Evacuation Planning as a Key Factor in Disaster Management: the contribution of the H2020 IN-PREP Action

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ABSTRACT

Emergency management of urban or territorial scale disasters can benefit from a new generation of applications that simulate mass evacuation. Most of emergency plans drawn for large scale emergencies, indeed, lack in quantitative assessments of the time the people need to escape from an active threat (flooding, forest fire, toxic spills, e.g.) and to reach a safe place.
The European Commission's H2020 Innovation Action IN-PREP [1] has developed a tool that gathers data to support decisions in emergencies involving large numbers of people. The tool was demonstrated for the first time in Spoleto (Italy) during a table-top exercise carried out on November 29, 2018. The exercise, simulating the occurrence of a HazMat leakage in urban environment, was organised by the Italian National Fire Corps. It aimed at providing first responders and emergency managers with a more efficient emergency planning, while contributing to improving preparedness and response to complex disasters in sensitive environments. The research demonstrated that traditional emergency plans are inadequate to deal with real case large scale emergencies, while the integrated decision support system developed by the IN-PREP action can already substantially help in reaching the goal set by rules and standards.

Keywords: Emergency Planning, Decision Support System, Mass Evacuation, Large Scale Disasters, Interoperability, Human behaviour.

1. INTRODUCTION

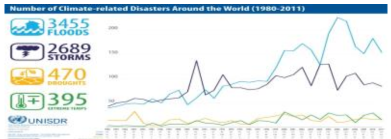

Fig. 1 Climate-related disaster in the period 1980-2011. UN Office for Disaster Risk Reduction. From [2].

According the United Nations Office for Disaster Risk Reduction (UNISDR), climate-related disasters are growing on a global basis [2].
More specialized data, like the vegetation fires in the US [3], show that the number of fires is decreasing with an increase of the areas burnt. In other words, the number of complex scenarios related to natural-caused emergencies is growing.
If we consider man-made emergencies, e.g., due to hazardous materials transport accidents or terrorist attacks, the issue of managing complex emergencies is evident, even if only for their

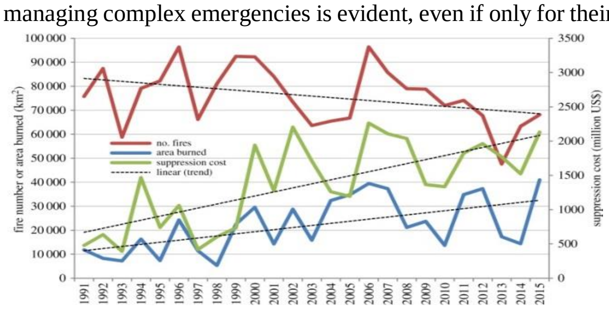

Fig. 2 Number of wildland fires and area burnt in the USA from 1991 to 2015. From [2].

effect on media and public opinion. In all cases, emergency management is often troublesome and frequently raises criticisms that affect public perception and policy choices (e.g., 2016 Great Smoky Mountains wildfires [4], June 2017 Portugal wildfires [5], 2018 Attica wildfires [6]).
In the framework of the research and innovation program Horizon 2020, the European Commission has selected the IN-PREP action, with the aim to develop a platform that can be used to help in planning emergency management through the integration of data, sensors and simulation tools. The software suite makes use of the EXODUS [7] mass evacuation simulation tools to apply - at urban scale - the same approach adopted by building fire standards to improve life safety.

2. COOPERATION IN COMPLEX SCENARIOS: THE WEAKEST LINK IN THE CHAIN

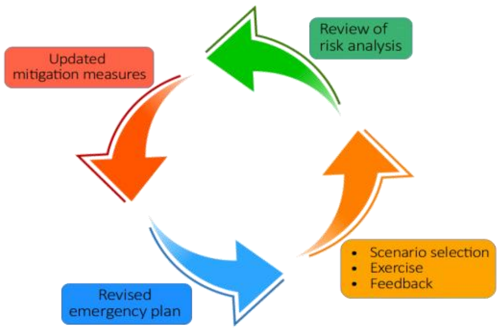

Fig. 3 The process of improving emergency plans.

The main peculiarity of the aforementioned crisis is the absolute need of cooperation between multiple agencies, far beyond the ones (e.g., police, fire and ambulance) used to cooperate in daily rescue operations. So that, when we look for the reasons why the management of disasters is sub-optimal, the main suspect is the preparedness. In such cases, emergency management is inadequate to the goals set by rules or legislation. The applicable regulations and procedures converge into an emergency plan which has been seldom applied (and challenged) by real emergencies, so that it is often raw and rigid, while most actors have not in-depth knowledge of the procedures and are not enough experienced into their roles. Even in the course of exercises, which should challenge the plan to detect weaknesses and improve it, the actors tend to apply the plan in a rigid, bureaucratic fashion, with a ritualistic approach. This is seldom the right approach for effectively manage emergencies.
Such considerations lead to wonder whether emergency plans are not efficient due to the poor skills of the involved parts and the low frequency and quality of exercises or, more probably, because they are not well designed by the authorities, which are numerous, with different background and very different approaches.
To overcome the issues exposed above, emergency planning should:

- be based on a shared analysis of the risks, supported by sound, reliable data, presented into an easy-to-understand way. Accessing such data, authorities with different background and criteria could find a common playground to agree on a more efficient plan. That implies that improving emergency management needs better tools that generate more complete data;
- define procedures, protocols and tools to share information and take real time decisions, as outcome of open cooperation between the involved parts. A list of the applicable procedures to draft an emergency plan is exposed in the standard NFPA 1616 Mass Evacuation and Sheltering Program [8].

3. BRINGING PEOPLE TO SAFE PLACES: BUILDING SCALE VS. URBAN SCALE

Due to a new legislative approach to civil protection (Codice della Protezione Civile [9]), the Italian National Fire Corps [10] is leading an effort in the field of urban-scale emergency planning, with the goal of applying to large scale evacuation the same approach adopted in the building fire safety regulation field. Such effort started with the EC-funded R&D project IDIRA [11]. Currently, safety planning of buildings can benefit from consolidated methods and tools which help the safety expert to assess the risk providing quantitative assessments of the risk reduction. In particular, the approach defined by the ISO standard with regards to the fire safety engineering approach to building safety in case of fire [12] [13], is based on a comparison between the time needed to escape the areas exposed to risk of fire effluents (RSET) and the time needed by smoke, toxic gases and heat to make the areas occupied by people untenable (ASET). In other words, to verify that a given safety performance of the building is met (the main target of the process), the expert has to compare the time needed to reach a safe place, against the time that the fire allows people to escape. As such, the expert makes three assumptions: 1) there is always a safe place, 2) the procedure has to ensure safety for all the occupants, and 3) it is possible to calculate the spread of fire effluents and the escape process of people.

Fig. 4 The process of defining an emergency plan commonly adopted in building safety.

It is evident that in the case of urban-scale emergency plans, these assumptions are far weaker: 1) it is not always possible to identify a safe place before the emergency: emergency plans select safe places, but only the emergency evolution dictates if they are still safe, moreover, the safest shelter could be outside the area covered by the emergency plan; 2) the evolution of the crisis could impose to leave people in a relative state of risk, if it is considered less of a risk than leaving the area (such cases normally justify a shelter-in-place instructions); 3) several models are available to calculate fire and smoke spreading and the evacuation process, but such models can generate reliable outcomes only if fed with the up-to-date and accurate data, which are not easy to access at short notice.
Some of the decisions mentioned above are not easy to be taken: leaving people in a relatively safe place within the danger area, while safer in the short term, could leave them at the mercy of unfavorable evolutions of the event, exposing them to untenable conditions, as the 2009 Black Saturday bushfires [14] have demonstrated. Such cases highlight that critical decisions are necessarily based on the situation awareness, which relies on the available data, including any forecast on the evolution of the threat (e.g., if the weather forecast predicts a wind direction change able to move the heavy toxic cloud from the area in the short term, then it may be safer to issue instructions to shelter-in-place and move to a higher level in the building, waiting for the cloud to move away and the air to clear). It is evident too that the tools which generate data and forecasts have to be reliable (as the outcomes have to be clear and actionable), because important decisions may heavily rely on them. As such, only the availability of tools capable of giving an adequate level of precision could improve the quality of emergency plans, giving them more flexibility in the course of complex emergency scenarios.

4. THE NEED OF A NEW APPROACH TO THE EMERGENCY MANAGEMENT CYCLE

One of the areas that could benefit from the use of modelling tools is the emergency planning process. When the analysis of risks of the area of concern has been completed, the attention moves to the mitigation measures. Since risk is a function of Hazard, Exposure and Vulnerability [15], the mitigation measures will have to impact on those factors, namely, on hazard (only for man-made risks) (e.g., imposing limitations to the quantity of hazmat transported), on vulnerability (e.g., informing the population on how to self-protect) and/or on exposure (e.g., evacuating the exposed population).

In the case of urban-scale emergency plans the analysis and revision of risks is a complex task. The number of variables and parameters to be taken into account in identifying the most representative scenarios is a multitude (e.g., type of event, location, weather, population distribution, only to cite a few).

According to the current process adopted in building safety, risk analysis is aimed at defining a manageable number of scenarios, the worst reasonably possible ones. To obtain such scenarios, emergency planners assign values based on experience and judgement to the many parameters. But even being the plausible worst-case scenario, such scenarios will not represent many other ones that, while being less severe, will be so different from the reference scenario that will need different decisions. This is the reason why both the initial analysis and the exercise feedbacks could remain limited in scope. As soon as the planner arbitrarily assign 'reasonable' values to some parameter, they fall into the trap of obtaining exactly the feedback they were looking for.

Such limitation could be compensated through the introduction of an innovative chain of IT tools and models (i.e., able to accept as input the output of the previous ones), able to ensure easy access to real/realistic data, so as to run a high number of scenarios and generate equally numerous outcomes.

Finally, generating a high number of possible scenarios is not enough: their analysis will have to be manageable too, so that another tool devoted at clustering the outcomes and facilitate their analysis is needed. Such a tool will make it possible to analyze the collective outcomes of the other ones and iteratively evaluate the potential impact of different mitigation measures so as to revise the risk analysis. This process should be able to generate a "convolution" of many different outcomes, hopefully including unexpected but plausible scenarios, the ones which they fail to detect now.

The emergency plan that will be generated through the process previously described will hardly fit into a document: the number of input and the consequent number of possible outcomes would make the document unmanageable and impossible to interpret quickly in the time frame available. Instead, such a plan will probably evolve into a decision support system (DSS), able to access real/realistic data in (quasi) real time at need and present a manageable number of possible measures to take, which will of course be strictly linked to the response tools in place (e.g., available alerting systems and pre-formatted messages to alert and instruct the population for the considered scenarios).

In the framework of the IN-PREP action, the approach briefly described above has been concretely applied to a specific type of incidents: the release of toxics from fixed infrastructure or transport systems involving an urban area.

5. A CASE STUDY: EMERGENCY MANAGEMENT AND PLANNING IN HAZMAT INCIDENTS

The National Toxic Substance Incidents Program (NTSIP) reports [16] that during 2013, an estimated 14,175 incidents occurred across the United States, with 1,527 injured persons, 37 of whom were fatalities. Injuries can occur if the spilled chemical readily volatilizes and exposes a large number of people before they have time to evacuate or shelter in place. Therefore, results show that future response plans should target reducing exposure following a volatile chemical incident.

The HSEES 2009 annual report [17] analyses the 260 events (of 3,419) for which evacuation status was reported. Of these evacuations, the majority (82.3%) were from the building or affected areas of the building. Fewer evacuations were from a circular area surrounding the event generated by computer or defined by investigator (10.4%), areas downwind or downstream (2.8%), or a circular and downwind or downstream area (1.2%). Sheltering-in-place was ordered in only 34 incidents (1.0%).

The data reported above further demonstrates the difficulties for emergency managers at issuing instructions for sheltering-in-place. When dealing with a toxic agent, the population want to escape as soon and as far as possible, and the emergency manager wants the same too – in fear of unforeseen circumstances where the scenario deteriorates and people remain trapped. Unfortunately, the analysis of the outcomes of past evacuations demonstrates that the risks of evacuation was not properly considered (most notably, the massive evacuation of Fukushima, where "Official figures show that there have been well over 1.000 deaths from maintaining the evacuation, in contrast to little risk from radiation if early return had been allowed" [18]).

For the reason reported above, when considering their personal liability, emergency managers could find the safer option being to order an evacuation. This consideration will remain valid only up to when it will be assumed that they could not foresee unfavorable evolutions of the event. But this may change: as soon as the available forecast tools will be more consolidated, used and accepted, the related liability may change too.

Further level of complexities is added when considering vulnerable people: as clarified by the HSEES 2009 annual report [17], the proximity of a chemical release to vulnerable populations is a concern because these populations may need additional time or assistance during an evacuation and may be more sensitive to the effects of a particular chemical. Therefore, identifying vulnerable populations prior to the occurrence of a hazmat incident is critical to ensure that they receive additional assistance during an evacuation or following a shelter-in-place order. Examples of places where vulnerable populations may be present include residences, schools, hospitals, nursing homes, licensed day care facilities, or recreational areas (e.g., parks). The most frequently reported location where acute chemical spills could affect vulnerable populations was residences (n=3,480 within .25 mile from the acute chemical incident), followed by day care centres (n=541) [16].

6. THE H2020 IN-PREP ACTION APPROACH

The IN-PREP [1] innovation action has been selected from the European Commission to improve common response capacity in disasters through better preparedness. To focus the effort throughout the action progress, three Table-Top Exercises and three Demos have been planned:

- 1st TTX: HazMat in urban environment table-top exercise, Spoleto (IT), 29 NOV 2018 (deployed);
- 2nd TTX: Sea-land table-top exercise, Savona (IT), JUN 2019;
- 3rd TTX: Massive flood table-top exercise, Zwolle (NL), OCT 2019;
- 1st Demo: Cross-border terrorist attack demonstration, Belfast (UK), DEC 2019;
- 2nd Demo: Earthquake, forest fires, cascading failures demonstration, Spoleto, FEB 2020;
- 3rd Demo: Large fire & refugee crisis in Rhodes, (GR), APR 2020.

7. EXODUS LARGE SCALE EVACUATION MODEL

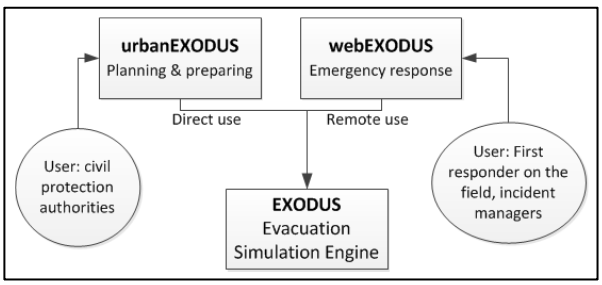

Fig. 5 The use of urbanEXODUS, webEXODUS and the EXODUS engine

The evacuation simulation model used during TTX1 is EXODUS [7]. The EXODUS large scale evacuation model is an Agent Based Model (ABM) micro-simulation tool capable of simulating the evacuation of large populations – measured in the tens or hundreds of thousands – from large scale environment – measuring many square kilometers. It is based on the buildingEXODUS software [19] and consists of three main components: urbanEXODUS, webEXODUS and the EXODUS engine as shown in Fig. 5. urbanEXODUS was developed to enable the EXODUS engine to easily represent large scale urban spaces. It is capable of receiving geospatial vector map data from OSM XML file and converting it into a virtual representation of space that is suitable for modelling pedestrian evacuation. It is capable of producing simulation output in the form of shapefiles representing the movement of the population that can in turn be published on GIS servers aiding in the visualization of simulation output on web-based GIS interfaces. The main purpose of urbanEXODUS is to aid in the pre-incident planning and preparation phase by simulating various *what-if* evacuation scenarios. webEXODUS is a GIS based web interface that was primarily developed to be used during an incident as a tool to aid crisis managers in their decision process as they attempt to mitigate the effects of an incident.

The EXODUS engine receives input from either urbanEXODUS or webEXODUS, performs the simulations and returns the results. Within the EXODUS engine the population is represented as individual agents with each agents being defined by a set of attributes. These attributes broadly fall into four categories: physical (e.g. age, gender, agility, mobility), psychological (e.g. patience, drive, response time), experiential (e.g. distance travelled, travelling time, time waited in congestion) and physiological (e.g. respiratory rate, impact of narcotic and irritant gasses, impact of heat). Each agent can have their own evacuation agenda or follow the currently defined evacuation procedures. EXODUS is stochastic in nature meaning that variation in the output results can be observed as multiple simulations are run. This represents the variability of human behavior and human decision processes. EXODUS produces a plethora of output data including both quantitative and qualitative data. It produces a visual representation of the entire evacuation process depicting the movement of the agents towards the exits, the overall evacuation times, the usage of paths and assembly points, the time the agents remained stationary due to congestion, the distance travelled, the impact that hazards have on the population, etc. This amount of data allows crisis managers to assess the validity of existing evacuation procedures, test numerous *what-if* scenarios and predict what may happen during a real incident.

8. TTX1 HAZMAT LEAKAGE IN URBAN ENVIRONMENT

The approach described previously has been applied for the Table-Top Exercise in Spoleto, November 2018. For several months before the TTX1 National Fire Corps officers have been working with the Municipal Civil Protection Authority to identify the variables to consider for a CBRN scenario in the urban environment in Spoleto.

To ensure consistency, a specific scenario of interest was defined, so as to clearly identify the parameters to be fed to the modelling tools (i.e. evacuation, hazmat propagation simulation, weather forecast). Then the variability of input parameters was extended considering multiple input data to stress test the approach described above and to obtain multiple scenarios.

All the scenarios started from a single non-intentional incident: a truck carrying hazardous material (Chlorine or LPG) capsizes within an urban area. The whole exercise was assumed to evolve based on procedures that could be applied with the resources realistically available at specific dates and hours. The models were fed with real/realistic data, taking into account the possibility that such data could be realistically accessed in the time available by the crisis managers.

The schema of fig. 6 synthesizes the role of such parameters as follows:

- **Modelling area**: careful definition of the area to be modelled within the EXODUS evacuation tool is needed to limit time and CPU power required to prepare the base map (i.e. imported and "cleaned" road network, from OpenStreetMaps), define borders and "exits" from the area, and gathering points as well as to run the simulations. The area defined for TTX1 included down-town Spoleto and included 6,876 residents, associated into 3,520 families.

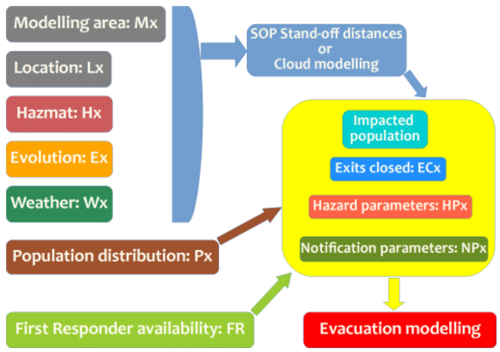

Fig. 6 The process/architecture adopted in the IN-PREP project to improve emergency management.

- **Location**: three accident location were selected, even if only one was taken into account for the TTX1.
- **Hazmat**: two hazmat were considered: Chlorine, a toxic substance which does not ignite, but remains buoyant harming people in its path; and LPG which is flammable.
- **Evolution**: four release quantities and durations for Chlorine (135, 720, 1170 and 1308 kg) and four other cases for LPG were considered (no leak, leak of LPG in liquid phase, jet-fire fueled by a leak of LPG in gaseous phase, fire fueled by a leak of LPG in liquid phase).
- **Weather and Population distribution by date/time of day**: The incident was assumed to take place on three days representing different seasons and weather conditions. Weather forecast over 6-8 hours after the event time were calculated through the U.S. National Oceanic and Atmospheric Administration HYSPLIT [20] web application. While having many limitations (e.g., the spatial resolution is quite coarse: 100 meters), such model could be used by an unexperienced person in real time, obtaining forecast in real time too. As such, it could be used by first responders with minimal training in the very first phase of the considered event. In all cases the population considered included people at home and office, hotel guests and people on the road, both for the daytime and night-time case.
- **SOP Stand-off distances or Cloud modelling**: the scenario depicted from all the parameters described previously determined the stand-off distances for rescuers and the public. For the LPG scenarios the distances were derived from the WISER app and software [21], while for the toxic it was used a "level of concern" (LoC) set equal to the AEGL-1 value [22].

Using the weather model described above, a kinematic spreading of the toxic was simulated, allowing for the creation of scenario-dependent time series of equal-concentration shapes (adapted to take into account the resolution data available and its applicability to the generic scenarios considered), that were rapidly proposed to the emergency managers as cordons/Stand-off distances for the population to be applied.

- **First responder availability**: a realistic first responder availability as a function of date and hour for the selected days was considered. This included their role and appropriate activation sequence and distance from their base.
- **Exit closed**: the cordons/Stand-off distances impacted on the modelling area exits. Both the spontaneous behavior of people aware of the danger as well as the impact on them of the instructions provided were represented. The selection by the population of the exits and/or the gathering points, which did not bring to safe places anymore, were "penalized" by a simulation that deemed them unfavorable within the scenarios.
- **Hazard parameters**: the evacuation model allowed for the calculation of time-distribution of the exposure of the population to risk for all the LPG scenarios and of the potential impact on health in case of chlorine propagation. To do the latter, the model received as input the scenario-depending time series of iso-concentration shapes based on two toxic concentrations: AEGL-1 and AEGL-2 [22].
- **Simulation stop times**: for each scenario the evacuation simulation ended at the first-time step where the hazard parameters fell below the previously-mentioned thresholds.
- **Notification parameters**: Egress times strongly depend on the time needed for people to become aware of the risks: to obtain realistic outcomes it is crucial to model the different notification methods available and reasonably used to warn people to evacuate from an area. For TTX1 the notification methods taken into account included: 1) the most common soon after the event, based on officers' direct alert, by ringing the intercom, and 2) Automated Phone Call systems (or texts).

Even limiting the input parameters as specified above, it was possible to obtain 32 different scenarios with equal number of evacuation simulation outcomes.

Due to the limited available time, however, it was not possible to develop a dedicated interface to present all the available modelling outcomes: these were presented as separate tables similar to the one shown in Fig. 7.

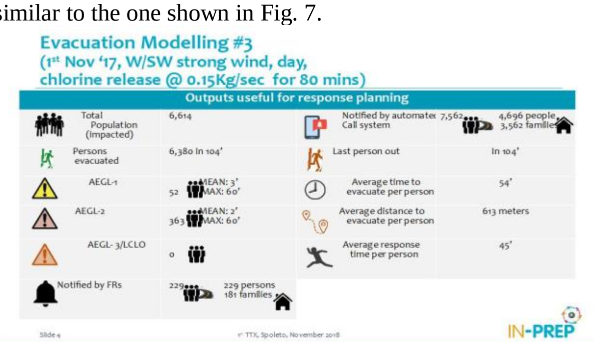

Fig. 7 Screenshot of the information produced by the IN-PREP platform in case of emergency evacuation

The exercise evidenced the activities to be pursued to further improve the outcomes. It was agreed that further issues will be addressed into the action framework, e.g., taking into consideration Hospital and hospice evacuation, places of interest (offices, cinema, theatre, restaurants, shopping centers, etc.), public staircases and lifts, road pavement type and traffic barriers and hurdles.

The innovative features implemented into the mass evacuation simulation tool generated a wide set of results: between others, it was quantified the relative efficiency of the different notification systems, the average time to evacuate per person and the potential impact on the safety and health of citizens for each scenario. As a consequence, the concerned Authorities are evaluating the impact on their emergency plans: e.g., the Municipal Civil Protection Authority has been intensifying its efforts to implement more and more efficient mass alerting systems, as well as preparing alerting message schemas to be used in the different scenarios; while the Health Authority is considering the potential impact of those scenarios in terms of victims, so as to adapt the applicable procedures.

Moreover, it became clear that it is possible to apply at urban scale the approach adopted by building fire standards to improve life safety, as well as that future urban-scale emergency plans will evolve into a comprehensive DSS, able to access reliable and updated data in real-time and suggest the actions to take to best protect the population, basing on scientific-based models

9. CONCLUSION

In the framework of the IN-PREP action, the Italian National Fire Corps led the efforts to demonstrate that higher quality emergency planning is not only possible, but feasible and sustainable in the short term. The related activities coalesced around the first Table-Top Exercise deployed in Spoleto in November 2018, which simulated a HazMat leakage in urban environment. The scenarios taken into consideration forced a first integration of data and simulation tools concretely available in a timeframe compatible with the cases considered, within the applicable regulation framework.

To further facilitate the process, the action activities to come will focus on standardization too, so as to interface simulation models with reliable data repositories. Between others, it was agreed to work on a standard format for record offices to exchange actual personal data with evacuation models in real time when needed for rescue purposes as well as preparatory exercises.

More importantly, the effort and the simulation results demonstrated that the sheer number of possible scenarios makes traditional, paper-based emergency plans useless. In fact, they cannot take into consideration the many parameters of the real case emergencies and cannot access to reliable forecast, so that they are of no use when some of the most difficult decisions have to be taken (i.e. the extent of the evacuation or shelter-in-place instructions to be issued in the course of the scenario evolution). The two residual years of the IN-PREP action will further explore this venue so as to highlight the critical issues to raise and where to focus research initiatives to come.

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