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MIND-VERSA: A new Methodology for IdentifyiNg and Determining loopholes and the completeness Value of Emergency ResponSe plAns

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ABSTRACT

There is a need for organizations and public services to reinforce their overall emergency response capacity based not only in an ad hoc approach e.g. exercises, but also towards a more sophisticated and evidence-based approach to analyze emergency response plans, evaluate their overall capacity and maximize their efficacy based alternatively on modern systems' theory methods.

This paper focuses on the development of a new methodology, utilizing a systems' theory method, that: a) identifies emergency plans' loopholes and b) provides a numerical value that indicates the "distance" between what is planned and what should have been planned. For this purpose, a case study has been used and the proposed methodology was applied to the official evacuation plan due to forest fires, of Greece's Civil Protection Agency.

Thirty-one missing specifications or loopholes were identified which made the emergency response plan **dysfunctional** and a value was calculated indicating that there was a considerable distance between the initial plan and the enhanced plan. These results were compared and validated against the prosecutors' investigation findings of the 2018 forest fire in the small resort of "Mati" Greece, 18 miles east of Athens, where more than 100 people died because of the fire.

1. Introduction and background

Emergency response plans are documents that define the elements of a system which is responsible for managing a natural or a technological disaster when it occurs, together with its goals, responsibilities, objectives, and actions. These plans are utilized by executive entities to respond during a critical incident and help ensure preparedness in many cases of emergency while taking steps to mitigate losses to both people and properties (Perry and Lindell, 2019).

There are several standards for emergency response plans like the ones developed, e.g. by the National Fire Protection Association in the USA, or by Greece's Civil Protection Agency (General Secretariat of Civil Protection, 2007; General Secretariat of Civil Protection, 2009; Ministry of Interior, Public Administration and Decentralization, 2003; NFPA 1600, 2013). The four essential elements of any emergency response plan are: planning, reviewing, training, and testing. These cornerstones of emergency response plans work more in a somewhat circular process than a linear one (Vendrell and Watson, 2010). In any case, disaster response plans are the essential connection between the disaster planning activity and the disaster response activity (Perry, 2004).

However, contingency plans are typically presented as bulk documents with too much information that, in many cases, confuse the stakeholders, and complicate situations by creating gaps. Plans, designed like this, tend to become obsolete and non-practical, giving a false sense of safety or preparedness of the system. On the other hand, it is simply not possible to anticipate every event or nuance that may arise in a disaster (Perry, 2004). Thus, when emergencies occur, the system's capacity to cope with them is limited and sometimes it fails to perform as desired. Even well-intentioned designers of a responsive system are confronted ultimately with a slowdown of decision-making processes, endanger immediate response of staff and create confusion when an unpredictable event occurs that was not included, or was not covered in the plan (Perry, 2004).

The main issue is that problems and loopholes in disaster response

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plans are realized after the occurrence of emergencies. Characteristic is what was reported in (Townsend, 2006), which looked at the response during 2005 hurricane Katrina and noted that: "*In terms of the management of the Federal response, our architecture of command and control mechanisms as well as our existing structure of plans did not serve us well. Command centers in the Department of Homeland Security (DHS) and elsewhere in the Federal government had unclear, and often overlapping, roles and responsibilities that were exposed as flawed during this disaster*". Another example is what was reported in the prosecutors' findings during the 2018 forest fire disaster in "*Mati*" Greece (Euronews, 2019; Kathimerini, 2019; Dasarxeio, 2019; Liberal, 2019; dikastiko, 2019; MacroPolis, 2019; The National Herald, 2019) where it was pointed out that "*the implementation of the plan has worked well in theory but in practice virtually nothing worked as planned, and the whole management has been spasmodic, without any coordination*".

This issue generates the need for methods that aim at identifying the loopholes in emergency response plans before disasters occur. Approaches which were introduced to deal with this problem can be categorized as follows: (a) Approaches based on stakeholder consultation and periodic drills, collaboration exercises and strategic exercises, (Perry, 2004; Berlin and Carlström, 2014; Peterson and Perry, 1999; Gwynne et al., 2020), (b) serious games approaches (Rothkrantz, 2016; Brawley, 2016), (c) computer based simulations (Chen et al., 2016; Khalil et al., 2009), (d) formal modeling approaches to compare existing disaster plans (Hoogendoorn et al., 2005), (e) a suite of tools for emergency plan management support like SAGA (Gai et al., 2018; Canós et al., 2013) and (f) content and semantic analysis methods (Jung et al., 2017; Khalid and Yusof, 2018).

This paper introduces a new methodology that aims at: a) identifying the emergency plans' loopholes and b) providing a numerical value that indicates what the "distance" of the emergency response plan is, against a version of the plan that has addressed the identified loopholes. To achieve that, the proposed methodology utilizes a systems' theoretic method called "Systems Theoretic Early Concept Analysis" (STECA) (Fleming, 2015; Urano, 2016; Fleming and Leveson 2016), and dissimilarity measures (Chatzimichailidou and Dokas, 2016).

The methodology has been applied in the evacuation plan of Greece's General Secretariat of Civil Protection, (doc.nr.2934/06–05-2015) entitled "*Guidelines for organized removal of citizens for the purpose of protection against an evolving or imminent destruction due to forest fires*" (General Secretariat of Civil Protection, 2015). Missing elements and loopholes have been identified, and thus, an enhanced concept of the plan has been created. Subsequently, two vectors were formed and compared, one with the enhanced elements and the other with the initially planned elements and with the use of Rogers-Tanimoto dissimilarity measures a numerical value had derived. Also, STECA's enhancements were validated by the findings of the prosecutors after the tragedy in "*Mati*" (Dasarxeio, 2019; dikastiko, 2019; Euronews, 2019; Kathimerini, 2019; Liberal, 2019; MacroPolis, 2019; The National Herald, 2019) area in Athens-Greece.

2. STECA & dissimilarity measures

2.1. STECA method - definitions

STECA is a novel method introduced by (Fleming, 2015) to assist stakeholders in the development of systems during the early concept development stages using a safety-driven approach. STECA is based on Systems-Theoretic Accident Model and Processes **STAMP** (Leveson, 2004, 2011) an accident causation model, and on Systems' Theory principles such as hierarchy, control, communication and emergence. Specifically, STECA utilizes the following concepts:

A. **Process Model:** A process model is the controller's internal beliefs and information that he/she uses to make decisions. Process models may include information about the process being controlled or other relevant aspects of the system or the environment (Leveson and Thomas, 2018).

B. **Feedback Control Loop:** A typical feedback control loop is shown in Fig. 1 and consists of the controller, actuator and sensor whose main objective is to control the behavior of a controlled process. The sensor sends information to the controller about the status of the controlled process thus creating streams of data, providing feedback information. The controller evaluates the sensor's data and tries to comprehend if the controlled process is in a desired, safe state, or not. The controller then, based on these models, decides if it is necessary to apply changes into the controlled process giving commands that will be executed by the actuator (Dokas et al., 2013).

C. **Hierarchical Control Structure:** A hierarchical control structure is a system model that is composed of feedback control loops where a controller in a specific hierarchical level of complexity imposes constraints to the behavior of the process it controls and takes feedback of the results of the constraints that were imposed. A hierarchical system consists of control structures, as shown in Fig. 2, and these structures interact with their environment, one level imposes constraints on the level below it, and feedback about its performance is transmitted back to the level above it.

When an element has specific properties, but its parts do not have them on their own, then **emergence** occurs. The properties or even the behaviors of an element, emerge only when its parts interact in a broader whole. The important aspect here, is that safety is an emergent property which means that safety emerges from the interactions of the components of a system (Leveson, 2011; Fleming, 2015). Thus, emergence is the idea that at a given level of complexity, some properties characteristic of that level (emergent at that level) are irreducible (Leveson, 2011).

D. **Safety Constraint:** Safety constraint is the constraint that a controller enforces on the behavior of the system. (Leveson and Thomas, 2018).

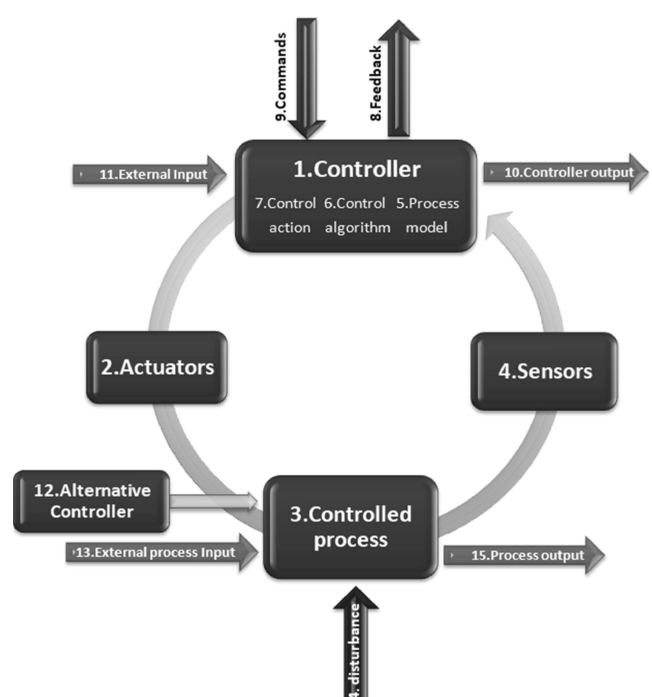

Fig. 1. A Typical Control Loop with its Entities.
adapted from Leveson & Thomas, 2018

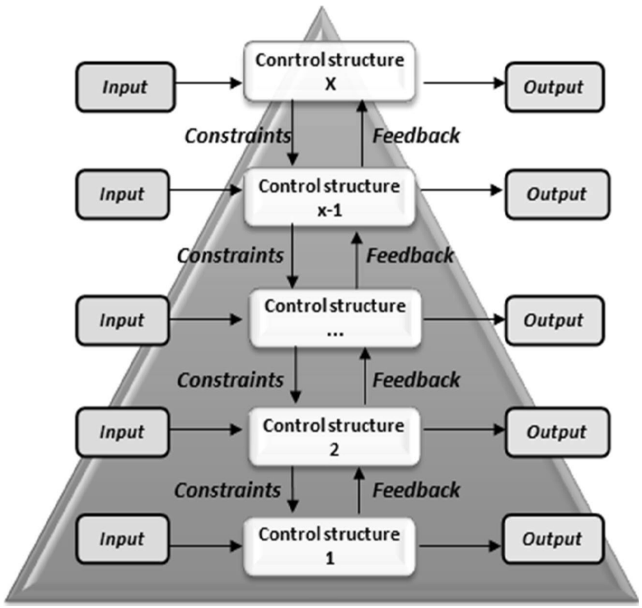

Fig. 2. Basic Features of a Hierarchical System (adapted from Mesarovič, D Macko, & Y Takahara, 1979 as cited in Fleming, 2015).

The utilization of STECA in the MIND VERSA methodology has the purpose of a) studying the system described in an emergency response plan, b) comparing its completeness against the systems' theoretic principles and c) identifying pathogens and loopholes in the plan that could be addressed in a future/updated version (i.e. inconsistent or conflicting information that may lead to hazardous behavior, undocumented assumptions, missing operational concepts that are required to understand safety and functionally-related behavior of the system (Fleming, 2015)). Within the concept of identifying pathogens, STECA has also the role, in the proposed methodology, to enhance the initial emergency response system described in the plan.

2.2. STECA method - steps

2.2.1. Identification of system level hazards and safety constraints

During the first step of STECA a preliminary hazard analysis takes place, in recognition of system's hazards that need to be avoided, within the concept of including the potential causes of those hazards, the effects on the system, the severity level of the hazards, and the supporting comments or recommendations (Vincoli, 2005 as cited in Fleming, 2015). A hazard, according to STAMP is ***"A system state or set of conditions that, together with a particular set of worst-case environmental conditions, will lead to an accident"*** (Leveson, 2011). After this hazard identification, the analyst translates the hazards into system's safety constraints.

2.2.2. Systematic control model development

The second step of STECA is composed of two sub-steps

1) First sub-step is the **identification of control concepts.** The analyst parses the informal-formal language of the text, or graphics in the plan and recognizes the entities which are defined in it, considering their basic roles, responsibilities, functions, and interactions with each other. Then the analyst places these entities as control elements into the corresponding feedback loops (i.e. actuators, controllers, sensors). Table 1 gives prompts of the properties of feedback loop elements that an analyst can use when reading (parsing) a text in a concept of operations (ConOps) within a document or plan (Fleming, 2015; Fleming and Leveson, 2016).

Table 1
Control-Theoretic Analysis of Text or Graphics (Fleming, 2015; Fleming and Leveson, 2016).

Source/ Subject	What is the primary subject of the text? What is the primary source of action that the text (or graphic) is describing?	
Role	Is the Source or Subject a Controller, Actuator, Controlled Process, or Sensor?	
Behavior Type	For the given role, which type (s) of behavior does it exhibit?	
	The Controller:	• creates, generates, or modifies control actions based on algorithm or procedure and perceived model of system • direct the process towards a reference • processes inputs from sensors to form and update process model
	The Actuator:	**• Translates controller-generated action into process-specific instruction, force, heat, torque, or other mechanism**
	The Controlled Process:	**• Interacts with environment via forces, heat transfer, chemical reactions, or other input** **• Translates higher level control actions into control actions directed at lower level processes (if it is not at the bottom of a control hierarchy)**
	The Sensor:	**• Transmits continuous dynamic state measurements to controller** **• Transmits binary or discretized state data to controller** **• Synthesizes and integrates measurement data**
Context	Provide a justification for categorizing the text (or graphic) in the chosen manner.	

2) The second, is the **system hierarchy synthesis step**, where the analyst: a) constructs the feedback loop hierarchy, based on the feedback loops identified and formed during the first step into a hierarchical control structure, and b) checks the consistency across hierarchy.

2.2.3. Systems-Theoretic analysis of model

After the initial control model is developed, the analyst identifies the potential **causal factors** and potential **hazardous scenarios** for each of the system's hazards (H-1, H-2, H-3…) i.e. hazardous scenarios that may lead to system failure. Three main groups of hazardous scenarios are classified by STECA:

- Scenarios due to incomplete control loop
- Scenarios due to gaps or conflict in safety-related responsibilities
- Scenarios due to lack of coordination or consistency among multiple controllers

For the analysis of these scenarios, the analyst asks questions such as:

a. Are the control loops complete? That is, does each control loop satisfy a Goal Condition, Action Condition, Model Condition, and Observability Condition?
b. Are the system-level safety responsibilities accounted for, or are there gaps?
c. Do control agent responsibilities conflict with safety responsibilities?
d. Do multiple control agents have the same safety responsibility (ies)?

etc. to analyze the system (Fleming, 2015).

After this procedure is done and both hazardous scenarios and causal factors are identified, all final and **improved safety constraints** (SC-1, SC-2, SC-3…) derive and the analyst can refine or modify the system's control structure and thus create an enhanced version of the initial contingency plan.

2.3. Dissimilarity measures

Similarity between two elements is the measure that determines the degree of similarity between them. On the other hand, **dissimilarity** between two objects is the measure that determines the degree to which the two elements are different. Ever since Jaccard (1901), a lot of binary similarity and distance measures have been proposed. Binary similarity and dissimilarity measures that consist of **binary vectors** are widely used in various fields and play a critical role during data processes. The binary vectors are representations of patterns and measure similarity or dissimilarity and distance between elements. (Seung-Seok et al., 2010).

The binary vectors, in order to be compared, need to have the same number of rows. So, a one-by-one relationship in the two vectors will be created between the binary data that shape the specific pair (Chatzimichailidou and Dokas, 2015).

In this paper the specifications defined in the emergency response plan are used to create a vector, the **plan's vector**. Then, a second vector is composed including STECA's results, the ***"enhanced"* vector**. The specifications of these vectors are compared line by line. The results of this comparison are then introduced to the **Rogers-Tanimoto** dissimilarity measure where a number is produced indicating how dissimilar the two vectors are.

Rogers-Tanimoto distance measure is given by the formula in the next equation:

$$RTd(I,P) = \frac{2S10 + 2S01}{S11 + S00 + 2S10 + 2S01} \tag{1}$$

It is a normalized dissimilarity measure and the minimum dissimilarity is "0" which means that the elements of two compared binary vectors are almost similar, while when dissimilarity of these vectors is "1", the vectors are almost dissimilar. In our case the comparison is between the enhanced and planned vectors where the enhanced vector has the value "1" except when some elements are considered redundant with the value "0", and the planned will have either value "0" or "1" in regard with the dissimilarity between them. The terms S00, S01, S10, and S11 in Rogers-Tanimoto Eq. (1), denote the total of corresponding (0 to 0), (0 to 1), (1 to 0), and (1 to 1) pairs of binary integers, of these two compared vectors (enhanced and plan's).

The Rogers-Tanimoto distance measure formula is used because it gives double weight to the dissimilarities between the two compared vectors, i.e. "2xS10", 2xS01" (Chatzimichailidou and Dokas, 2015).

After this comparison is done, a value is obtained indicating the distance between the vectors being compared. With this approach one can have a numerical view of the distance between the enhanced emergency response plan and the original plan and also *how far* the difference between their concepts lies. To sum up, the dissimilarity formula of Rogers-Tanimoto is used to create a value with the distance between the enhanced plan and the original emergency response plan. A depiction of the comparison of two binary vectors is given in Fig. 3.

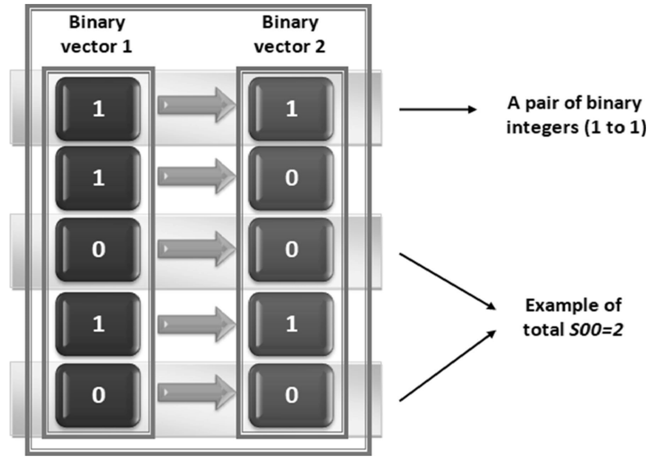

Fig. 3. Comparison between the two binary vectors: (vector 1 = plan's - vector 2 = enhanced) ().
adapted from Chatzimichailidou & Dokas, 2015

3. The proposed MIND-VERSA methodology

The proposed methodology consists of two steps and is graphically depicted in Fig. 4.

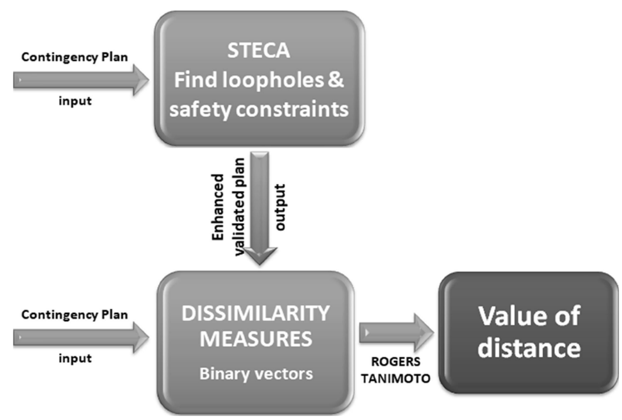

Fig. 4. Methodology steps to identify and determine the effectiveness value of emergency response plans.

3.1. Step 1: Enhancement of plan with STECA

STECA is used initially by the analyst to identify the loopholes of the emergency response plan and to impose new specifications to enhance the plan's efficiency. In this way problems in disaster response plans that may be realized after the occurrence of emergencies, are avoided, or addressed. So, the input for this first step is the contingency plan and the output is an enhanced plan that contains the improvements from STECA analysis, which have to be validated if possible.

3.2. Step 2: Dissimilarity measures

The second step is the calculation of dissimilarity measures. The purpose of calculating these measures is to show a numerical value to the designers of the system, of whether there is a deviation or not from what was initially planned and what ideally should apply and so help them to determine the plan's completeness. With this information at hand the designers will have the opportunity to alter the initial concept of operations (ConOps), according to their designing models, and can do that with low cost in both human lives and assets. Even more, the value from dissimilarity measures may be considered crucial when claiming liability in the event of plan failure.

After STECA results are obtained, two binary vectors are created. The first one, *the plan's vector,* will consist of all specifications from its systems theoretic analysis of the model and the other one, *the enhanced vector* will consist of both the plan's specifications and the enhanced ones' from STECA. This step takes as inputs the specifications from both the original plan and the enhanced plan. The specifications of these plans are transformed into vectors of 0 and 1 and the result is the total number of pairs: (0 to 0), (0 to 1), (1 to 0), and (1 to 1) of binary integers. Then the Rogers-Tanimoto formula is applied, and the output is a numerical value that represents the distance between the initial and the enhanced emergency response plan.

4. Case study

The proposed methodology, MIND-VERSA, was applied to the evacuation plan due to forest fires that was written by Greece's civil protection service (General Secretariat of Civil Protection, 2015). The plan defines the people responsible for deciding the evacuation based on the suggestion made by the Fire Department Officer. If the fire lies within the limits of a municipality, the one responsible to issue the evacuation command is its Mayor. If the fire affects more than two municipalities the ones responsible to issue the evacuation command are: the Regional Governor or the Deputy Governor of the Regional Unit. The course of action of the plan is shown in Fig. 5 where the decision-making process described, lies within the limits of one municipality and thus the Mayor is the one responsible for the decision. Analogous are the diagrams in cases where the fire affects more than one municipality or region.

The plan also imposes the creation of a memorandum of cooperation between the municipality and private transportation services (buses, taxis etc) and a memorandum of evacuation among the municipality's agencies by the Municipality's Bureau of civil protection. In the plan, 12 (twelve) decision making variables are mentioned according to which the Mayor decides whether to evacuate the affected area or not. These variables are shown in Fig. 5 from P1 to P12 and form the Mayor's process model. Some of them are: the number of people to be removed, the initial gathering place for citizens, the time required to alert citizens, the ability to control and manage traffic etc. The plan also mentions that the same procedure which is applied by the Mayor will apply proportionally when the decision on the organized evacuation of civilians is made by the Regional Governor or by the General Secretary of Civil Protection.

In Fig. 6 the hierarchical structure described in the plan is shown. As it is obvious, there is not a vertical hierarchical structure between the entities responsible for the decision-making of the evacuation. Instead

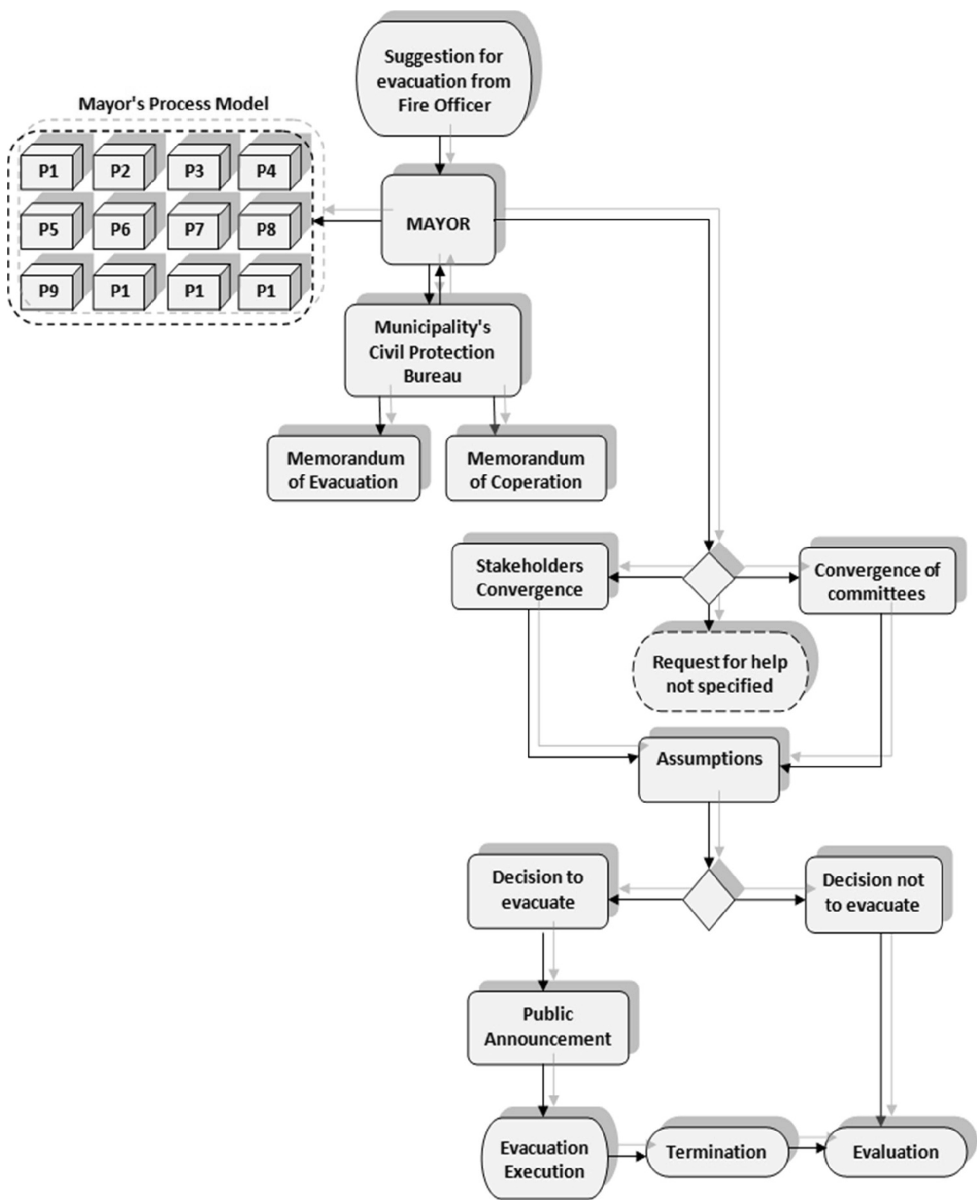

Fig. 5. Decision Making Process According to the Official Evacuation Plan.

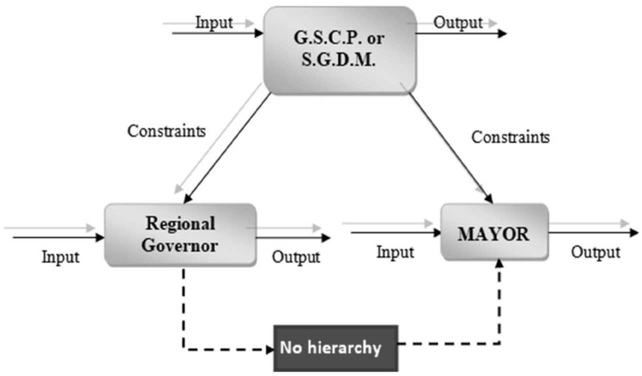

Fig. 6. Features of the Existing Hierarchical System (G.S.C.P. = General Secretary of Civil Protection, S.G.D.M. = Secretary General of Decentralized Management).

the only interaction between the levels of hierarchy appears when the General Secretary of Civil protection is to decide about the evacuation and then gives commands and enforces constraints both to the Mayors and the Regional Governor while these two act in parallel modes.

5. Application of MIND VERSA

5.1. Step 1: Enhancement of plan with STECA[2]

5.1.1. Identification of hazards and derived safety constraints of the system

Two high-level hazards of the system were identified according to the evacuation plan of Greece's General Secretariat of Civil Protection (G.S.C.P):

[H-1] The system does not evacuate when required
[H-2] The system does not evacuate effectively when required

Out of these hazards, the following system security constraints were defined.

[SC-1] The system must perform the evacuation when required
[SC-2] The system must perform the evacuation effectively when required

5.1.2. Systematic control model development

1)During the first sub-step (**identification of control concepts)** the text in the plan is analyzed (parsed) and is studied to a great extent. The entities which are defined in the plan such as the Mayor, the field officer of Fire Service, the police, the employees, port authorities, nursing institutions, decision variables etc. are identified together with their roles, responsibilities, functions and interactions. These entities are placed into the corresponding feedback loops that form the hierarchical control structure (i.e. actuators, controllers, sensors). An example of parsing and placing into position is given in Fig. 7 and the control concepts (entities) in the control loop gradually appear. Faded lines in this figure indicate missing control actions of the process.

2) The next step **(control information synthesis into system hierarchy)** includes tables that describe the responsibilities of each entity in the control loop with the Mayor, Regional Governor or Deputy Governor, General Secretary of Civil Protection or the Secretary General of Decentralized Management, as the controllers. Table 2 is an illustrative example that refers to the control loop that the Mayor has as controller.

The results of the analysis produce a set of controllers, with their own actuators, processes, and sensors. The resulting control loops though, do not represent a model of the entire plan by themselves because they are parts of the system. In systems theory it is inappropriate to analyze individual control loops and then make a determination about the overall behavior of the system (Fleming, 2015). So, the system's behavior can be determined in the context and functionality of all the components and their interactions together as a whole. The main issue here is the interconnections of how the individual control elements relate to each other. So, a hierarchical system, shown below, is proposed for the best functionality of the system because time scale, decision complexity, or authority, define a hierarchy in a ***vertical manner.*** So all interactions between the Mayor, the Regional Governor or Deputy Governor and the General Secretary of civil protection or the Secretary General of Decentralized management as controllers, are shown in Fig. 8 where G.S.C.P. stands for the General Secretary of Civil Protection and S.G.D.M. stands for the Secretary General of Decentralized Management.

5.1.3. Systems-Theoretic analysis of model

After gathering the appropriate information, **hazardous scenarios** and **causal factors** that correspond to *system hazards* (H-1, H-2, H-3…) and *system safety constraints* are identified and so **improved safety constraints** (SC-1, SC-2, SC-3…) are created to improve the existing plan. Some examples of dangerous scenarios, causal factors, and improved safety constraints with Mayor as a controller, which correspond to a specific hazard are given below:

Controller: Mayor
[H-2]
Dangerous Scenario A.1: The Field Officer of the Fire Brigade does not accurately define the boundaries of the evacuation area.
Scenario A.1.1:
- Field Officer believes it doesn't matter if the region boundaries are not defined accurately.

Causal Factors:
- Not well aware of the procedures provided by the General Secretariat of Civil Protection
- Field Officer is also charged with the fire extinguishing process.
- There is no available time

Scenario A.1.2
Field Officer does not have sufficient information on the boundaries of the Municipalities
Causal Factors:
- Does not know the area well
- Field Officer is newly transferred and has not studied about local Municipality's boundaries

Improved Safety Constraints [SC]
[SC-A.1.1.1] The Field Officer should have a good knowledge of the procedures provided by the General Secretariat of Civil Protection
[SC-A.1.1.2] The Field Officer should be able to act as a manager in multiple procedures
[SC-A.1.1.3] The Field Officer should act in a very short time
[SC-A.1.2] The Field Officer should be well aware of the area and the natural boundaries of the Municipality

[H-1]
Dangerous Scenario A.2: The Field Officer of the Fire Brigade does not make the suggestion for evacuation in time.
Scenario A.2.1:
He cannot find the Mayor
Causal Factors:
- The Mayor is missing or is sick or his phone does not work.
- There is no predetermined way of direct communication between these two.

Scenario A.2.2
He does not know whom to address to in the absence of the Mayor (e.g. Deputy Mayor? Regional Governor? Deputy Regional Governor? etc.)
Causal Factors:
- It has not been determined who replaces the Mayor in case of absence

Improved Safety Constraints [SC]
[SC-A.2.1] An alert or communication system between the Mayor and the Fire Brigade Service should apply.
[SC-A.2.2] The Field Officer should know who replaces the Mayor in a successive or a hierarchical manner

[2] Due to space limitations only some indicative parts of the analysis are presented here. For detailed results see Appendix A.

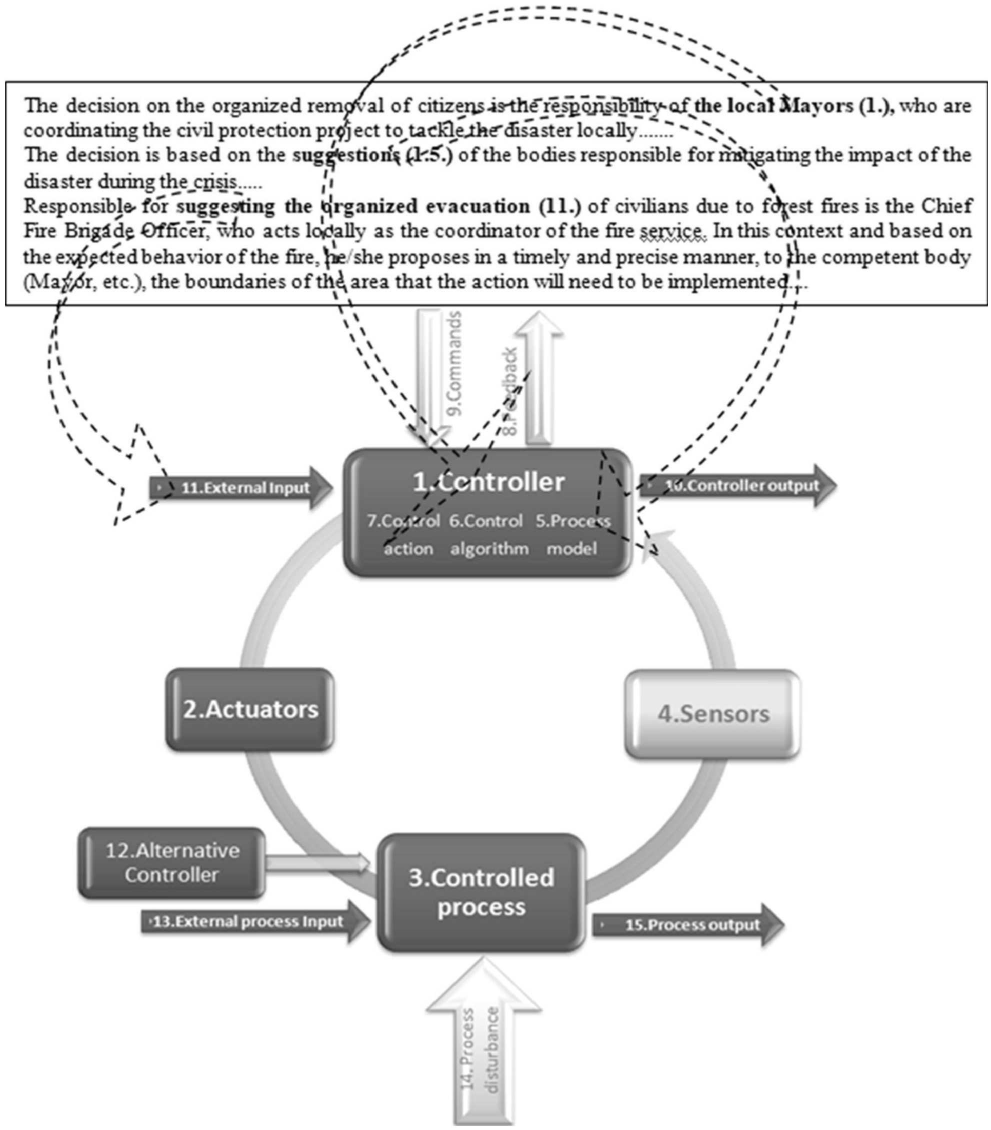

Fig. 7. (Parsing) System Control Loop for Case 1 (Blurry entities indicate missing control actions of the process).

5.1.4. STECA results

Thirty-one (31) loopholes of the plan are identified and also the corresponding **improved safety constraints** regarding all three cases (i.e. (a) the Mayor, (b) the Regional Governor or the Deputy Governor of the regional unit and (c) the Secretary General of Civil Protection or the Decentralized Secretary) are presented in detail in Appendix A. So, the enhanced plan's specifications are created and will be used in *dissimilarity measures* step.

5.2. Validation of STECA analysis results

These findings can also be validated by comparing them against the official investigation reports of the case study (dikastiko, 2019; Euronews, 2019; Kathimerini, 2019; Liberal, 2019; MacroPolis, 2019; The National Herald, 2019; Dasarxeio, 2019) where the prosecutors mentioned that *"the implementation of the plan has worked well in theory but in practice virtually nothing worked as planned, and the whole management has been spasmodic, without any coordination"*. In Table 3, SC1.1 to SC19 represent the improved safety constraints from STECA method while F1 to F10 represent the findings of the prosecutors. Detailed findings are shown in Appendix C. The boxes labeled "common" show that there is full matching between improved safety constraints from STECA and the findings of prosecutors while the rest of the lines show that additional improvements to the plan may be implemented. With the F1 vertical box it is indicated that the whole set of safety constraints (improvements of the plan) prove that there is a gap between theory and practice.

5.3. Step 2: Dissimilarity measures

With these new enhanced specifications of the plan, two binary vectors are created. The first one is *the plan's vector* and the other one is *the enhanced vector.* All described specifications of the plan with the improvements of STECA form the enhanced vector are now compared to the initial vector's specifications. As clarified in dissimilarity measures chapter, the comparison is done between the enhanced and planned vectors where the enhanced vector has the value '1′ except when some specifications are considered redundant and so assigned to value '0′, and the planned which will have either value '0′ or '1′ in regard with the dissimilarity between them. Table 4 poses an example of the comparison while analytical data can be found in Appendix B.

After applying this binary comparison, the next result gives the requested value:

S10 = 31, S01 = 4, S11 = 41, S00 = 0 (Appendix B) and the

Table 2
Description of Responsibilities in the Control Loop with the Mayor as the Controller.

S/N	Entity	Description
1	Controller	Mayor: 1. Coordination 2.Meeting with stakeholders 3. Convergence of MLCC 4.Evacuation decision 5. Announcement to the public 6.Evacuation order
2	Actuator	Police, Employees, Port Authorities
3	Cntl'd Process	Organized removal of citizens from the area which is estimated to be threatened by an evolving or imminent disaster due to forest fire
4	Sensor	Not mentioned
5	Process Model	Decision variables P1 to P12
6	Control Algorithm	• The risk of staying in is greater than the risk of evacuating (if Rs > Re then Evacuate) • Ensure timely organization of safe evacuation (if Time Evac = true then evacuate else not evacuate) • Early provision of means of transportation for evacuation (if Trans = true then evacuate else not evacuate) • Securing communications between stakeholders
7	Control Actions	• Order to inform citizens about evacuation (announcement) • Evacuation order
8	Controller Status	Not mentioned
9	Control Input	Not mentioned
10	Controller Output	Announcement to the public through local media
11	External Input	Fire Brigade Coordinating Officer1. Suggestion for evacuation2. Boundaries of the area to be evacuated
12	Alternative Controller	Regional Governor or Deputy Governor, General Secretary of Civil Protection or Secretary General of Decentralized Management
13	Process Input	Evacuation of Nursing Institutions, Children's Country camping sites, Holy Monasteries, Archaeological Sites, Hotel Units, Army and Security Forces Facilities
14	Process Disturbance	Not mentioned
15	Process Output	Evacuation of people, assets etc.

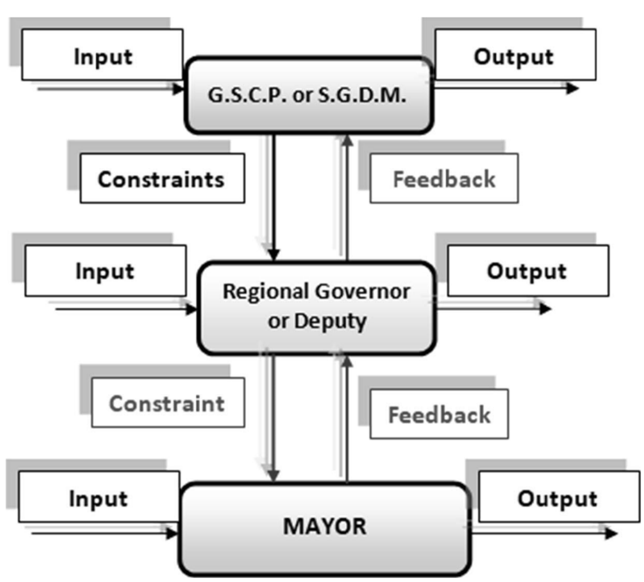

Fig. 8. Features of the Improved Hierarchical System (Missing Elements: Hierarchical Control Actions and Feedback of the Process).

mathematical formula is applied

$$RTd(I,P) = \frac{2S10 + 2S01}{S11 + S00 + 2S10 + 2S01} = \frac{2x31 + 2x4}{41 + 0 + 2x31 + 2x4} = 0,63$$

The dissimilarity value between the enhanced specifications and the initial ones is 0.63.This numerical value indicates the fact that the plan is in need of improvement from its initial concept **when it is compared against systems theoretic principles**, since there is a considerable deviation between the planned and enhanced vectors. The designers of the system are now able to prove that a change of plan is imperative and by taking into consideration all necessary data that were discovered during the application of MIND VERSA methodology they will be able to form a new version of the emergency response plan. Since this kind of **early warning value** of the plan can be imposed before the disaster, a great cost in human lives and assets could be avoided in the future, during or after the disaster, and financial resources could also be saved.

6. Discussion

MIND VERSA produces two types of results: 1) Enhanced emergency response plans which are updated versions of existing emergency response plans that have been enhanced by incorporating recommendations on how to address the loopholes, which were identified after analyzing each plan with the proposed methodology. 2) An evaluation number indicating how well "equipped" is the emergency response plan to help the system perform better during a real situation of emergency.

Scientific and/or social impact will be the gain from the utilization of MIND VERSA methodology that will also give the opportunity to the designers of emergency systems to enrich their understanding of crisis management and their capacity in developing emergency response plans, as well as to prepare and evaluate emergency response drills. Eventually, all society at large will benefit from the use of MIND VERSA in developing a more responsive and resilient crisis management system and thus enabling society to reduce vulnerability in emergency situations.

Even more, when it is not possible for the designers to alter the concept of operations due to extrinsic factors such as problems of plan financing, then in the plan itself a deviation value from what ideally should apply can be estimated. This value may be considered crucial when claiming liability in the event of plan failure. Overall, with the use of the proposed methodology it has been demonstrated that a plan can become enhanced and more efficient.

On the other hand, one may propose limitations of MIND VERSA methodology such as: (1) the way of how to validate the results. In the case described in this paper the results were validated after a disaster. It is not however viable to wait for a disaster to strike to evaluate a methodology, thus there is a need to evaluate emergency response plans with MIND VERSA utilizing the periodic drills. This is something that needs to be further researched; (2) the estimation of a smoothing factor: i.e. a plus or minus percentage of the plan needs to be researched in future work because in practice the plan may prove to have a fluctuating deviation from unpredictable factors not estimated during the design; (3) the estimation of the tolerable design limits in which the plan can be operable by its stakeholders as an efficiency factor. Finally, the system to be analyzed (i.e. emergency response plan) needs someone with expertise in order to understand its functions in depth. This means that the analysis of complex systems must sometimes be done in collaboration with its designers or stakeholders. Future work needs to be done to implement this methodology to different types of contingency plans in the field of safety and protection against natural and technological disasters. Some of them are forest fire protection plans, flood plans, as well as evacuation plans of high hazard industries.

7. Conclusion

After applying the proposed methodology in the evacuation plan, thirty-one missing specifications or loopholes, which made the emergency response plan **dysfunctional** in practice, were identified with STECA. Then, with the use of dissimilarity measures and Rorers-Tanimoto formula a value of 0.63 was calculated indicating the distance between the initial plan and the enhanced plan. These findings

Table 3
Validation Results' Checklist (STECA Method -"Mati" Prosecutor Findings).

S/N	Safety Constraints	F1 Gap Theory-practice	F2 Coordination problems	F3 Time	F4 Communication	F5 Lack of cooperation	F6 Public announcement	F7 Disorderly evacuation	F8 Problems with the chief of ground forces	F9 Control action	F10 Lack of feedback
1	**SC1.1**	**All safety constraints apply**	**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
2	**SC1.2**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
3	**SC1.3**								**Common**		
4	**SC1.4**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
5	**SC1.5**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
6	**SC1.6**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
7	**SC1.7**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
8	**SC2**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
9	**SC3**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
10	**SC4.1**				**Common**						
11	**SC4.2**				**Common**						
12	**SC4.3**				**Common**						
13	**SC5.1**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
14	**SC5.2**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
15	**SC5.3**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
16	**SC6**			**Common ς**							
17	**SC7**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
18	**SC8**									**Common**	
19	**SC9**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
20	**SC10**					**Common ς**					
21	**SC11.1**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
22	**SC11.2**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
23	**SC12**						**Common**				
24	**SC13**						**Common**				
25	**SC14**		**Common**								**Common**
26	**SC15**		**Common**								
27	**SC16**		**Common**								
28	**SC17**			**Common**				**Common**			
29	**SC18**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
30	**SC19**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								
31	**SC20**		**A d d i t i o n a l S T E C A i m p r o v e m e n t**								

Table 4
Part of the table of comparison between the two binary vectors: enhanced and planned.

S/n	Activity Description	Enhanced		Planned
1	The controller is responsible for coordination	1	→	1
2	The controller should call the meeting with stakeholders	1	→	1
3	The controller is responsible for convergence of MLCC etc.	1	→	1
4	The controller is responsible for the evacuation decision	1	→	1
5	In advance, a specific way of communication and coordination should also be identified with those responsible of the facilities inside the evacuation area (Nursing Institutions, Children's Excursions, Camps, Holly Monasteries, Archaeological Sites, Hotel Units, Armed Forces and Police Corps Units)	1	→	0
6	At the members of the stakeholders, the responsible ones for the livestock of the evacuated area should also be added	1	→	0
7	A Memorandum of Actions should be drawn up providing for actions on livestock	1	→	0
8	The actuators of evacuation process are the employees	0	→	1

reinforce the notion that the proposed methodology of this paper has the potential to be used effectively in the context of emergency response and management to evaluate emergency response plans and identify important missing specifications and loopholes and also to determine the level of efficiency of what is planned with the use of a numerical value. Therefore, it is concluded that **MIND-VERSA** can become a tool to improve disaster response plans and thus gain significant advantage before the occurrence of emergencies.

Additionally, the numerical value can also be used to support the designers of the system at **early stages,** during the concept of the plan, to help them form an enhanced version of the plan with low cost.

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We would like to thank also Apostolos Zeleskikdis for his comments on the mathematical part of the analysis.

Appendix A

Enhanced specifications (Improvements)

S/N	Safety Constraints	Description
1	SC 1.1	The Field Officer of the Fire Brigade must have proven good knowledge of the procedures provided by the General Secretariat of Civil Protection
2	SC 1.2	The Field Officer of the Fire Brigade should know whom he/she should address to and make his/her suggestion for evacuation
3	SC 1.3	The Field Officer of the Fire Brigade should be able to act as a manager on multiple occasions and processes
4	SC 1.4	The Field Officer of the Fire Brigade should be able to act quickly and in a very short period of time
5	SC 1.5	The Field Officer of the Fire Brigade should be well aware of the area in which He/She serves and the natural boundaries of the Municipalities and Regions
6	SC 1.6	The Field Officer of the Fire Brigade should know who successively replaces the Mayor or the Regional Governor
7	SC 1.7	The Field Officer of the Fire Brigade should know which senior hierarchical unit he/she will address to and make his/her suggestion for evacuation if communication is not feasible
8	SC 2	It is necessary that the plan ensures who is ultimately the one to whom the Fire Brigade Officer will make his/her suggestion for evacuation: to the Regional Governor or to the Deputy Governor?
9	SC 3	It should be clearly stipulated who is responsible for the Evacuation Decision (if needed): the Secretary General for Civil Protection or the Deputy Secretary General of Decentralized Management and also when and to which of those two persons the Field Officer of the Fire Department will make his/her suggestion for evacuation
10	SC 4.1	An alert-communication system between the Mayor, the Fire Service Dept., the members involved and the members of the Coordinating Committees. (including their replacements) should apply
11	SC 4.2	An alert-communication system between the Regional Governor or the Deputy Governor, the Fire Service Dept., the members involved and the members of the Coordinating Committees. (including their replacements) should apply
12	SC 4.3	An alert-communication system between the members of the Central Coordinating Committee (including their replacements) should apply
13	SC 5.1	A special meeting place in the Municipality or a mobile one should be determined in advance
14	SC 5.2	A special meeting place in the Region or a mobile one should be determined in advance
15	SC 5.3	A special meeting place in the Regional Unit or a mobile one should be determined in advance
16	SC 6	The response time of the system is a critical factor and the minimum time required for taking the decision for the evacuation process should be determined
17	SC 7	For the service agents involved in the evacuation process, working in a 24 h basis in shifts, should apply during the whole year
18	SC 8	The progress of Civil Protection Agency's work (and also the staffing) should be checked (a) by the Mayor at regular intervals (b) by the Regional Governor or the Deputy Governor at regular intervals because it is a critical Agency
19	SC 9	One of the key stakeholders in the meeting should be an environmental agency that will be able to measure the atmosphere, smog, air particles, etc.
20	SC 10	It is necessary to ensure the "common language" (training in the competence of the other stakeholders) between the bodies with different competencies
21	SC 11.1	It is necessary to ensure in the contingency plan who is the superior hierarchical unit of the Mayor and also to ensure that there is an interaction (orders, feedback, etc.) between the hierarchical superior and the Mayor
22	SC 11.2	It is necessary to ensure in the contingency plan who is the superior hierarchical unit of the Regional Governor or the Deputy Governor and also to ensure that there is an interaction (orders, feedback, etc.) between the hierarchical superior and the Regional Governor or the Deputy Governor
23	SC 12	A system of alerting the public by the use of technology (mobile phones, loudspeakers, etc.) should be established
24	SC 13	A Memorandum of Cooperation with the Media should be foreseen.
25	SC 14	The controllers (Mayor, Regional Governor, Deputy Governor, etc.) in order to be able to co-ordinate the parties involved, should have direct information from a specific person or persons (sensor) about the evolving situation of the evacuation at any time
26	SC 15	The controllers (Mayor, Regional Governor, Deputy Governor, etc) should in some way be given the possibility of giving direct orders to other bodies who are responsible to execute during the evacuation process
27	SC 16	An on-the-spot coordinator should be appointed to be able to give direct instructions to workers of different Bodies in order to achieve better coordination
28	SC 17	In the contingency plan, after taking into account the "time" factor, individual times should also be determined to achieve the purpose of the evacuation. Also, different scenarios should be considered: "If available Time < Required Time then go to contingency plan B.
29	SC 18	In advance, a specific way of communication and coordination should also be identified with those responsible of the facilities inside the evacuation area (Nursing Institutions, Children's Excursions, Camps, Holly Monasteries, Archaeological Sites, Hotel Units, Armed Forces and Police Corps Units)
30	SC 19	At the members of the stakeholders, the responsible ones for the livestock of the evacuated area should also be added
31	SC 20	A Memorandum of Actions should be drawn up providing for actions on livestock

Appendix B

Detailed Vector comparison

S/N	Activity Description (Elements)	Enhanced Vector		Planned Vector
1	The controller is responsible for coordination	1	→	1
2	The controller should call the meeting with stakeholders	1	→	1
3	The controller is responsible for convergence of MLCC etc.	1	→	1
4	The controller is responsible for the evacuation decision	1	→	1
5	The controller is responsible for the announcement to the public	1	→	1
6	The controller is responsible to give the evacuation order	1	→	1
7	The actuators of evacuation process are the police	1	→	1
8	The actuators of evacuation process are the employees	0	→	1
9	The actuators of evacuation process are Port Authorities	1	→	1
10	The process model includes the number of people to be removed	1	→	1
11	The process model includes the specification of means of transportation	1	→	1
12	The process model includes the Memorandum of Understanding of the Municipality's Civil Protection Bureau	1	→	1
13	The process model includes the Memorandum of Cooperation of the Municipality's Civil Protection Bureau	1	→	1
14	The process model includes the initial gathering place for citizens	1	→	1
15	The process model includes the time required to alert citizens after the decision is made	1	→	1
16	The process model includes the way of identifying and alerting citizens	1	→	1
17	The process model includes the ability to control and manage traffic	0	→	1
18	The process model includes ensuring communications between responsible authorities	1	→	1
19	The process model includes the reception and care of people being removed in selected safe places including medical assistance and psychosocial support.	1	→	1
20	The process model includes the time required to move away from the area (e.g. for 6 h) until the risk of forest fire is minimized	1	→	1

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(*continued*)

Detailed Vector comparison				
S/N	Activity Description (Elements)	Enhanced Vector		Planned Vector
21	The process model includes caring for the return of displaced citizens	1	→	1
22	The process model includes the suggestions of the bodies involved in the meeting	1	→	1
23	The process model includes the dangers of high temperatures, of smoke, of airborne particles etc.	1	→	1
24	The process model includes the disposal of floating media	1	→	1
25	The process model includes the Announcement in a foreign language	1	→	1
26	The process model includes contingency plans of camps etc.(by their administrations)	0	→	1
27	The process model includes the decisions for evacuation by controllers of other facilities (e.g. Hospitals, Archaeological sites, Hotels, Armed Forces and Security Corps facilities, Sacred Monasteries)	1	→	1
28	The control algorithm includes the risk of no evacuation is greater than the risk of evacuating (if Rn > Re then Evacuate)	1	→	1
29	The control algorithm ensures timely organization of safe evacuation (if TimeEvac = true then evacuate else not evacuate)	1	→	1
30	The control algorithm includes early provision of means of transportation for evacuation (if Trans = true then evacuate else not evacuate)	1	→	1
31	The control algorithm includes securing communications between stakeholders	1	→	1
32	A control action is to inform citizens about evacuation (announcement)	1	→	1
33	A control action is the evacuation order	1	→	1
34	A controller output is the announcement to the public through local media	1	→	1
35	External output is the suggestion for evacuation by fire Brigade Coordinating Officer	1	→	1
36	External output are the boundaries of the area to be evacuated	1	→	1
37	Alternative controller for Mayor: Regional Governor or Deputy Governor	0	→	1
38	Alternative controller for Mayor: General Secretary of Civil Protection or Secretary General of Decentralized Management	1	→	1
39	Process Input: Evacuation of Nursing Institutions	1	→	1
40	Process Input: Evacuation of Children’s Country camping sites	1	→	1
41	Process Input: Evacuation of Holy Monasteries	1	→	1
42	Process Input: Evacuation of Archaeological Sites	1	→	1
43	Process Input: Evacuation of Hotel Units	1	→	1
44	Process Input: Evacuation of Army and Security Forces Facilities	1	→	1
45	Process Output: Evacuation of people, assets etc.	1	→	1
46	The Field Officer of the Fire Brigade must have proven good knowledge of the procedures provided by the General Secretariat of Civil Protection	1	→	0
47	The Field Officer of the Fire Brigade should know whom he/she should address to and make his/her suggestion for evacuation	1	→	0
48	The Field Officer of the Fire Brigade should be able to act as a manager on multiple occasions and processes	1	→	0
49	The Field Officer of the Fire Brigade should be able to act quickly and in a very short period of time	1	→	0
50	The Field Officer of the Fire Brigade should be well aware of the area in which He/She serves and the natural boundaries of the Municipalities	1	→	0
51	The Field Officer of the Fire Brigade should know who successively replaces the Mayor	1	→	0
52	The Field Officer of the Fire Brigade should know which senior hierarchical unit he/she will address to and make his/her suggestion for evacuation if communication is not feasible	1	→	0
53	It is necessary that the plan ensures who is ultimately the one to whom the Fire Brigade Officer will make his/her suggestion for evacuation: to the Regional Governor or to the Deputy Governor?	1	→	0
54	It should be clearly stipulated who is responsible for the Evacuation Decision (if needed): the Secretary General for Civil Protection or the Deputy Secretary General of Decentralized Management and also when and to which of those two persons the Field Officer of the Fire Department will make his/her suggestion for evacuation	1	→	0
55	Prior notice must be given to an alert-communication system between the Mayor, the Fire Service Dept., the members involved and the members of the Coordinating Committees. (including their replacements)	1	→	0
56	Prior notice must be given to an alert-communication system between the Regional Governor or the Deputy Governor, the Fire Service Dept., the members involved and the members of the Coordinating Committees. (including their replacements)	1	→	0
57	Prior notice must be given to an alert-communication system between the members of the CCC (including their replacements)	1	→	0
58	A special meeting place in the Municipality or a mobile one should be determined in advance	1	→	0
59	A special meeting place in the Region or a mobile one should be determined in advance	1	→	0
60	A special meeting place in the Regional Unit or a mobile one should be determined in advance	1	→	0
61	The response time of the system is a critical factor and the minimum time required for taking the decision for the evacuation process should be determined	1	→	0
62	For the service agents involved in the evacuation process, working in a 24 h basis in shifts, should apply	1	→	0
63	The progress of Civil Protection Agency’s work (and also the staffing) should be checked (a) by the Mayor at regular intervals (b) by the Regional Governor or the Deputy Governor at regular intervals because it is a critical Agency	1	→	0
64	One of the key stakeholders in the meeting should be an environmental agency that will be able to measure the atmosphere, smog, air particles, etc.	1	→	0
65	It is necessary to ensure the “common language” (training in the competence of the other stakeholders) between the bodies with different competencies	1	→	0
66	It is necessary to ensure in the contingency plan who is the superior hierarchical unit of the Mayor and also to ensure that there is an interaction (orders, feedback, etc.) between the hierarchical superior and the Mayor	1	→	0
67	It is necessary to ensure in the contingency plan who is the superior hierarchical unit of the Regional Governor or the Deputy Governor and also to ensure that there is an interaction (orders, feedback, etc.) between the hierarchical superior and the Regional Governor or the Deputy Governor	1	→	0
68	A system of alerting the public by the use of technology (mobile phones, loudspeakers, etc.) should be established	1	→	0
69	A Memorandum of Cooperation with the Media should be foreseen.	1	→	0
70	The controllers (Mayor, Regional Governor, Deputy Governor, etc.) in order to be able to co-ordinate the parties involved, should have direct information from a specific person or persons (sensor) about the evolving situation of the evacuation at any time	1	→	0
71	The controllers (Mayor, Regional Governor, Deputy Governor, etc) should in some way be given the possibility of giving direct orders to other bodies who are responsible to execute during the evacuation process	1	→	0
72	An on-the-spot coordinator should be appointed to be able to give direct instructions to workers of different Bodies in order to achieve better coordination	1	→	0
73		1	→	0

(*continued on next page*)

(*continued*)

Detailed Vector comparison				
S/N	Activity Description (Elements)	Enhanced Vector		Planned Vector
	In the contingency plan, after taking into account the "time" factor, individual times should also be determined to achieve the purpose of the evacuation. Also, different scenarios should be considered: "If available Time < Required Time then go to contingency plan B.			
74	In advance, a specific way of communication and coordination should also be identified with those responsible of the facilities inside the evacuation area (Nursing Institutions, Children's Excursions, Camps, Holly Monasteries, Archaeological Sites, Hotel Units, Armed Forces and Police Corps Units)	1	→	0
75	At the members of the stakeholders, the responsible ones for the livestock of the evacuated area should also be added	1	→	0
76	A Memorandum of Actions should be drawn up providing for actions on livestock	1	→	0

Appendix C

Detailed Findings of Prosecutors After the Tragedy in "Mati" Area, Greece

S/N	Finding	Description
F1	Gap between theory and action	In theory everything worked very well, but in practice virtually nothing worked as planned, and the whole management was spasmodic, without any coordination.
F2	Coordination problems	Image of total confusion and absolute lack of coordination between the ones responsible
F3	Time	If the decision to evacuate had been taken at 17:00 pm, the chances of organized removal would have been "extremely positive".
F4	Communication	Absolute lack of communication.
F5	Lack of co-operation	Lack of co-operation of the stakeholders involved.
F6	Public announcement	The absence of any information to the residents of the area, who were left to burn alive.
F7	Disorderly evacuation	Under the circumstances, even disorderly evacuation would be preferable.
F8	Problems with the chief of ground forces	"complete confusion and ignorance of the real situation and the image of the fire front in the various settlements", "they did not know who the fire chief was any time"
F9	Control action	They attribute to the police a "formal" state of readiness prior to the fire, which "was only at the level of forecasts and documents, without actually being executed".
F10	Lack of feedback	The Region authorities had to ask for all the information needed to form an image of the situation.

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