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Emergency response plan: Model-based assessment with multi-state degradation

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ABSTRACT

Local Emergency Response Plans (LERP) must be assessed before being triggered, to ensure proper execution of missions in a crisis situation. However, there is very little research on plan assessment methods. Plan assessment has traditionally involved consideration of only two states: complete functioning, or failure.

In this paper, we propose an LERP assessment method that evaluates LERP performance under multiple states of its resource degradation. Our method relies on Function-Interaction-Structure (FIS) modeling to describe interaction between resource degradation and plan failure. Our multi-state and model-based approach allows a comprehensive analysis of LERP weak points, and provides the framework for evaluating a wide range of engaged resources. Consideration of multiple states of resource degradation is needed in order to show to what extent an LERP is required. We propose to combine a Fault-Tree embedded in FIS with a Multi-State System approach. With this approach, plan evaluators can study LERP effectiveness at various levels of incomplete functioning, and can analyze the risk of resource degradation leading to functional impairment of LERP missions. The Multi-State System approach provides knowledge about the likelihood of an LERP being in multiple states of degradation on disaster day. Input data for the analysis are gathered using developed questionnaires. These are used by Emergency Response Plan makers to evaluate the probability of resource degradation states, and to develop strategies to increase the likelihood of LERP success.

This paper shows how the proposed methodology, based on modeling and Multi-Level Fault-Trees, can inform the analysis of an LERP evacuation function.

1. Introduction

The Local Emergency Response Plan (LERP) is a French administrative organizational document (République Française, 2004, 2005) discussing territorial hazard and vulnerability assessments. The LERP describes the response from public authorities when a threatening event (exceeding current management) occurs. The LERP identifies missions guaranteeing population integrity.

LERP plans are designed for undesirable events. However, because plans are made of paper, plan designers do not have the means to ensure *a priori* proper execution of the missions, which are planned and described in the plan. It is of prime importance to test emergency response plans prior to a disaster, to make sure they will work correctly in a real emergency. Mission indicators and a methodology for gathering necessary information are needed in order to test plan construction and functioning prior to a disaster. Although evaluation is difficult, mission success indicators will permit identification of plan phases that would not be optimally implemented in a real emergency. Such testing would help decision-makers to make changes that would optimize their plans.

LERP assessment is difficult for many reasons. Indeed, LERPs are a collection of static procedures, which are complex and employed in dynamic situations. LERPs involve many different stakeholders (public authorities, private authorities, NGO, population) and resources, over large territories. While public authorities are responsible for protection of the population under their jurisdiction, paradoxically they are under pressure to plan emergency responses. Although the public does not necessarily demand that public authorities take time to plan emergency responses, nevertheless it expects emergency response plans to work correctly

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when needed (Henstra, 2010). Before the crisis response phase, public authorities have to be prepared to manage such events with maps, procedures and scenarios. In the crisis response phase, public authorities execute the plan. They have to set up the planned organization, using all necessary means (technical, human, organizational, informational), to guarantee safety of the population.

Research abounds on emergency management, especially in evacuation and emergency sheltering, during natural and industrial disasters. These works mainly deal with evacuation for example: (Siebeneck and Cova, 2012; Georgiadou et al., 2007; Kolen et al., 2013; Georgiadou et al., 2007; Dombroski et al., 2006) or sheltering (Li et al., 2012; Dombroski et al., 2006), some are embedded in studies geared to final loss of life (Groenendaal et al., 2013; Kolen et al., 2013; Jonkman et al., 2010). They use models as a support to give indicators to decision-makers. Others tried to model the global process of emergency management such as for instance Flaus (2010), Jain and McLean (2003), Massaguer et al. (2006), and Georgiadou et al. (2010). Use of modeling techniques in emergency management is increasing (Jain and McLean, 2003), because it enhances a variety of points:

- Training of first aid responses.
- Knowledge of consequences.
- Continuous operation where the event is not occurring.
- Traffic management.
- Dispatch of victims to hospitals.

Modeling is necessary to grasp the complexity of the real world. Various kinds of models exist but communication between models is no easy task. Vaez and Nourai (2013) propose an integrated framework for emergency response taking into account operational and cognitive errors thanks to a reliability block diagram. Flaus (2011) design a whole framework for any model-based risk analysis. Part of this framework will be described and adopted in this paper.

However, it is difficult to find research on assessment of the entire LERP. Previous works focus on some functions (e.g. evacuation, sheltering, area protection, alert spreading, etc.) but do not examine the interrelations between functions. Some exist, but are limited to assessments of individual planned emergency phases. They test whether, for each one, corresponding procedures exist (Henstra, 2010), and thus are limited to document checking. However, they do not study the states of resources engaged in LERP missions.

The goal of this paper is to estimate the achievement of LERP missions, considering the current resources in the field. This will include performing a diagnosis on resource states. This analysis will provide *a priori* knowledge about the reachable level of mission accomplishment (for evacuation, sheltering or any other emergency missions). For instance, total evacuation, partial evacuation (with described degrees), or total evacuation failure.

This paper proposes an assessment method for LERP. The goal of this assessment is to provide the user with a list of indicators on the state of the functioning missions. The achievement level of LERP functions is estimated, propagating resource failure states through the dysfunctional LERP model. For this reason, in the presented work, formalism of Fault-Tree Analysis (FTA) is used to connect basic events from resource failures to top-events, which are the mission state indicators. Additionally, the paper deals with Multi-State System theory (MSS) through FTA. This choice was made because to consider failures as a total functioning or dysfunctioning (0/1) is a reductive hypothesis. We prefer to consider intermediate states to acquire a more precise view of mission states. The entire approach is supported by previous identification of possible resource and mission failures. This identification takes place at the metamodel level of what is involved in a LERP. It permits use of generic failure modes (e.g. unavailable, not working, unreachable, etc.) covering a huge variety of failure scenarios.

Section 2 describes LERP for the French administration case. Section 3 presents the model-based methodology, proposed to assess LERP. This methodology permits a systematic analysis of LERP, and accesses FTA formalism for perturbation propagation with more than two discrete states. In this section, the chosen modeling method is justified, as well as the choice of FTA to represent perturbation propagation. Finally, the method for assessing emergency mission functioning is presented. This method is based on multi-level assessment of resource failures, building functioning function state indicators. Section 4 presents an example of application of the proposed method on an evacuation function, in a real study case.

2. LERP, local level of emergency management

Emergency management is the top priority of local administration.

All public authority levels are implied in an emergency management process (National, Zonal and Local). However, priority functions are managed by local authorities (Waugh and Hy, 1990) for two main reasons:

- Most of the time, local rescue teams are closest to the event (Cigler, 1988).
- It is at local level that hazards and vulnerabilities are best known (Newkirk, 2001).

It is essential that local authorities be well prepared to face emergency situations. A planned organization must be used to organize and formalize emergency management processes.

LERP consists of four themes (DDSC, 2009): hazard and vulnerability diagnosis, alert (reception and spreading), response actions with operating means and coordination. Hazard diagnosis is designed to identify which kind of event the local administration will face, while vulnerability diagnosis will identify the population area to be impacted. When alert of an event is given, emergency teams must be mobilized, while spreading of the alert has to inform the population about the behavior to adapt. Actions are then performed by operating means. The last item concerns coordination, which impulses consistent action and prioritizes missions.

3. Methodology to assess the Local Emergency Response Plan

The method we present is based on the FIS modeling method, FTA and MSS. The main steps are as follows:

1. Modeling LERP to grasp complexity: functions, resources and failures lists.
2. Building cause-effect dependency via Fault-Tree Analysis between structural (resource) failures and functional failures (mission success indicators).
3. Assessing structural failure to obtain functional indicator results.
4. Taking decisions (not detailed in this paper), building the action plan.

3.1. Modeling for systematic representation

Assessment of LERP is difficult because it is related to an organization built to deal with complex situations (Flaus, 2010). Many