Functional and Dysfunctional modelling and assessment of an Emergency Response Plan

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ABSTRACT

The objective of crisis management is to limit the impact of a feared event that has occurred and to restore the conditions corresponding to a nominal situation. In this context, we will focus on emergency response plans for mass casualty crises. In this paper, we propose a functional modelling of the French generic emergency plan, ORSEC plan, using the Business Process Model and Notation (BPMN). On the basis of this representation, a dysfunctional analysis is performed from a new approach identifying Failure mode, effects and criticality analysis (FMECA), in order to better anticipate, the events likely to interrupt the intervention plan. This work will then be used in a multi-agent dynamic planning and scheduling model to allow an actor to choose among the dynamic planning approaches the one that allows him/her to reach his/her goal.

Keywords

Crisis management, risk analysis, FMECA, BPMN, emergency response plan.

INTRODUCTION

For a long time, we have been hearing about environmental and humanitarian disasters around the world and their impact on property, the environment and the population. The effects of human-caused disasters are as significant as natural disasters. Wars, pollution, terrorist attacks, technological accidents, etc. are the effects of person on him/herself, the environment and goods. Unfortunately, whatever the nature of the disaster, and whether it is predictable or not, we cannot know its intensity. Sometimes the disaster impact can be limited or more global, in terms of the number of people affected, the economic cost, the geographical extent or the persistence of the hazard over a long period. We are interested in crises with a high human impact.

A crisis has three stages: pre-crisis, crisis response and post-crisis. Our work focuses on the response phase and more specifically on the response level in a rescue plan where the reaction must be quick and efficient as much as possible in order to minimize the human loss by providing help and rescue to the injured people. In a crisis rescue plan, each actor has a sequence of actions to perform to achieve a goal. When executing this latter, unforeseen events may arise that disrupt it. In this context, we aim to model the emergency plan using BPMN and to conduct a failure mode analysis on it. The structure of the rest of the paper is as follows. We present a state-of-the-art in Section 2. In Section 3, we outline a functional modelling of the ORSEC plan and we distinguish between three sets of activities namely: Informational, Decisional and Operational. Then, the dysfunctional modelling and analysis are provided in Section 4 (FMECA) and Section 5 (vulnerability assessment). Section 6 provides an overview of the integration of this work in the multi-agent dynamic planning model. In Section 7, we present the major conclusions of this paper as well as future works to be undertaken.

STATE-OF-THE-ART

Crisis Response Levels

Elmhadhbi, (2020) explains the three hierarchical levels of a crisis rescue plan as below:

Strategic Level

The highest level of decision-making is the strategic level and it is managed by public authorities. The latter provide the media with valuable information about events to alert citizens and play an essential role in inter-agency communication. In addition, they define strategies and guide the organizations concerned to engage in crisis response. The command of the crisis response process is determined based on three factors: the event type, its impact and the administrative division of the country.

Tactical Level

Despite the fact that goals are determined at the strategic level, these objectives are translated into actions at the tactical level. In order to implement a strategy, stakeholders at this level define the steps to be implemented by other actors on the site to end a potential threat. Note that for each emergency response organization (ERO), there is a command post managed by a commander. Thus, stakeholder commanders compose the tactical level.

Operational Level

Finally, at the operational level, the tactical plan is executed by the emergency responders on the site of the crisis like firefighters and healthcare services. These actors work together under a unified command in a dynamic environment where uncertainty is high.

Figure 1. Crisis Response Levels

Emergency Response Plan

According to Dautun, (2007), emergency planning, in France, is currently based on law n°2004-811 of 13 August 2004 on modernization of civil security and more particularly on implementing decree n ° 2005-1156 of the Communal Safety Plan (PCS) and decree n ° 2005-115 7 of the ORSEC plan. Since this last decree, the ORSEC plan has become the only emergency organization plan either in each department or in each zone. It now revolves around a common and simplified crisis management organization accompanied by an inventory of risks. In addition, according to Rongier, (2012), in France, there are two types of crisis response plans that are triggered when a natural or technological crisis occurs, depending on the needs. On the one hand, the ORSEC plan that is set up when the local means are not sufficient. There are three types of ORSEC plans: zonal, departmental and maritime. On the other hand, emergency plans such as the white plan and the red plan. The first one is activated when dealing with the arrival of numerous casualties while the second one is triggered if an emergency has a large number of injured in a limited area.

BPMN

BPMN is a graphical notation language developed by Business Process Management Initiative (BPMI). In 2005, BPMI and the Object Management Group (OMG) merged together and since then, OMG maintained BPMN Geambasu, (2012). BPMN version 2.0 was released in 2011 to extend the adequacy of BPMN 1.2 OMG, (2011). The main objective of BPMN is providing a notation that is easily understood by all business users, from the business analysts to the business people passing by the technical developers. The business analysts create the initial drafts of the processes, while the technical developers implement the technology that will execute these processes and finally the business users manage and monitor these processes. BPMN 2.0 can be serialized to BPMN 2.0 XML.

The process model depicts four element types to model business process diagrams as shown in Figure 2: flow objects (events, gateways and activities), connecting objects (sequence flows, message flows and associations), swimlanes (lane or pool), and artifacts (data object, group and annotation).

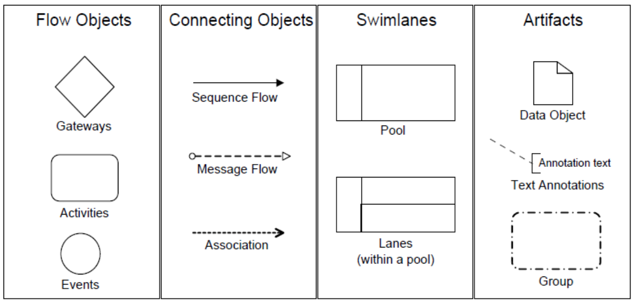

Figure 2. BPMN Core Elements of Process Diagram. kluza *et al.*, (2017)

FMECA

Failure Mode and Effects Analysis (FMEA) is a qualitative technique which defines main causes and effects of failures. The quantitative FMECA is an extension of FMEA which identifies the criticality level of failures. It is a predictive approach. Failure cause is the reason for a problem while failure mode is the way a problem is observed (a process can fail). It describes how the failure occurs and its effect on equipment operation. Failure effect is the consequence of a failure mode. The criticality analysis evaluates the failure mode criticality Brahim *et al.*, (2019).

In addition, FMECA is a decision-making tool. It reduces the critical failures' probability and analyzes potential failures to prioritize the improvement of actions in order to enhance the performance of the system Brahim *et al.*, (2019). Moreover, the failure factors to determine the risk priority number (RPN), which is an integrated measure of risk, (Chang and Paul Sun, 2009; Deng *et al.*, 2020; García and Gilabert, 2011) are:

- Severity (S) represents the seriousness of the failure effect.
- Occurrence (O) indicates the likelihood (probability) of this failure to happen.
- Detection (D) refers to the difficulty of detecting a failure.

Each input factor takes a discrete value in the range [0, 10]. The RPN is obtained by multiplying these three ranks. The higher the RPN, the higher the chances of failure of the mode.

Event/Fault Trees

A tree is a way to synthetically present the results of studies showing the relationships between causes and consequences both qualitatively and quantitatively. Event tree is a forward, bottom-up (inductive) method, starts from an event and describes the potential outcome consequences resulting from it depending on the conditions under which it occurred and the events with which it combines Mortureux, (2005). While fault tree is a top-down (deductive) method. Logical OR or AND links represent the combination(s) that can produce the event in the top line to which they are attached. The first line contains the event to be described.

Multi-agent System (MAS)

MAS is an organized corpus of agents in which a certain number of phenomena comes out as the result of interaction between these aforesaid agents. Briot *et al.*, (2001) define a MAS as a set of interacting agents that can organize in a dynamic and adaptive way. One of the interesting features is the distribution of the complexity over several agents. In this work, the MAS is used to model our scenario in different architectures. Several definitions have described the agent because of the variety of contexts and applications for which the agent is designed. Ferber & Perrot, (1995) defined an agent as a physical or virtual entity that can reproduce itself, has its own resources and skills to achieve its goal and tendencies. It can act, communicate and perceive its environment. Its environment's representation is either partial or null. According to Weiss, (2004), it is a computer system located in an environment where it has the ability to act through autonomous actions to achieve its design goals. EL FALOU, (2010) declares other characteristics of a MAS, we mention:

- Collaboration: consists in making all the agents work on the same project. It refers to techniques that allow agents to divide the tasks, the information, and the resources.
- Observability: is all the information that is accessible to an agent.
- Uncertainty: is when the environment of the agents is considered stochastic and the uncertainties are represented using e.g. probability distributions, intervals of values or fuzzy intervals.

Planning and Scheduling

Planning aims to determine the various operations to be carried out and the material and the human resources to be allocated to them. While scheduling aims to determine the different dates and resources corresponding to known activities Baki, (2006). According to Ghallab *et al.*, (2004), planning in Artificial Intelligence is concerned with solving problems in several domains. Problem solving in planning is achieving a goal by taking a series of actions. According to Lopez & Roubellat, (2001), solving a scheduling problem consists in placing actions in time, taking into account temporal constraints (deadlines, precedence constraints, etc.) and constraints relating to the use and availability of the required resources by the actions.

Bidot *et al.*, (2008) presented four different approaches for planning under uncertainty that keep the balance between plan generation and execution:

- Proactive technique has a knowledge base about uncertainty in order to have the power to decide offline. Since the solution is insensitive to perturbations, it is not revised during execution. Knowledge about uncertainty is included to create more robust and reliable schedules.
- Reactive technique generates a complete schedule and if during execution the solution differs from the observed situation, then the plan can be changed through online schedule re-generation.
- With progressive technique, It is possible to both plan and execute incrementally online. They generate the plan only in the short term. New steps are generated the rest is generated online either on a specific timestamp or whenever a condition expressing that some uncertainties are resolved is satisfied.
- Mixed Technique is an approach that combines at least two pure-generation techniques.

FUNCTIONAL MODELLING

Functional model is a graphical representation of functions within a system. It transfers a concept to a comprehensive representation. In this work, the emergency plan is modelled using BPMN with the Camunda modeler tool.

Emergency Response Plan Modelling

Introduction of Decisional, Informational and Operational Sets

Analysis of the ORSEC plan in France shows that decisions are not taken by actors directly in the field. The decisions are distributed to the different levels of the plan. In this case, we distinguish between three sets:

- Informational set is the tasks performed by actors to communicate with other agents in order to inform them of a situation or a decision. Actors may receive information directly from actors on the site or from external actors. In addition, communication can be visual. For example, the tag's color on the victim informs an actor of his/her situation.
- Decisional set: represents the decisions made by decision-makers.
- Operational set: shows the tasks to be carried out by the actors on the site.

In order to defer in the next figures between the activities of each set, we color an activity belonging to the informational set, decisional set and operational set, in blue, green and pink, respectively. In addition, an action can belong to one or more sets.

We modeled a generic model (see Figure 4) that shows the process when there are decisions, information exchange and execution of an action (act). This model makes it possible to represent in a general way the interaction between the three sets. When an actor receives information, s/he analyzes it in order to make a decision. The latter is taken if the actor has enough information, otherwise, s/he asks to be better informed. The decision made by an actor is either executed by the actor themselves or by other actors, so s/he must first transfer the decision to them. While executing a task, an event can interrupt it at any time, in this case, the actors inform the other actors of the situation. Furthermore, if the task is performed by the decision maker themselves, s/he will make another decision depending on the situation.

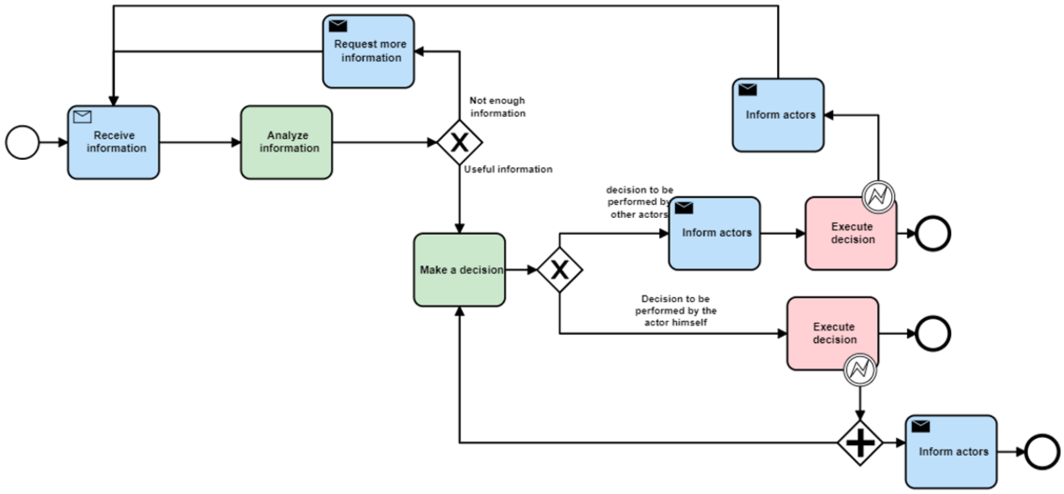

Figure 3. Generic Model: The Interaction Between The Three Sets

ORSEC Plan Modelling with BPMN

In France, intervention plans are available in a textual format defining the actors involved and their roles. In order to provide a global view of the collaboration between the emergency services, we have established models distinguishing between the three sets mentioned above. These models were built from the BPMN standard. We give for each service a number from A to L (see Table 1) and for each activity a number. Note that the number assigned to a service is also the category to which this service belongs. In this paper, we present the pickup sector process in the ORSEC plan as an example of process modelling.

Table 1. Code of Physical Entities

	Service
Number A	Alert centre
Number B	Departmental operational centre (COD)
Number C	Operational command post (PCO)
Number D	Pick up sector
Number E	Advanced medical post (PMA)
Number F	Mortuary
Number G	Meeting place for unharmed people (LRI)
Number H	Health care centre
Number I	Evacuation sector
Number J	Police centre
Number K	Departmental fire and rescue services (SDIS)
Number L	Urgent medical aid service (SAMU) centre

Pick Up Sector

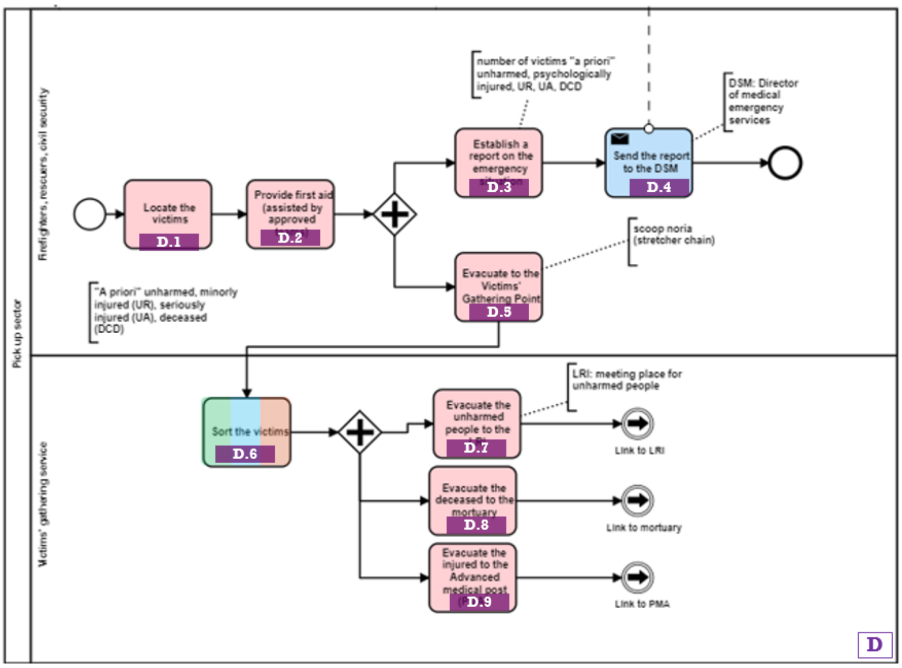

Figure 4. Pick Up Sector Process

It is provided mainly by the doctors and nurses of the health service and medical rescue (SSSM) and the firefighters, possibly assisted by other stakeholders, in order to provide first aid. These operations are placed under the authority of the director of fire and rescue services assisted by an officer from the SSSM identified by a yellow "health officer" chasuble. Those involved and victims are grouped together at the victim's gathering point (PRV).

When victims are located, the rescuers provide them with first aid. After these operations, the victims are evacuated to the PRV where first triage is carried out. Unharmed people are evacuated to the LRI, corpses are removed to the mortuary and finally the injured are transported to the PMA. In parallel, an emergency report is established and is sent to the director of medical rescue at regular intervals.

DYSFUNCTIONAL MODELLING

Dysfunctional modelling adds to functional modeling information about potential failures that a system may encounter. This allows the decision maker to determine the causes of failure as well as to specify the effects of these causes on the system.

FMECA of the ORSEC Plan

Failure Modes

Whatever process a function belongs to, we identified seven types of problems numbered from 0 to 6. Each activity (function) in BPMN has one or more failure modes that correspond to a category of a problem.

Table 2. Problems Code's Category

	Description
Category 0	It is not activated
Category 1	It is not carried out
Category 2	It gives no results
Category 3	It lasts longer than expected
Category 4	It gives

	incomplete results
Category 5	It gives incorrect results
Category 6	It is carried out intermittently

Causes

Problems have reasons behind them that can be direct or indirect, internal or external to the process and dynamic or static. Unlike external causes, an internal cause means that the origin of the cause comes from within the process. Moreover, unlike static, dynamic means that the cause may change over time but cannot be controlled at the moment.

As indicated in Figure 5, we identify three causes levels in a bottom-up fault tree. A cause is represented by a square called an event in the fault tree. The two colours blue and green represent internal causes and external causes, respectively. Static and dynamic are designated by light and dark colours, respectively. The symbols "←" and "🕒" designate when a cause is generated (before or during the execution of a process). In this work, the source of a cause can be from the input (I), control (C) or mechanism (S). For example, if the cause belongs to level one (denoted N1) and comes from the input (I), the category of the cause is IN1.

Level one causes or direct causes are three:

- Non-compliance of inputs which means that the input is incorrect, incomplete, etc.
- Inability of the support to support the task which means that the system is not compliant (state, capacity, availability of resources, willingness).
- Non-standard disturbances (intensity, specificity) represent external constraints that are too strong and internal organization that is insufficient.

We find the level two causes by going up in the fault tree:

- The non-compliance of inputs results from an upstream function malfunction, an unreliable source of the input or non-standard disturbances.
- Inability of the mechanism to support the task results either from the poor physical and psychological condition of the mechanism or from the default in design, system's realization and maintenance.
- Non-standard disturbances result either from an event occurring simultaneously with another event or from a non-conforming system response.

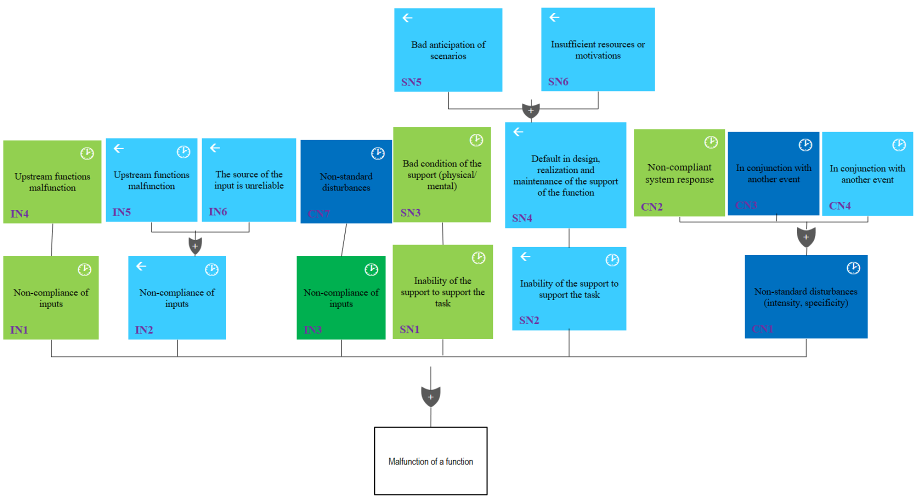

Figure 5. Level of Causes

In level three, we identify two causes for the default in design, system's realization and maintenance cause. It results from either the bad anticipation of the scenario or from the insufficient budget of the state or the center.

Effects

Problems also have effects on the functionality of the activity itself or subsequent activities. We use a top-down fault tree in order to show the three levels of consequences identified in this work and their category. The latter is denoted by O denoting output, followed by the level of the consequence. Effects are generated either during the execution of the process or after the end of the process. Events' colors and the symbol "🕒" have the same meaning as in causes. We added symbol "→" to indicate that the effect occurs after the process is completed.

Direct consequences are three:

- Non-compliance of outputs which means that the output is incorrect, incomplete, etc.
- Bad effect on the mechanism itself which means that the service is physically or/and psychologically affected.
- No outputs; i.e there are no results.

We find the level two consequences by going down in the fault tree. We identified two effects:

- The non-compliance of outputs affects a downstream function malfunction.
- The consequences can also affect other mechanisms involved in saving victims.

Figure 6. Level of Consequences

In level three consequences, we find that the results may not be optimal or non-standard consequences (climate change, state's image, problems with neighboring countries, economic and social problems, death, etc.).

Criticality

In FMECA, criticality is measured by multiplying the failure's severity, its probability of occurrence and the probability of its detection. As in this paper, certain authors consider the first two criteria to calculate the criticality of the failure mode.

Table 3. Probability of Occurrence Scale

	Rank	Description
Very high	10	Very high probability of occurrence
High	7-9	High probability of occurrence
Moderate	4-6	Moderate probability of occurrence
Low	2-3	Low probability of occurrence
Very low	1	Very low probability of occurrence

Table 4. Severity Scale

	Rank	Description
Catastrophic	10	Cause the death of the victim and/or affect the process of the service itself and/or the other processes
High	7-9	Cause the victim's situation to evolve and affect the process of the service itself and other services
Moderate	4-6	Cause the victim's situation to evolve and affect the process of the service itself or the process of other services
Low	1-3	The effect are not severe enough to cause the death or to affect a process

Application of Pickup Sector in Functional and Dysfunctional Modelling

The ORSEC plan defines the missions of each service, the list of resources and the methods of their mobilization. Our work is completed by a multi-agent dynamic planning of the operational level of an emergency plan, i.e. we are interested in the list of actions taken by an actor from its initial state (alert reception) to its target state (e.g. for an ambulance, it is its arrival at the hospital). Furthermore, the ORSEC plan lists the missions of the operational level assuming that the actors of the latter are on the site of the event, whereas in this article, we also take into account the actions taken by the operational level's actors in order to arrive at the site. For this reason, we perform a dysfunctional modelling on the pick-up sector process presented in Figure 7. For clarity reasons, part of this model is shown in Figure 8.

In our work, FMECA table consists of the following columns: activity's name, activity's number in BPMN (code), failure mode and its category, causes and consequences levels as well as their categories, the service executing the activity (source) and on which services it has an effect (Target). At the end of the table, we added the severity and the occurrence in order to calculate the criticality of the failure mode.

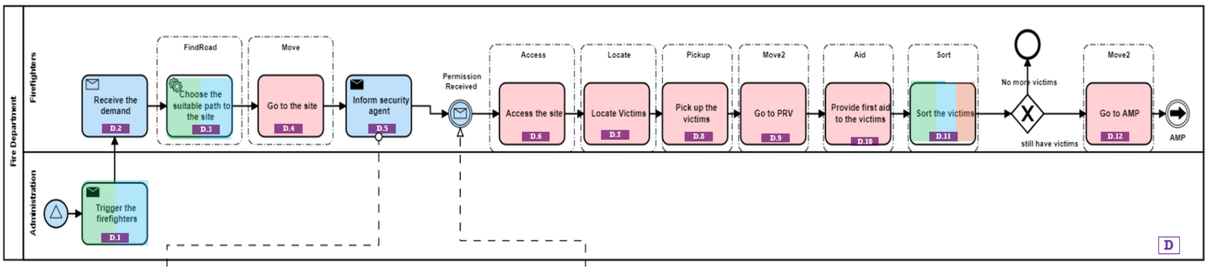

Figure 7. Pick-Up Sector Process from the receipt of the alert

Activity	Code	Mode	Category	Cause I	Category of cause I (Before)	Category of cause I (During)	Cause II	Category of cause II (Before)	Category of cause II (During)	Cause III	Category of cause III (Before)	Source
Choose the suitable path to the site	D.3	No road to the site is found	0	Actors are not triggered	-	IN1	-	-	-	-	-	D
		No road to the site is found	1	They don't know the destination	-	IN1	Destination is not received	-	IN4	-	-	D
				All roads leading to the site are closed	-	CN1	There is another big event in the city	-	CN4	-	-	
		A road to the site cannot be found	2	The GPS is out of service	-	SN2	No maintenance for GPS is performed	SN4	-	No budget for maintenance	SN6	D
		Choosing/finding a road takes longer than expected	3	There is a bad connection	-	CN1	-	-	-	-	-	D
				Actors hesitate to choose a route	-	SN1	They are stressed	-	SN3	-	-	
		Road is wrongly chosen	5	Actors enter the wrong destination	-	SN1	They did not pay attention	-	SN3	-	-	D
		The road is chosen at an irregular pace	6	There are a lot of uncertainties on the road (an accident may occur in front of the actors)	-	CN1	-	-	-	-	-	D
Go to the site	D.4	The actors are not going to the site	0	They don't know which road to take	-	IN1	No available roads were found	-	IN4	-	-	D
		The actors are not going to the site	1	No available trucks at the centre	-	SN2	centre does not have a lot of trucks	SN4	-	centre does not have the budget to buy new trucks	SN6	D
		The actors cannot go to the site	2	All the trucks are out of order	-	SN2	centre did not maintain the trucks	SN4	-	centre does not have the budget to maintain them	SN6	D
		Going to the site takes longer than expected	3	There is traffic	-	CN1	-	-	-	-	-	D
		Not all actors are going to the site	4	There are no places available for everyone to go	-	SN2	Not enough trucks for all actors	SN4	-	No budget to buy enough trucks	SN6	D
		Actors are going to the site at an irregular pace	6	No available places to take all actors at the same time	-	SN2	lack of resource management	SN4	-	No budget to buy enough trucks	SN6	D

Effect I	Category of effect I		Effect II	Category of effect II		Effect III	Category of effet III		Target	S	O	Criticality
	During	After		During	After		During	After				
They did not search for a road	ON4	-	-	-	-	-	-	-	D	10	1	10
They did not search for a road No available road is found	ON4	-	-	-	-	-	-	-	D	10	1	10
No road is found	ON4	-	-	-	-	-	-	-	D	10	1	10
Actors belatedly find a road to the site	ON2	-	The actors go to the site late	ON7	-	Possibility of death	ON10	-	D	10	3	30
Choosing a road is under discussion	ON4	-	-	-	-	-	-	-				
The chosen road does not lead to the site	ON2	-	Actors go to the wrong place	ON7	-	Victims death	ON10	-	D	10	1	10
Actors may take the long road	ON2	-	Actors arrive late at the site	ON7	-	Possibility of death	ON10	-	D	8	5	40
Actors did not leave the centre	ON4	-	-	-	-	-	-	-	D	10	1	10
Actors did not leave the centre	ON4	-	-	-	-	-	-	-	D	10	1	10
Actors did not leave the centre	ON4	-	-	-	-	-	-	-	D	10	1	10
Actors arrive late at the site	ON2	-	Locating victims starts late	ON7	-	More victims could die	ON10	-	D	7	8	56
Actors are not enough	ON2	-	Locating victims takes longer than expected	ON7	-	Victims can increase	ON10	-	D	10	1	10
Not all the needed actors are on site at the same time	ON2	-	Locating victims takes longer than expected	ON7	-	Increasing number of victims	ON10	-	D	8	6	48

Figure 8. FMECA Table of D.3 and D.4 Activities in Figure 7

VULNERABILITY ASSESSMENT

The process must allow attending as quickly and efficiently as possible the potential victims of a crisis. It is temporally bounded on the left by the instant of occurrence of the catastrophic event and on the right by the instant of resolution of the crisis situation. Despite the fact that the vulnerability is a widely used concept in many fields, its definition varies depending on the authors. Vulnerability focuses on the system capacity to resist a hazard or threat Johansson, (2010). According to Haimes, (2006), vulnerability is the way of the degradation of a system, an organization or human performance when certain hazards or threats exploit the vulnerability. The vulnerability of a system results from its sensitivity, its exposure, and its response capacity. It can be characterized by the potential of damage, the exposition function and sensitivity of a system Adger, (2006). Johansson, (2010) explicates the vulnerability as the consequences that arise when a system is exposed to a strain for a given type and magnitude. The system moves from a planned state into an unplanned state. In our work, we define vulnerability as the stake's sensitivity to a threat (a hazard).

In this section, we represent the vulnerability of an activity by observing 11 indicators. An activity is vulnerable if it can potentially be unable to be performed (no output) or if it is performed but potentially gives non-compliant results.

Codification of a Function

The vulnerability indicators are represented in Table 5 which is a clear and simple method to better analyze each function. The three processes Decision-making (D), informational (I) and operational (O) are represented in column "Nature". In addition, the "interaction" column indicates whether the function has an internal (I) or external (E) interaction to the process. Moreover, the "Cost" column allows us to know if the function has a direct (D), indirect (I) or not significant (A) economic impact. In contrast to symbol (I) in the column "impact", D indicates whether the function induces an immediate risk of death. If it is neither (I) nor (D), it means there is no risk (A). In the "recurrence" column, a function can be performed only once (U), or intermittently (I) or several times (R). Furthermore, it may need a high (H), average (M) or elementary (E) technicality in order to be performed. It may also require heavy materials, fluids, networks or infrastructures (Y if yes and N if not). Finally, the last column indicates which failure modes may have a function.

This table is filled once we have finished our functional (BPMN) and dysfunctional modelling (FMECA).

Table 5. Vulnerability Indicators

	Type	Interactions	Cost	Impact	Recurrence	Technicality	Material	Fluids	Network	Infrastructure	Failure modes
D.1	D, I	I	D	I	U	H	N	N	N	Y	0,1,2,3,5,6
D.2	I	I	A	A	U	E	N	N	N	N	0,1,5

D.3	D, I	I	A	A	U	E	Y	N	Y	N	0,1,2,3,5,6
D.4	I	E	A	I	U	M	Y	Y	N	N	0,1,2,3,4,6
D.5	O	I	A	A	U	E	Y	N	N	N	0,1,2,3
D.6	I	I	A	A	U	E	N	N	N	N	0,3,6
D.7	O	I	A	D	R	H	Y	N	Y	N	0,1,2,3,4,5,6
D.8	O	I	A	D	R	H	Y	N	N	N	0,1,3,4,5,6
D.9	O	I	A	I	R	M	Y	N	N	N	0,1,2,3,4,5
D.10	O	I	A	D	R	H	Y	N	N	N	0,1,2,3,4,5,6
D.11	D, I, O	I	A	D	R	H	Y	N	N	N	0,1,2,3,4,5
D.12	O	E	A	I	R	M	Y	N	N	N	0,1,2,3,4,5

D.1 is the only activity that has an economic cost (triggering more stakeholders than necessary requires more money) and needs an infrastructure (the center) to be executed. Both D.5 and D.12 have external interaction with the Police and the PMA, respectively. All the activities require the use of some materials except for D.1, D.2 and D.6. Only D.4 needs fluids (gas or fuel) to be achieved while the network is necessary for the execution of D.3 and D.7. In addition, some activities require a high level of technicality to be implemented (D.1, D.7, D.8, D.10 and D.11) while for others an average level (D.4, D.9 and D.12) or an elementary level (D.2, D.3, D.5 and D.6) are sufficient. Some activities can directly cause the death of a victim (D.7, D.8, D.10 and D.11), while others have either an indirect impact (D.1, D.3, D.9 and D.12) or no impact at all (D.2, D.4, D.5 and D.6). Actors of D.2 and D.5 may have difficulties in receiving a decision and informing other services, respectively. D.11 belongs to the three processes which means that actors may have a problem in deciding, informing and operating the task. The rest of the activities are part of the operational process which means that stakeholders may have problems in operating these tasks. Activities from D.7 to D.12 are repeated until a condition is satisfied. For example, actors continue to transfer victims to the PMA until there are no more victims. In contrast, the activities from D.1 to D.6 are performed only once. We note that some activities have the failure mode number 6, which means that they can be executed at an irregular pace under certain conditions (e.g. D.7).

Causes and Failure modes

Figure 9 shows the relationship between causes and failure modes based on the FMECA table of the pick-up service.

	Cause I								Cause II										Cause III			
	IN1	IN2		IN3	SN1	SN2		CN1	IN4	IN5		IN6	CN7	SN3	SN4	CN2	CN3	CN4	SN5	SN6		
Failure mode	During	Before	During	During	During	Before	During	During	During	Before	During	Before	During	During	Before	During	During	During	Before	Before	Total	Percentage
0	7	2	2	0	0	0	0	1	6	2	2	0	0	0	0	0	0	0	0	0	22	10.37735849
1	1	2	0	1	0	0	4	4	1	2	0	0	1	0	5	2	0	2	2	3	30	14.1509434
2	0	0	0	1	1	0	7	4	0	0	0	0	1	1	7	3	0	0	1	7	33	15.56603774
3	0	0	0	0	1	3	10	8	0	0	0	0	0	1	13	5	0	0	8	7	56	26.41509434
4	1	0	0	0	0	0	7	3	1	0	0	0	0	0	7	3	0	0	4	5	31	14.62264151
5	2	0	1	0	2	3	0	4	1	0	0	1	0	2	3	4	0	0	0	3	26	12.26415094
6	0	0	1	0	0	0	2	5	0	0	0	1	0	0	2	1	0	0	0	2	14	6.603773585
Total	11	4	4	2	4	6	30	29	9	4	2	2	2	4	37	18	0	2	15	27	212	
Percentage	5.188679245	1.886792453	1.886792453	0.9433962264	1.886792453	2.830188679	14.1509434	13.67924528	4.245283019	1.886792453	0.9433962264	0.9433962264	0.9433962264	1.886792453	17.45283019	8.490566038	0	0.9433962264	7.075471698	12.73584906		

Figure 9. Causes - Failure Modes Table

26,41% of the causes belong to failure mode 3. We find that most of their origins are external and are of type SN2 for level I (10), SN4 for level II (13) and SN5 (8) and SN6 (7) for level III. We conclude that the causes are related to the functioning of the service. Moreover, there are a large number of causes that arise due to external disturbances at level I and consequently, for the resistance of the service to these disturbances at level II. In addition, 15,56% of the causes belonging to failure mode 2 are also external, have the same type for each level in causes and are linked to the functioning of the service. While the failure modes 2 and 4 have almost the same percentage of causes (14%). They also have the same type and origin of causes as failure mode 3. Briefly, the ability of the support to sustain the task will be affected by the training carried out by the support before the crisis, the experience of the actors in dealing with a crisis and the need to maintain and purchase equipment, check stocks, etc. Nevertheless, sometimes actors find themselves in a difficult situation because of the crisis environment, which means that some of the uncertainties cannot be anticipated because of the crisis impact. In global, we find that both SN2 (14,15%) and CN1 (13,67%) are the most present in the pick-up service process and, consequently, SN4 (17,45%) and CN2 (8,49%) have the highest percentage at level II.

Failure modes and Effects

Figure 10 shows the relationship between failure modes and effects based on the FMECA table of the pick-up service.

	Effect I									Effect II				Effect III						
	ON1		ON2		ON3	ON4	ON5	ON6		ON7	ON8	ON9		ON10	ON11		ON12			
Failure mode	During	After	During	After	During	During	During	During	After	During	During	During	After	During	During	After	During	After	Total	Percentage
0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	12	8
1	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	11	7.333333333
2	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	9	6
3	1	0	9	0	4	0	0	1	0	9	4	1	0	9	3	0	3	0	44	29.33333333
4	0	0	5	0	3	0	0	0	0	5	3	0	0	5	2	0	2	0	25	16.66666667
5	1	0	7	0	1	0	0	1	0	6	1	1	0	6	0	0	1	0	25	16.66666667
6	0	0	3	0	5	0	0	0	0	3	4	0	0	3	2	0	4	0	24	16
Total	2	0	24	0	13	32	0	2	0	23	12	2	0	23	7	0	10	0	150	
Percentage	1.333333333	0	16	0	8.666666667	21.33333333	0	1.333333333	0	15.33333333	8	1.333333333	0	15.33333333	4.666666667	0	6.666666667	0		

Figure 10. Failure Modes – Effects Table

29,33% of the effects belong to failure mode 3. We find that most of their origins are internal and are of type ON2 (9) for level I, ON7 (9) for level II and ON10 (9) for level III. We conclude that the effects affect the successor activities in the process of the service itself. In addition, some of the effects affect the operation of the service itself at level I (ON3) and therefore the operation of other services (ON8), which may lead to non-standard consequences and/or non-optimal results. Both failure modes 4 and 5 have the same percentage 16.67% of effects, most of which are internal and belong to ON2 at level I. This results in ON8 effects at level II and ON10 effects at level III. The failure mode 6 has almost the same percentage effect (16%) as the previous failure modes. It affects the functioning of the service itself and other services (ON8), which may lead to non-standard consequences (ON3). Overall, we find that the two internal effects of not having results (ON4=21.33%) and not having compliant results (ON2=16) are most present at level I. ON4 has no resulting effects that is why ON7 (15.33%) is producing the most at level II and therefore, ON10 (15.33%) is the most produced at level III.

FROM FUNCTIONAL AND DYSFUNCTIONAL MODELLING TO SIMULATION LEVEL

Although the simulation level and the link between the latter and the conceptual level are beyond the scope of this paper, this section provides an overview of how the work in this paper will be further integrated into the simulation level. The functional model gives an overall view of the actors in the response plan, their missions and the coordination between them. Each actor has missions that must be carried out in a specific order. In addition, the different actors coordinate to help the victims. In this context, MAS is used as a decision support system to simulate our scenario and observe the coordination between the agents (services). For example, the pick-up sector consists of firefighters is considered as firefighter agent in MAS. An agent executes a set of actions that form a plan in order to achieve its objective. The set of actions is determined from BPMN where each activity represents an action. Choosing the appropriate action, knowing when to execute it and by whom in a dynamic environment full of uncertainty require one or more technique of the dynamic planning approaches. The dysfunctional analysis helps us determine the best technique to automatically generate plans for each agent to analyze its performance.

CONCLUSION AND PERSPECTIVES

We represented in a comprehensible and global way the actors' behaviours in an emergency rescue plan, using BPMN. We also distinguish between three sets: decisional, operational and informational sets. Based on this functional modelling, we proposed a new FMECA approach by adding levels and durations to causes and effects. For each failure mode of an activity, we calculate its criticality. The functional and dysfunctional modelling allowed us to see the indicators of each activity in order to analyse its vulnerability. The relationship between causes and failure modes shows clearly to which failure mode most causes in a process belong and their origins. Whereas the relationship between failure modes and effects shows the effects associated with each failure mode in a process and their origins and type.

Both modelling will be used in our multi-agent dynamic planning and scheduling model. Based on functional modelling, we identify the actors involved at the operational level to assist the victims and their actions. In addition, dysfunctional modelling allows an actor (agent) to take into account some uncertainties that may disturb his/her plan and thus, decide which dynamic planning approach to use in order to achieve his/her goal.

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