither standard nor research project focusing exclusively on cross-border crisis management.

2.3. Survey among international crisis managers

In order to raise first-hand information focusing on transboundary cooperation in crises, a survey was conducted. The aim was to gather information on the current state of the art of the crisis management in the companies, the current cross-border cooperation practices as well as future trends. The respective questionnaire predominantly consists of multiple choice questions but partially required free text responses. The questions are focused on cross-border partnerships, joint exercises and training, communication/shared knowledge and potential for optimization. In a first cycle, the survey was handed out in paper at the UIC Security Week in June 2017. In order to reach more crisis managers, the same survey was additionally carried out as an online survey via the lime survey platform and distributed via the mailing list of the COLPOFER Group (the European association of railway companies and railway police forces). This way, a total of 16 crisis management experts from Europe, North America and Asia responded to the survey.

Due to the survey being anonymous and due to the limited number of participants, the achieved results have to be interpreted particularly carefully. It has to be taken into consideration that the same organization could have participated multiple times and that there is no way of ensuring all participants to be experts in crisis management. Also, it might be argued that the different forms of the questionnaires (paper vs. online) and the different settings during the completion (in a room with other experts vs. alone) could impact the results. Nevertheless, indications can be deduced from the survey results.

When comparing the expert’s answers, it became obvious that their opinions about as well as their level of involvement in cross-border cooperation is nowhere near uniform. For example, out of twelve experts, who answered the questions, *Are there standardized alarm procedures for crisis scenarios in exchange with foreign railway companies?* and *Do you know the crisis organization structure within your foreign partner companies?* in both cases six answered “yes” and six answered “no”. This was the case for several questions regarding cooperation and joint procedures. In accordance, experts are evenly distributed regarding their use of standards for preparing cross-border crisis management: Five participants consider such standards, six others do not. This shows, how differently the surveyed experts structure and also how differently they perceive their crisis management systems. There are, however, two things that nearly all experts consider useful and beneficial for cross-border crisis management: joint exercises and exchange programs for crisis managers.

The findings from the survey contribute to developing recommendations on cross-border crisis management[1]. Among others, it is recommended to

- conduct regular joint exercises,
- establish a common framework for communication, including alerting protocols with foreign partner companies and
- get to know each other crisis organization structure, potentially by means of a crisis mangers exchange.

Another interesting finding derived from the free text responses and contradicts efforts to harmonize organization structures and crisis response procedures on an international level. In spite of the fact that most crisis managers (six out of eleven) say they would consider a uniform guide to cross-border crisis management useful for their work, four experts disagreed, specifying in their free text responses that differences in organization and regulations between states are too extensive to be harmonized in one single guideline. In the course of the research project EPISECC (2015) differences in approaches of different countries were identified as crisis management procedures and standards from various European countries were collected and compared. This suggests that another approach, instead of pursuing harmonization, might be more promising. In the following chapters, the concept of SoS and the possibility to automatically switch between different operating modes that could potentially be applied to crisis management is introduced.

3. Background

3.1. SoS

The “System of Systems” is a new research domain and several works have addressed the theoretical aspects of the SoS concept: Jamshidi (2008) considers that SoSs are large-scale integrated systems that are heterogeneous and independently operable on their own but are networked together for a common goal. Luzeaux and Ruault (2010) consider that SoSs are an assemblage of systems that can be used independently, for which the designer and/or the user tries to maximize the performance of the global value chain, at a given time and for a set of foreseeable assemblages. The International Council on Systems Engineering (INCOSE (2006)) considers that the term SoS should be applied to a system-of-interest whose system elements are themselves systems.
CMSs are independent systems. However, in order to deal with major and border crises, these systems work together as an SoS on the basis of the previous definitions.

3.2. Multi-model approach for operating mode management

In what follows, the studied SoS is regarded as a Discrete Event System (DES). Among several methods proposing the safe control in the DES domain, we adopt SCT, initiated by Ramadge and Wonham (1989). SCT is a formal method to ensure safe operation without extensive use of validation and verification. It is the theory of analyzing discrete event control systems and it allows the definition of different control strategies for each operating mode based on operating modes management. This technology aims to ensure the switching from one operating mode to another one according to the user input and safety requirements and it is the subject of several researches (Kamach et al. (2003), Faraut et al. (2009) and Kadri et al. (2013, 2014)).
In order to define separate behavior of the studied SoS, we consider the multi-model approach. Applied to our research project, this approach assumes that only one CMP is activated at a time for each crisis, while the others are deactivated. This allows us to define a separate model for each system’s plan. Each model in our approach is a behavior description represented by a HLPN. The previous concepts permit the composition of the SoS and Fig.1 graphically describes the obtained composition: an SoS consists of multiple NCMSs, each system consisting of multiple CMPs.

3.3. High Level Petri Net (HLPN)

HLPN is an algebraic structure that allows a representation of the static and the dynamic aspects of the considered system. Among the several types of HLPN (colored, timed, stochastic, etc.), we use the Prioritized Colored Petri Net with inhibitor arc. This imposes the precondition that the transition may only fire when the place connected to it has zero tokens. The convenience of inhibitor arcs providing the ability to test for the absence of tokens has been known in the Petri net area for a long time (Zaitsev (2014)).

[1] A comprehensive list of recommendations will be verified with experts for crisis management and railway operations at the *End-user workshop* of the research project RE(H)STRAIN, Köln, Germany, 11-12 September 2017 and published afterwards.

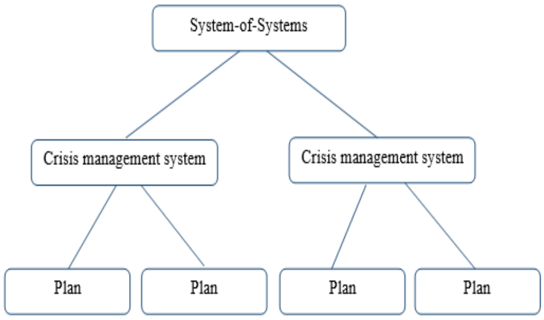

Fig.1. Proposed hierarchical structure of an SoS.

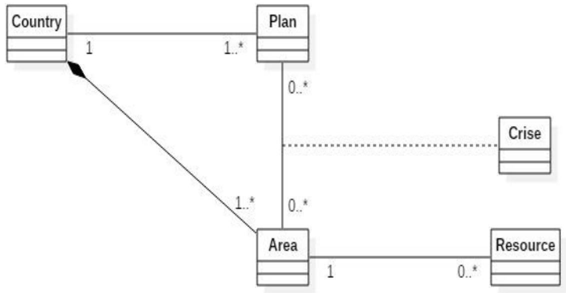

Fig.2. Class diagram of crisis management systems.

A HLPN is a tuple $\langle P, T, K, D, W^-, W^+, \Phi, M_0, \pi\rangle$ where P is a set of places; T is a set of transitions; $K=\{C_1,\dots,C_{|K|}\}$ is a set of object classes; D is the color *domain* function; W^-, W^+ are the incidence functions; Φ is a function that associates a guard with any transition; $M_0$the initial marking and π is a priority function that maps transitions into non-negative natural numbers representing their priority level.

4. SoS concept for crisis management

This subsection presents formally the management of crisis by the SoS concept. For each CMS, when incidents occur, a CMP is activated and the level of response, the available resources control and coordination to be activated are determined through a clear decision-making process. Each CMP represents an operating mode. Moreover, emergency response management action plans must be pro-active and consider the possibilities and eventualities of emerging incidents. Such incidents allow the increase of level of emergencies or/and international cooperation with other systems and it induces the deactivation of the current CMP and the activation of another one. Fig.2 represents a class diagram that describes the structure of the obtained SoS. Formally, let $Cn = \{cn_1, cn_2, \dots, cn_{|Cn|}\}$ be the set of countries, where$|Cn| \geq 1$ and let SoS be the set of NCMSs. For reasons of simplicity, we name the NCMS of a country using the name of its associated country and we obtain then $Cn = SoS$.

$\forall\, cn_i \in SoS$, let$A_i = \{a_{i,1}, a_{i,2}, \dots, a_{i,|A_i|}\}$, where $|A_i| \geq 1$ be its set of the areas and $Pl_i = \{pl_{i,1}, pl_{i,2}, \dots, pl_{i,|Pl_i|}\}$, where$|Pl_i| \geq 1$ be its set of CMP.

For a given country cn_i, we call an operating mode the CMP $pl_{i,j}$ where $pl_{i,j} \in Pl_i$ and $A'_i \subseteq A_i$and we associate a HLPN$< P_{i,j}, T_{i,j}, K_{i,j}, D_{i,j}, W^-_{i,j}, W^+_{i,j}, \phi_{i,j}, M_{i,(0,j)}, \pi_{i,j} >$.

In the following, we give the same identity of the mode $pl_{i,j}$ to its associated HLPN and we denote the set of all models of a system $cn_i Pl_i$.

4.1. Common Submodel

This subsection allows the identification of common submodels in every NCMS in order to be represented without redundancy in the SoS model. This provides a more compact final model. A submodel is a part of a HLPN and it is called common if it appears in at least in the description of two operating modes in the same system.

Formally, let $pl_{i,j} = < P_{i,j}, T_{i,j}, K_{i,j}, D_{i,j}, W^-_{i,j}, W^+_{i,j}, \phi_{i,j}, M_{i,(0,j)}, \pi_{i,j} >$be an operating mode of the CMS cn_i, $s = < P_{i,r}, T_{i,r}, W^-_{i,r}, W^+_{i,r}, M_{i,(0,r)} >$is a submodel of $pl_{i,j}$ if and only if $(P_{i,r} \subseteq P_{i,j})$ and $(T_{i,r} \subseteq T_{i,j})$. Therefore, $\forall (p,t) \in P_{i,r} \times T_{i,r}, W^-_{i,r} = W^-_{i,j}$ and $W^+_{i,r} = W^+_{i,j}$.

Let Pl_ibe the set of operating modes of a country cn_i. $\forall \left(lp_{i,j}, pl_{i,k}\right) \in P_i \times P_i$ such as $j \neq k$. If $\exists\, s =< P_{i,r}, T_{i,r}, W^-_{i,r}, W^+_{i,r}, M_{i,(0,r)} >$ such as $(P_{i,r} = \left(P_{i,j} \cap P_{i,k}\right) \neq \emptyset)$ or $(T_{i,r} = \left(T_{i,j} \cap T_{i,k}\right) \neq \emptyset)$ or $\left(M_{i,(0,r)} = \left(M_{i,(0,j)} \cap M_{i,(0,k)}\right) \neq \emptyset\right)$, then r is a common component for the two modes $pl_{i,j}$ and $pl_{i,k}$.

4.2. Communication Intra-system

The intra-system communication is done, for an emerging incident, when the decision-maker decides to increase the level of response and the extent of emergency control and coordination. This communication, ensured by specific transitions, allows the activation of a plan more critical instead of the first one. To distinguish such transitions, we define a function to provide the information on the next plan to activate.

Let $pl_{i,j}$ be an operating mode of a country cn_i and $T'_{i,j} \subset T_{i,j}$ be the set of intra-system communication transitions. Let $Next\ plan: T'_{i,j} \rightarrow Pl_i$ be a function such that $Next\ plan\ (t)$ indicates the active operating mode after firing $t\ (\forall\ t \in T'_{i,j})$.

4.3. Crisis management system model

Let us call the place containing activated modes in a system cn_i "*Activated Plans Country i*".

Based on previous concepts, we are able now to model each system alone based on the operating modes management. For each country $cn_j \in SoS$, the associate HLPN is a tuple$< P_k, T_k, K_k, D_k, W_k^-, W_k^+, \phi_k, M_{k,0}, \pi_k >$ where

- $P_k = \cup_{(i=1..|Pl_i|)} P_{k,i}; T_k = \cup_{(i=1..|Pl_i|)} T_{k,i}; K_k = \cup_{(i=1..|Pl_i|)} K_{k,i};$
- D_k is defined, by extension, from $P_k \cup T_k$ into the set of color domains;
- $\forall\ pl_{k,i} \in Pl_k, \forall\ (p,t) \in P_{k,i} \times T_{k,i},\ W_k^-(p,t) = W_{k,i}^-(p,t)$ and $W_k^+(p,t) = W_{k,i}^+(p,t); \forall\ (pl_{k,i}, pl_{k,j}) \in Pl_k \times Pl_k(\ i \neq j), \forall (p,t) \in P_{k,i} \times T_{k,j},$
  $p \notin P_{k,j}$ and $t \notin T_{k,i}\ , W_k^-(p,t) = W_k^+(p,t) = 0;$
  $\forall\ pl_{k,i} \in Pl_k, \forall\ t \in T'_{k,i}, W^+(Activated\ Plans\ Country\ i, t) = Next\ plan(t);$
- $\forall\ pl_{k,i} \in Pl_k$, and $\forall\ t \in T_{k,i},\ \phi(t) = \phi_{k,i}\ (t);$
- $\forall\ pl_{k,i} \in Pl_k$, and $\forall\ p \in P_{k,i}, M_{k,0} = \cup\ M_{k,(0,i)};$
- $\forall\ \mathrm{pl_{k,i}} \in \mathrm{Pl_k}$, and $\forall\ \mathrm{t} \in \mathrm{T_{k,i}},\ \pi_k(t) = \pi_{k,i}\ (t).$

4.4. Communication inter-systems

International cooperation in the case of crisis provides precious supplementary resources. This cooperation is more benefits when countries are neighbors because the rapid response. Indeed, the neighboring system triggers an appropriate CMP in the requested border areas in order to make its resources available to the country of the incident.

Formally, let us note S_c the inter-systems communication and let it modeled by a HLPN$< P_c, T_c, K_c, D_c, W_c^-, W_c^+, \phi_c, M_{c,0}, \pi_c >$.

4.5. SoS Model

Now, let us model the whole SoS. An SoS is a Tuple$< P, T\ , K\ , D\ , W_-\ , W_+\ , \Phi\ , M_0, \pi>$ where

- $P = \cup_{(i=1..|SoS|)} P_i \cup \{P_c\};$
- $T = \cup_{(i=1..|SoS|)} T_i \cup \{T_c\};$
- $K = \cup_{(i=1..|SoS|)} K_i \cup \{K_c\};$
- D is defined, by extension, from $P \cup T$ into the set of color domains;
- $\forall\ cn_i \in SoS, \forall\ (p,t) \in P_i \times T_i,\ W^-(p,t) = W_i^-(p,t)\ and\ W^+(p,t) = W_i^+(p,t),$
  $\forall\ (cn_i, cn_j) \in SoS \times SoS(i \neq j), \forall (p,t) \in P_i \times T_j\ , p \notin P_j$ and $t \notin T_i\ , W^-(p,t) = W^+(p,t) = 0;$
  $\forall\ (p,t) \in P_c \times T_c, W^-(p,t) = W_c^-(p,t)$ and $W^+(p,t) = W_c^+(p,t);$
- $\forall\ cn_i \in SoS, \forall\ t \in T_i, \phi(t) = \phi_i(t);$
  $\forall\ t \in T_c, \quad \phi(t) = \phi_c(t);$
- $\forall\ cn_i \in SoS, \forall\ p \in P_i, \quad M_0(p) = \cup\ M_{0,i}(p);$
  $\forall\ p \in P_c, \quad M_0(p) = \cup\ M_{0,c}(p);$
- $\forall\ \mathrm{cn_i} \in \mathrm{SoS}, \forall\ \mathrm{t} \in \mathrm{T_i},\ \pi = \cup\ \pi_i;$
  $\forall\ t \in T_c, \pi(t) = \pi_c\ (t).$

5. Case study

5.1. System Description

In order to show the approach of modeling, the article examines an example inspired from the reality of an explosion in a passenger train on the border of two countries $Country1$ and $Country2$ (see Fig.3) causing dozens of people injured. And for saving lives, $Country1$ request assistance from $Country2$ to respond quickly to this emergency and to take advantage of the existing close resources beyond the border.

$Country1$ and $Country2$ are subdivided respectively into areas $\mathrm{A_1} = \{\mathrm{A_1}, \mathrm{A_2}, \mathrm{A_3}, \mathrm{A_4}, \mathrm{A_5}, \mathrm{A_6}, \mathrm{A_7}, \mathrm{A_8}, \mathrm{A_9}, \mathrm{A_{10}}, \mathrm{A_{11}}, \mathrm{A_{12}}, \mathrm{A_{13}}, \mathrm{A_{14}}, \mathrm{A_{15}}, \mathrm{A_{16}}, \mathrm{A_{17}}, \mathrm{A_{18}}\}$ *and* $\mathrm{A_2} = \{\mathrm{B_1}, \mathrm{B_2}, \mathrm{B_3}, \mathrm{B_4}, \mathrm{B_5}, \mathrm{B_6}, \mathrm{B_7}, \mathrm{B_8}, \mathrm{B_9}, \mathrm{B_{10}}, \mathrm{B_{11}}\}$ and they provide respectively various plans of emergencies ranging in complexity $\mathrm{P_1} = \{Plan1, Plan2, Plan3\}$ and $P_2 =$

$\{PlanYellow, PlanRed\}$. $Plan$ 1 (resp. $PlanYellow$) is for limited crisis which will not seriously affect the functional capacity of its concerned area, but nevertheless requires some degree of action and only the resources of the concerned area can be available. $Plan$ 2 (resp. $PlanRed$) is for emergency or disaster which may be severe and cause damage, fatalities or injuries and/or interruption to the concerned area operations and it may develop from incidents beginning at the $Plan1$. The resources of the area concerned and those of the neighboring areas are made available to the decision-maker. $Plan$ 3 is for major crisis such as natural disasters and can be caused by incidents beginning at the $Plan2$. In this plan, all the resources of the country are available.
In the studied example and as the major priority in a disaster is the protection of lives, $Country1$ request assistance from $Country2$ to respond quickly to this emergency and to take advantage of the existing close resources beyond the border.

5.2. HLPN Models

This section describes the HLPN modeling technique developed using the environment CPN Tools 4[2] for an SoS representing two NCMSs in cooperation, $SoS = \{Country1, Country2\}$.
Fig. 4, Fig. 5 and Fig. 6 represent respectively the HLPN of $Plan1$, $Plan2$ and $Plan3$ of $Country1$. The HLPN of $PlanYellow$ and $PlanRed$ of $Country2$ is respectively same of $Plan1$, $Plan2$ except tokens and transition of plan switching. Each plan is an operating mode that can be activated or disabled for a crisis and it controls the availability of resources.
Fig. 7 represents the obtained models of $Country1$after merging their corresponding plans and integration of the internal system of communication. Likewise the models of $Country2$ is obtained. Each model allows commutation for an incident from one plan to another plan more critical and it controls resources availability.

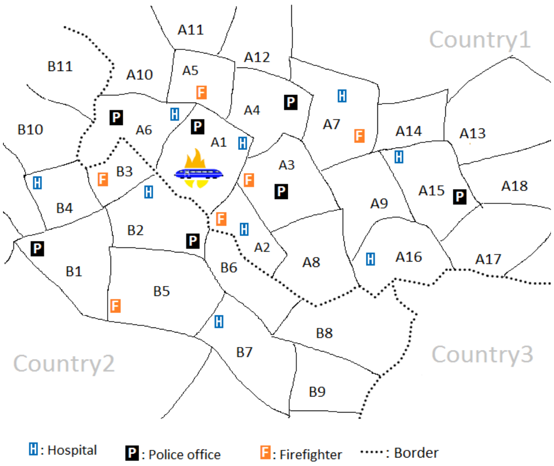

Fig. 3. Situation map.

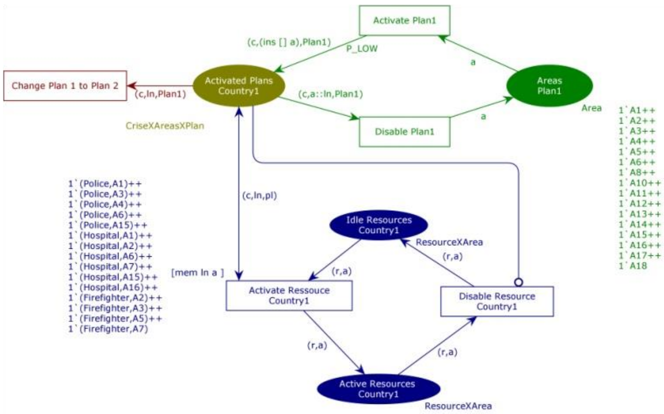

Fig. 4. HLPN of Plan 1.

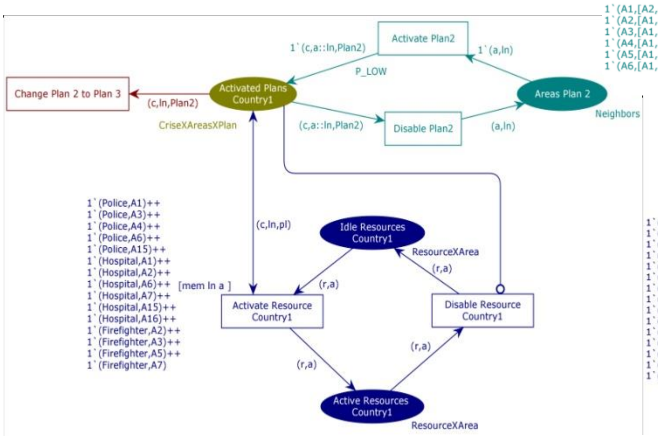

Fig. 5. HLPN of Plan 2.

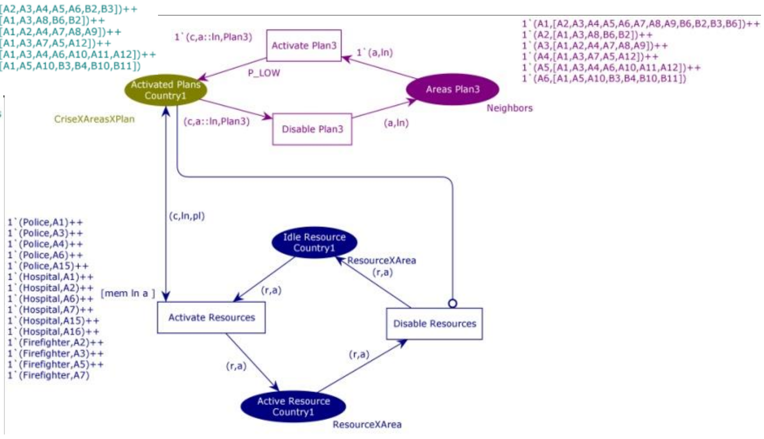

Fig. 6. HLPN of Plan 3.

[2] http://cpntools.org/

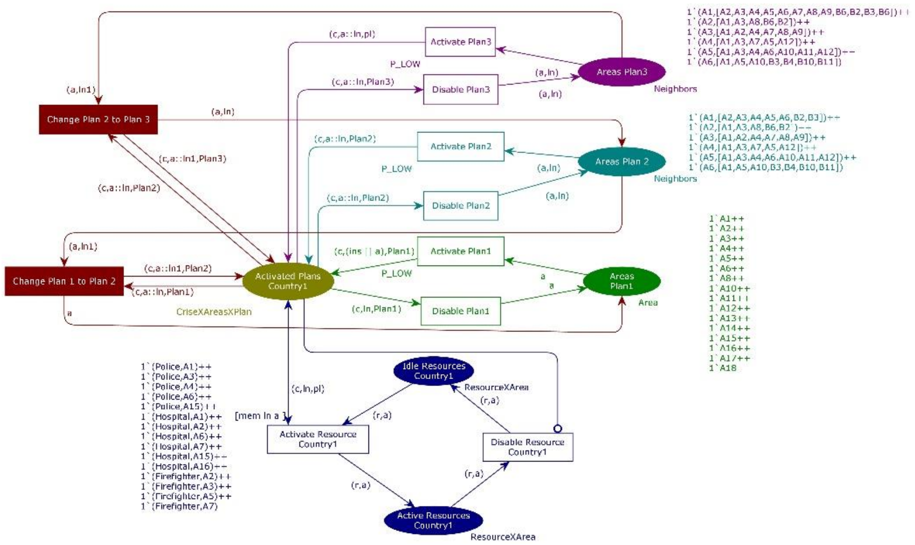

Fig.7. HLPN of $Country1$.

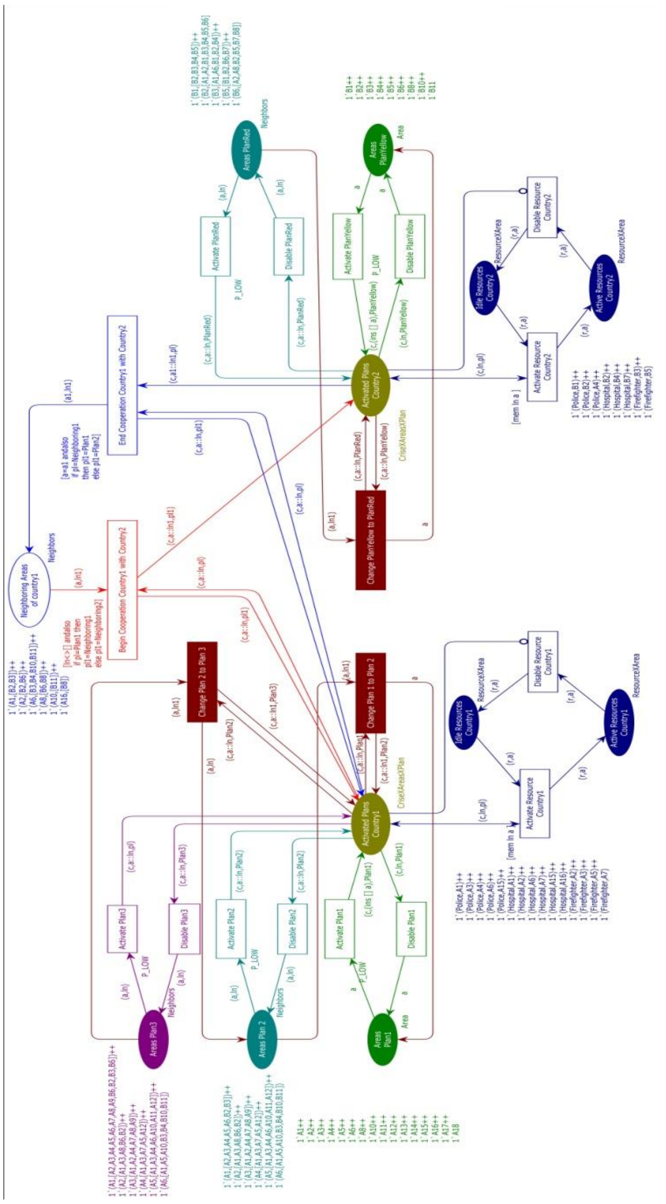

Fig. 8. HLPN of the SoS.

Fig.10 represents the SoS modelling the two systems and integrating the external communication system. In this model, each system operates independently from another one and in the case of international cooperation, communication is allowed based a specific standard.

6. Conclusion

In this paper, we have shown that collaborations of different stakeholders have a very positive impact on CM but are to this date not commonly established in border areas. The developed recommendations are a first step to approach this problem but they need to be extended and validated in future works. Additionally, we proposed a formal modelling method for an SoS representing CMSs in cooperationbased on different HLPNs associated with each operating mode. Our approach takes into account the change of plans and the communication inside the SoS. In addition, we have also presented CMS and all phases of emergency management operations in order to minimize the impacts of emergencies and disasters and to protect people and property.
In our future work, we intend to enrich our model by introducing the behavior of the CMS when a series of crises occurs.

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