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Report No: D3.2

Emergency management plans from task 2. A reference plan for emergency management including: processes; activities; actors; resources; decision variables; decision procedures.

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Contents

1. Executive Summary

This deliverable is focused on the capability of San Raffaele Hospital (OSR) to respond to a terrorist attack against it. It builds on the previous deliverable (D3.1) which concerned the risk of an attack as expressed by hazard and vulnerability assessments conducted with SVA methodology. The OSR Emergency Management Plans (EMPs) were analysed in terms of both Internal and External emergency management, benchmarking these plans with the ones of other European Hospitals of the same size and type and of some other non-health Critical Infrastructures available in the literature.

The purpose was to understand where OSR's already existing plans:

1) Seem to have strengths and weaknesses;
2) be modelled and used to simulate the response to terrorist attacks according with the selected scenarios (D 3.1);
3) be effective in managing a terrorist scenario.

The results were:

1) OSR's External plans are more developed than their internal ones, as is likely to be the case with other hospitals.

2) both the Internal and the External EMPs can be modelled using IDEFØ and this model can be used for simulating the response to terrorist attacks according with the selected scenarios (D 3.1) with the assistance of CPLEX software

3) with respect to the specific threat of terrorist attacks at OSR, EMPs show evident weaknesses and appear inadequate to face such a scenario. This is because:
   - the plans do not consider terrorism as a real risk (terrorist attack is not even considered as hazard in the High Value Activities);
   - the open access nature of a hospital makes it vulnerable.

These findings appear to tally with the state of the Health sector in the EU as described in previous THREATS project deliverables (WP1D3, WP1D4, WP2D1).
Possible recommendations that can be made include:

1) Considering terrorism as a potential threat, assessing that risk and putting in place possible countermeasures for mitigation, preparedness, response and recovery;
2) Recognising and responding to the risk that arises from being open access. Possible measures to harden a hospital against a terrorist threat would include:
   - Increasing the level of security, implementing measures like prevention of unauthorized access to the hospital, security checking for vehicles and people, "lock down", "evacuation", "shelter in place", as effective options to increase the protection;
   - These measures are most effective in buildings that necessarily require public access when applied as a layered approach to security; no single layer will fulfil all needs but concentric layers work together to mitigate multiple risks.
3) Preparedness is key and the THREATS project encourages actions aimed at promoting awareness, training and simulation of potential terrorist scenarios among the hospital personnel. Preparedness needs to ensure sufficient resilience, within the hospital resource pool to recover critical components, within the Maximum Time of Permissible Outage. Personnel need to be educated, informed, trained, rehearsed and exercised to respond to emergencies, and this should be embedded within the hospital culture from top down. These will include measures to help to deter, detect and respond, as described in the THREATS toolbox (D1.6).

2. Introduction

The main themes of this deliverable are:

1) to present the work done to assess San Raffaele Hospital Emergency Management plans (both for internal and external emergencies);
2) to report on the benchmark between these plans and the ones of other European Hospitals of the same shape and type and of other non-health Critical Infrastructures (airports, schools, industries…) available in the literature;
3) to explain how San Raffaele Emergency Management plans have been evaluated in terms of capability to manage a terrorist scenario and to introduce some preliminary results and possible early suggestions on how to increase the hospital resilience;
4) finally to show how VISIO, the tool selected in Task 1 for modelling San Raffaele Hospital's assets, is suitable also for modelling the Emergency Management plans (static model) as well as the CPLEX software (dynamic model) to simulate the hospital activation in case of terrorist attack, allowing to analyse the outputs of the simulation of the selected scenarios (D3.1) and deducing the weak points and the possible countermeasures to increase the resilience of the hospital. Any output depends of course on the inputs, and in this case the inputs will come from the oncoming Task 3 (Hospital processes measurement and evaluation). Section 4 of this document gives a preliminary idea about how CPLEX software application (mathematical linear programming techniques) will be used in searching for optimization and solving complex decisions of moving resources or patients flows, in conditions of activation of the Hospital Emergency Management plan (Task 4: development of decision making tools for mitigation of terrorist attacks), and in addressing the simulation of the ability of the existing San Raffaele Hospital's Emergency management plans to manage the selected (D3.1) terrorist scenarios (Task 6: simulation of several scenarios involving different measures to enhance the security).

To summarize:

- Section 3 will deal with the definition and best practices of Emergency Management Plan, in particular related to hospitals.
- Section 4 will refer to the San Raffaele Hospital Internal and External Emergency Management plans and their ability to respond to a terrorist scenario.
- Section 5 will give a quick snapshot on how the VISIO model and the CPLEX software will be used in the next WP3 tasks to simulate the selected (D3.1) terrorist scenarios allowing the team to recognize the weaknesses and produce recommendations for a more resilient hospital.

3. Definition and Best Practices about Emergency Management Plan (EMP)

3.1 Definition

The Emergency Management Plan (EMP) or Disaster Management Plan (DMP) is the plan through which communities or single installations reduce vulnerability to hazards and cope with emergencies/disasters (Drabek, 1991). The EMP (DMP) aims to recognize and estimate the risks of disasters (risk assessment), prepare activities which eliminate or reduce the probability of occurrence of the disaster events (prevention), and/or mitigate the consequences of predictable hazards (preparedness), protecting populations and property, and restore as quick as possible the ordinary activity affected by disasters (IFRC: International Federation of Red Cross and Red Crescent Societies). According to Emergency Management Framework of Canada, the management of emergencies concerns all hazards and risk management measures which can reduce the vulnerability to hazards.

3.2 Characteristics

Blanchard et al. (2007) proposed eight principles to guide the establishment of emergency management plans. The summary provided below lists the eight principles and a brief description of each one:

- Comprehensive: All hazards, all phases, all stakeholders and all impacts relevant to disasters should be taken into account.
- Progressive: Emergency managers anticipate future disasters and take preventive and preparatory measures to build disaster-resistant and disaster-resilient communities.
- Risk-driven: Emergency managers use the principles of emergency management plans to decide how the available resources can be used reasonably and effectively.
- Integrated: Emergency managers organize the concerted efforts of different departments and organizations.
- Collaborative: Emergency managers should inspire trust among the team members, build a good team atmosphere, and make the communication easier and so on. All these factors have a positive impact on the effective collaboration.
- Coordinated: To accomplish a common purpose, the activities of all relevant stakeholders should be organized and synchronized by emergency managers effectively.
- Flexible: Emergency managers can deal with difficult problems with different methods according to the specific situation.
- Professional: To evaluate the emergency management plans, several approaches can be used. These approaches should be integrated and consider the following factors, education, training, experience and continuous improvement possibility.

Even though disagreements exist for the division of phases of the disaster management plan, most of the researchers concur the following four phases: mitigation, preparedness, response, and recovery or reconstruction (Altay and Walter, 2006). They constitute the “Disaster management cycle” (Figure 1). The activities in the mitigation and preparedness are the pre-disaster activities. And the activities in the response and recovery are the post-disaster activities. The explanation of these four phases and the typical activities involved in each of these four stages are as follows:

- Mitigation: Mitigation phase serves the purpose to minimize the number of casualties and reduce the loss of property when the disaster really occurs. Thus the management of national stockpile, the organization of logistics, the resource prediction, and so on, belong to the mitigation phase. The mitigation phase also concerns laws and policies to be taken to prevent the disaster. Therefore, the phase involves the government policies and laws more than the direct participation of logisticians (Cozzolino, 2012) especially at the

National level. At the level of the installation it may be desirable to identify areas of criticality and focus effort and resource on those areas.

- Preparedness: Preparedness gets all relevant stakeholders ready for the disaster. The details of the emergency management plans are completed in this phase. The necessary capabilities will be built up in this phase. According to Paul (2008), preparedness measures include: communication plans, maintenance and training of emergency services, development and exercise of emergency population, warning methods combined with emergency shelters and evacuation plans, stockpiling, streamline food supplies, and other disaster supplies. It is desirable to exercise in order to test the plans at operational level.

- Response: Response includes the arrangement of resources and emergency working procedures according to the emergency management plans to protect the life, property, and environment. Factors that need to be considered include the coordination of response and recovery by a competent authority, damage limitation and the media strategy.

- Recovery or reconstruction: The main objective of this phase is to restore and reconstruct the affected area after disasters. All the efforts which can restore the affected area to its normal state are included in this phase, such as reconstruct of the building and re-employment of the workers. An understanding of what needs to be up and running soonest is desirable to make this phase effective.

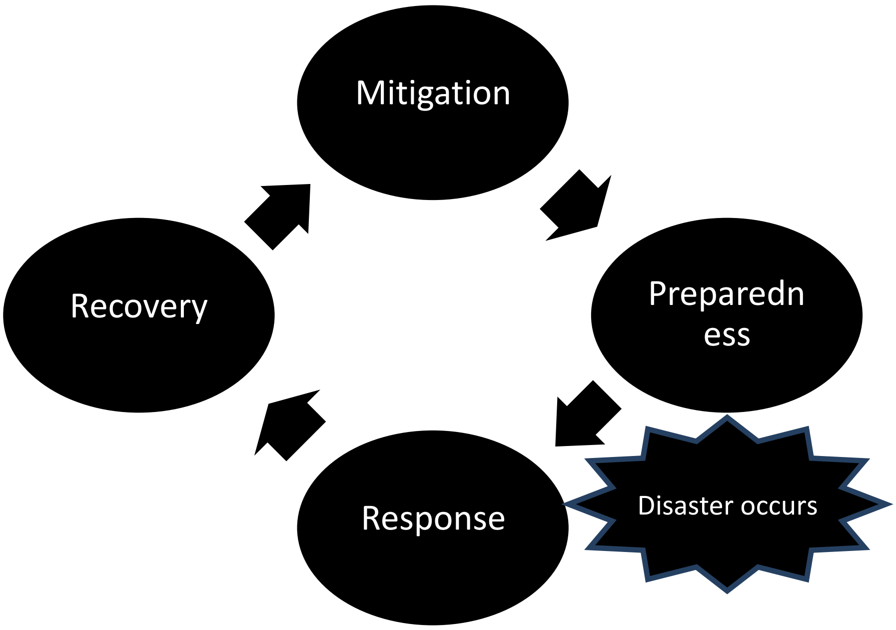

Figure 1: Disaster management cycle

IFRC proposes another way to divide the disaster management based on the relationship between humanitarian logistics and disasters. In this framework, the Emergency Management Plan is divided into three phases: preparedness, response and recovery. All of these phases need the support of humanitarian logistics to reduce the risk of disaster:

- Preparedness: Disaster preparedness refers to all the activities which can be conducted to establish an effective supply chain to support the activities during the disaster response.
- Response: The response aims to deliver vital goods and care to the largest possible number of the affected people. In this phase, the coordination and collaboration among

all the actors involved in the disaster relief are of paramount importance (Balcik et al., 2008).
- Recovery: Recovery refers to those logistics activities which go beyond the provision of immediate relief to assist those who have suffered from a disaster. This phase aims to rebuild the homes and lives of suffers, reconstruct the services of organizations, and to strengthen the response capacity to cope with future disasters.

3.3 Emergency Management Plan in the Health Care Sector

The EMP can be directed at events that take place outside of the hospital but involve the hospital in managing an influx of causalities, "External EMP", or an event inside the hospital such as a flood, "Internal EMP" (Blanchard et al., 2007).

In an external crisis the aim is to give the best of care to an unexpected number of patients and the challenge is the disproportion between needs and resources while in an internal crisis the challenge is to partition the event, reducing the people exposed or to evacuate people to a safety place to move them away from danger.

External Emergency Management Plan

Traditionally the Health Sector and associated literature have focused on external EMPs i.e. plans for an influx of patients. The mission of health care is providing medical care, and emergencies typically put a strain on hospital resources. Most Master Surgeons will have experience of medical emergencies; the combination of financial constraints and high performance standards can limit the ability of hospitals to treat increased patient numbers. Health sector institutions generally have plans to address major incidents, mass casualties and pandemics. Hospital response to an external emergency may include plans to:
- Manage the arrival of patients,
- Care of patients,
- Protection of personnel and others from infection: Isolation, Chemoprophylaxis and Vaccination.

Ideally all the actors of the medical response to any kind of emergencies should work inside a common framework and in a cooperative, coordinated way; the different single health institution plans should be integrated in a regional/national plan. There are many initiatives to create also trans-national health emergency plans to face the challenges of a global health economy.

Traumatic Emergencies (Major Incidents/Mass casualties)
Although almost all major EU hospitals have a major incident plan on paper, experience shows that many of these plans have never been disseminated, exercised and evaluated. It is not necessarily the case that the Plan Characteristics have been satisfied. The participation in emergency planning by hospital personnel, is another way to increase the awareness about the need of Emergency/Disaster Planning, as well as the participation in national or international network working in the field of the Disaster Medicine.

Contagious Diseases
The Contagious Diseases management plans can be considered as guidelines to help the decision makers to adopt the appropriate disease response policy and accelerate the cooperation among the different stakeholders, with the reasonable use of broad categories of pharmaceutical and non-pharmaceutical resources to reduce the impacts of diseases (Breban et al., 2007). Usually, they focus on 2 main separate lines: prevention and control.

Disease prevention consists of three main parts: maintaining certain quantities of necessary resources to assist a prompt response to the outbreak of epidemic; establishing the detection system of any possible outbreak and carrying out the policy to minimize potential causes which can trigger the disease. Disease control includes different response policies and the related logistics deployments. The response policy consists of several main branches: the individuals' priority policy (prioritising help); the quarantine policy; the isolation policy; the vaccination policy and the medical care coverage policy.

Two vaccination policies are popular in academics and practitioners, ring vaccination (traced vaccination) and mass vaccination. Ring vaccination is a strategy by which only direct contacts of confirmed victims are traced and vaccinated. Mass vaccination is to vaccinate everyone in the infected area. Ferguson et al. (2006) used simulation to examine the effects of antiviral treatment, vaccination, isolation, household quarantine, school closure, workplace closure and travel restrictions in the United Kingdom and United States. Jamrog et al. (2007) studied the effect of mass vaccination, ring vaccination and combined strategy of mass vaccination and ring vaccination by using the Markov chain model. Because of stockpiles are limited and the vaccines or drugs have side effects, medical care coverage policy gives the medical help (vaccines or drugs) to only a certain percentage of individuals to control the disease.

The logistics of response can be managed both at national and local levels. At the national level, people should decide the time and the amount of medical resources which be delivered from national stockpiles to local distribution centres or hospitals. At the local level, a complex network delivering both services and products must be built. Miller et al (2006) designed a disease response plan for San Antonio (USA). Two simulation models are proposed in this paper, the casualty prediction model and the health-care model. The casualty prediction model predicts the number of infected patients. The health-care model uses the number of infected patients predicted by the first simulation model to improve the health-care delivery activities. Because different diseases have their own characteristics, different disease response plans are needed to prevent and control the diseases. Therefore, most of the available disease prevention plans and disease control plans are disease specific.

Internal Emergency Management Plan

Hospitals and other large health facilities may have planned for internal emergencies which are man-made e.g. power failure or natural e.g. floods. Clinical staff are not traditionally the people most likely to undertake this function, which may be better aligned to a specialised area such as Business Resilience. However, although hospitals have some of the characteristics of other crowded places such as airports that may need Internal EMPs. The planning for hospitals is complicated by the presence of patients who have varying levels of medical and physical needs. These complex medical needs make it desirable to include medical personnel in the planning phase. It is also necessary to understand the role of the security department, and to understand who owns the EMPs: who will declare that an emergency has occurred?

The Internal EMP should address the protection of people and assets; the equipment in hospital may be specialised, expensive and hard to replace. Internally driven emergency events may or may not require evacuation of the hospital, either full or partial. Plans typically are better at addressing concrete events like a flood, and are typically less clear on protection against attack or plans for evacuation. For example, an internal emergency management plan has mainly been specified for the Hospital St-Joseph/St-Luc in Lyon, to face a flood (Guinet et al., 2012). Activities, Actors, data, and information supports are detailed for each process. Process simulation allows the hospital to dimension the resources required for evacuation.

Hospital evacuation is a difficult process that requires a robust strategy and careful execution, the omission of plans for this is therefore a worrying gap. Taaffe et al. (2005) described the complexity of hospital evacuation. Augustine et al. (2005) discussed strategies and considerations involved in the evacuation plan of a rural hospital. The role of emergency department and nursing staff throughout the evacuation process has been highlighted. Blaser et al. (1985) studied the evacuation of a veteran hospital at night-time. Burgess (1999) reviewed hospital evacuation due to the hazardous materials incidents in Washington State hospitals. Bish et al. (2011) used a mixed integer linear formulation to classify the different kinds of patients to be evacuated. Chen et al. (2015) combined simulation with mathematical programming to study the evacuation of a hospital according to a French extended white plan. The power of mathematical models and simulation, has been shown in this paper.

It seems from the published literature that even where the Internal EMP is well designed and developed, the risk of intentional incident is rarely taken into consideration and in very few cases the risk of terrorism mentioned. It is important that hospitals begin to consider security issues in their emergency management planning.

3.4 Emergency Management Planning Outside the Health Care Sector

External Emergency Management Plan

The distribution of human and material resources during an external emergency has been a suitable topic for academic study by modelling experts. Fiedrich et al. (2000) proposed a dynamic combinatorial optimisation model with the goal function of minimising the total number of fatalities during the crucial rescue period (the first 72 hours after the earthquake). The resources have been classified according to the requirements of the areas of earthquakes. Sheu (2007) presented a hybrid fuzzy clustering-optimization approach to solve the resource distribution problems responding to the urgent relief demands in the crucial rescue period. The proposed methodology involves two recursive mechanisms: (1) disaster-affected area grouping, and (2) relief distribution. Haghani and Oh (1996) proposed an optimisation model with the objective of minimising the sum of the vehicular flow costs, the supply or demand carry-over costs, and the transfer costs over all time periods. Chang et al. (2007) developed a stochastic programming model that can be used by government agencies in planning for flood emergency logistics. Barbarosoglu et al. (2002) optimised the use of helicopter during the response to disaster. Berman et al. (2012) studied about resource allocation after a potential bioterrorism attack on an airport. Tzeng et al. (2007) constructed a relief-distribution model using the multi-objective programming method. The model features three objectives: minimising the total cost, minimising the total travel time, and maximising the minimal people satisfaction during the planning horizon. Sheu (2010) presented a dynamic relief-demand management model for emergency logistics operations under imperfect information conditions in large-scale natural disasters. The proposed methodology consists of three steps: (1) data fusion to forecast relief demand in multiple areas, (2) fuzzy clustering to classify affected area into groups, and (3) multi-criteria decision making to rank the order of priority of groups. Yan and Shih (2009) optimised the schedule for relief distribution during the emergency response. Yuan and Wang (2009) proposed two mathematical models to help the decision makers to choose the paths during the disaster response. All of these papers present the usefuness of Operation Research in the study of emergency management plan.

Some papers study the field of bombing or nuclear accidents. Raiter et al. (2008) concluded the mass casualty incident management lessons learned from a suicide bomber attack in downtown. Williams et al. (2000) focused on the study of the impact of the bomb on the city centre. It reviewed briefly the emergency management plan and concluded the lessons learnt from this experience. Ford (2000) identified nine ways that emergency response training programs can be modified to improve the effectiveness of nuclear power plant personnel who must respond to accident conditions. For example, Ford (2000) found that enhanced teamwork can decrease the aftermath of disasters.

There are some other interesting papers in the field of emergency management plan design. Ramabrahmam et al. (1996) provided an overview of ammonia release accidents, response, organizations, communication systems, key personnel with specified responsibilities, work emergency procedures, education and training. Kapucu (2008) suggested that pre-planning, open communication between emergency managers and elected officials, and the use of technology all had a significant impact on responses. Flin et al. (1996) summarized the findings of emergency response to Occidental Petroleum accidents in 1996. Five questions about an effective emergency management plan proposed by Drabek (1995) are the following: (1) What is the content of disaster evacuation planning? (2) What factors account for the variations in this planning? (3) What behavioral patterns occur during actual evacuations? (4) What factors account for these pattern variations? (5) What are the policy implications of these behavioral assessments? Tsai et al. (2010) studied the emergency response to earthquake for tourism industry. Jain and McLean (2003) proposed a framework to integrate the modelling, simulation and visualization tools for emergency response. Harrald (2006) tried to interview all the important factors which can impact the emergency management plans. Alexander (2005) enumerated 18 principles that can be used to judge the quality of emergency plans. The principles proposed in this paper can be treated as basic criteria to be used when formulating a standard. Next, the paper reviewed existing standards in civil protection, risk management, emergency preparedness and humanitarian relief.

Internal emergency management plan

The main activity of internal emergency management plans outside Health Care Sector is also evacuation, and modelling can be used to assess plans for this. With the help of evacuation, victims can be transported from affected places to safety areas. There are some interesting papers about the evacuation from buildings that may be relevant to hospitals. Shen (2005) evaluated evacuation safety of buildings by an evacuation simulation model. The model proposed in this paper can investigate the evacuation processes in the case of building fires, can trace the occupants in every compartment of the building at each time period and describe the passage between compartments during the simulation. This model used, “Evacuability”, which is defined as the percentage of successful evacuees of the total occupants in the building to evaluate the evacuation processes. Zhang et al. (2008) proposed a mathematical model to study the evacuation process of students from a classroom. Tavares et al. (2009) presented a methodology which combines the evacuation models, numerical experiments design and numerical optimization technique together to improve the enclosed design of building. Xu and Song (2009) proposed a simulation model to study the evacuation process of a four-story building. The characteristics of the building have been taken into account. Lin et al. (2008) used mathematical model to estimate the minimal clearance time for evacuating the occupants of a building in an emergency situation. Oven and Cakici (2009) concentrated on two issues: firstly, what methodology should be pursued to accurately model an evacuation problem; the second issue is how to improve the evacuation behaviour in a high-rise office building. Thompson and Marchant (1995a) proposed a computer model to simulate the escape movement of thousands of individual people through large, geometrically complex building spaces. The computer program assigns a variety of attributes to each individual in the building population. These attributes include a coordinate position, angle of orientation, and a walking speed for each person. Lovas (1995) combined simulation and queuing network theory to evaluate the evacuation processes from different aspects. Thompson and Marchant (1995b) proposed two models, a fluid model and a computer simulation model. The fluid model is intended to help people understand the mechanism of crowd flow during the evacuation. The evacuation model proposed by Pursals and Garzo (2009) takes into account the route situation during evacuation. Lo et al. (2006)

used game theory to simulate the evacuation processes. Yuan et al. (2009) combined two network model methods to simulate the evacuation processes in a building. Kobes et al. (2010) reviewed papers about the human behaviours during the fire evacuation. Gwynne et al. (1999) reviewed papers which used the simulation to study the evacuation. This is a useful paper but most of the papers studied by Gwynne et al. (1999) are now too old for detailed consideration.

3.5 Benchmarking of EMPs in European Hospitals

The benchmarking of the Emergency Management Plans in between the EU Hospitals activity has been very difficult because the availability of published documents in English language on the web is very limited as already mentioned in D1.1. Even directly consulting the websites of some of the EU big university hospitals (Karolinska University Hospital, Stockholm, Oslo University Hospital, Oslo, Hospital General Universitario Gregorio Maranon, Madrid, Charitè Universitatsmedizin, Berlin, University Medical Center, Utrecht, University Medical Centre, Ljubljiana, University Hospital Centre, Zagreb), we did not find published EMPs in English language. Some of these hospitals even do not have a website in English (Hospital General Universitario Gregorio Maranon, Madrid, University Medical Centre, Ljubljiana, University Hospital Centre, Zagreb).

So the benchmarking has been conducted more informally gaining information from users and experts during congresses and events and mostly taking advantage from the relationship between OSR and the MRMI&D International Association. http://www.macsim.se/

MRMI&D (Medical Response to Major Incidents and Disasters) is an International Association registered in Sweden whose main purpose is to promote the culture of management of major incidents and disasters. The Association is present in 7 EU Countries (Sweden, Denmark, Germany, Portugal, Italy, Slovenia, Croatia) with national chapters. Norway, UK and Spain are on process to have their, too. Since 2009, when the first MRMI&D Course has been organized, there were around 12 editions in Europe and 1 in Thailand, with around 600 participants and 50 instructors graduated.

Many of the National Representatives of the Association come from big general university hospitals. Some of them have been invited speakers during the June 2015 THREATS Event in Milano.

A list of the MRMI&D International Association representative and the institution where they perform the ordinary activity.

Sweden: Carl Montan; Karolinska University Hospital, Stockholm

Norway: Tina Gaarder; Oslo University Hospital

Netherlands: Mike Bemelman; St. Elisabeth Hospital, Tilburg

Germany: Philip Fisher; University Clinic Bonn

Spain: Fernando Turegano; Gregorio Maranon, Madrid

Portugal: Pedro Ramos; Sesaram, Funchal

Croazia: Boris Hreckovski; General Hospital Slavonski Brod

Slovenia: Simon Hermann; University Medical Centre, Ljubljiana

From the exchange of idea and experiences about the existing hospital EMPs, the following seem to pertain:

1) EMPs for external emergencies (massive influx of patients) are more developed, in particular those related to a traumatic emergency;
2) The EMPs for internal emergencies (evacuation plans) are traditionally business of non-medical personnel (maintenance…), although the particular setting (evacuation of patients who have varying levels of medical and physical needs) make it desirable to include medical personnel in the planning phase;
3) Internal EMPs Plans typically are better at addressing concrete accidental events like a flood, a fire and are typically less clear on protection against intentional attacks;
4) Internal EMPs usually address the protection of people (evacuation) while are inconsistent in addressing the protection of assets, goods and equipment (business continuity/resilience);
5) Terrorism is rarely taken into account as potential hazard inside both external and internal EMPs and when mentioned, there are no specific indications related to security management.

4 San Raffaele Hospital (OSR) Emergency Management Plans: study and model

Many factors dictate that OSR has to be emergency prepared: it is a big university hospital and referral point for all emergency and major trauma cases; it is the nearest hospital to Linate Airport; it has VIP patients and it is in charge of the medical service for many mass participation events. The investment of OSR in Emergency Management / Disaster Planning started several years ago (1993), when a terrorist bomb exploded in a car parked near the Palestro Metro Station, in Milano City Centre and OSR was one of the hospitals where casualties were sent. The hospital's active investment in the field of the emergency management planning was reinforced by a fire in 1998 that involved part of the main hospital building (Sector C) and caused one death, several injured, and the evacuation of the entire sector comprising six floors, four inpatient units with around 150 patients, the central lab and some operating theatres. Since then a very active committee composed of both medical and non-medical personnel has produced EMPs, and reviewed them in the light of important changes of the hospital compound through the years.

The plans were activated in 2001 when a Scandinavian Airlines plane crashed in Linate Airport although unfortunately 118 of the 119 people on board died. Since 2004 a group of people working for OSR, doctors, nurses and medical technicians (OSR Group for Major Emergencies) have been involved in missions for emergency medical relief after disasters (Sri Lanka in 2004, L'Aquila in 2009, Haiti in 2010, Emilia 2012, Iraq 2014). Since 2008 OSR has been part of a national and international network of experts in Disaster Medicine, the Italian representative for the MRMI&D International and one of the most active organisations on the education in medical emergency management.

OSR's investment in the External EMP has been continuous and effective, with the plan being reviewed, participated and simulated several times in the last 5 years, in contrast to the Internal EMP. There was an initial surge of interest after the fire in 1998, but there was little medical staff input to the process and the plan was little more than a technical plan to respond to a fire. Within the last year OSR's Internal EMP has been reviewed and medical personnel have been part of this process. In 2015 the plan for the management of an internal emergency of the General Intensive Care Unit was published, distributed to personnel and tested with a simulation (August 2015). It is most likely that this gap between the level of development of External and Internal Emergency Management Plans is representative of the situation of most EU hospitals.

4.1 OSR External Emergency Management Plan

The OSR's external emergency management plan is depicted in Figure 2 below, according to an IDEFØ modelling (see D 3.1).

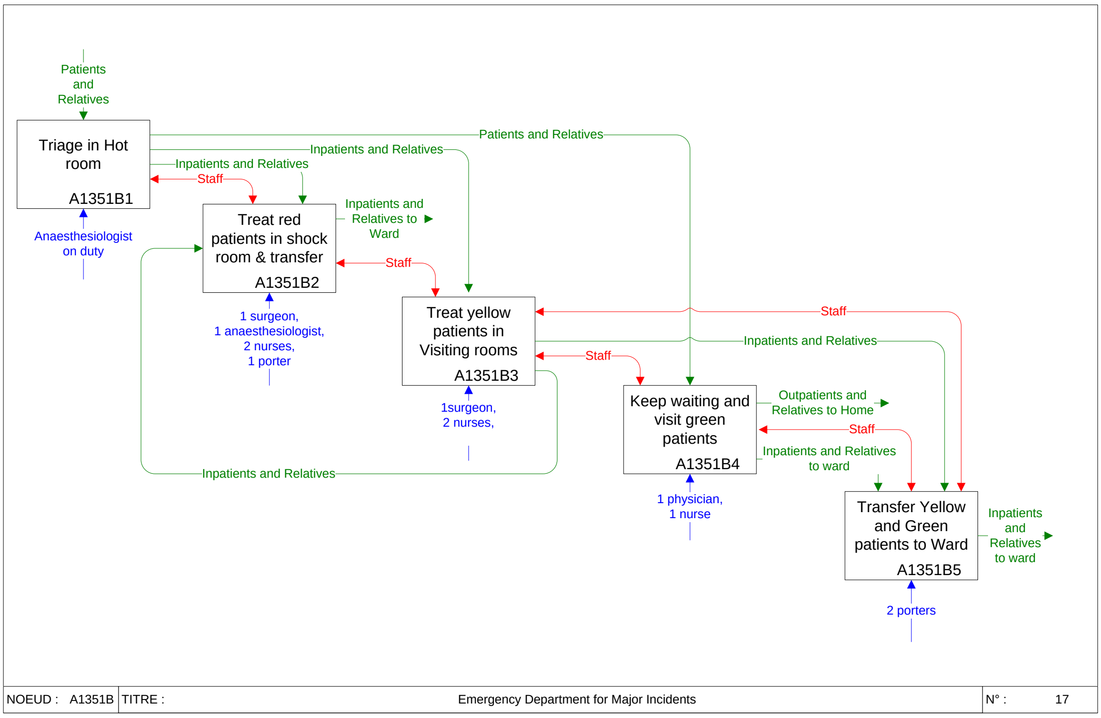

Figure 2: OSR external emergency management plan organisation.

The process is triggered when a major incident/mass casualties event occurs outside of the hospital. Wherever the information of a potential need of activating the plan comes from, the alarm is managed by the emergency department staff, on duty 24/24, 7/7. Until the alarm is not confirmed the hospital is in “alert” status, with few people involved (mainly the coordination and command key persons), and with the aim to assess the hospital readiness without interfering with the ordinary activities. If the arrival of casualties in number exceeds the actual available resources is confirmed, the plan is fully activated with a modular escalation, according with the need (level 1, level 2, level 3). The senior surgeon on duty is the hospital disaster manager (HDM) and decides whether to activate the plan and the level. The preparation phase starts with the assignment of rules and responsibilities according with action cards for each function. The emergency department is cleared of the already existing patients and prepared to accept the arriving ones. The ordinary non-emergency activities are frozen. The ED ordinary setting, normally split into surgical and medical activity (Figure 3), changes to a patient severity related configuration, with different functional areas: red (patients with major life-threatening injuries who are salvageable), yellow (patients with major injuries but potential worsening condition, whose treatments can be delayed but need strict observation) and green (patients with minor injuries) areas (Figure 2); other logistic areas are organized: triage area at the door, for sorting out the patients according with the severity, black area for dead patients, blue area for patients non salvageable but who needs compassionate care, areas for relatives, press, incoming staff… Every area must be staffed and equipped. The command chain must be organized and clear as well as the line of communication. A system of “cascading calls” for alerting and recruiting personnel is activated. The whole hospital is involved and the emergency department keeps the leadership until the hospital command group (health and administrative directions) is in place. The flow of the arriving vehicles, both ambulances and private transports, changes to one-way, to allow a rapid offload of patients and fast reversion to the scene of the ambulances. The patients are managed according with the needs and the available resources, applying modified protocols in the aim to do the best for the most and not the best for everyone (that is actually the guideline when you manage a single or few patients). The internal path from the ED to the radiological department, operating theatres, ICUs, wards is defined. If there are patients competing for the same resource (CT scan, operating theatre, ventilator are the common “bottle necks” during a major incident/mass casualties event) the triage is utilized to prioritize. A “disaster ward” (A1351B4) is opened to keep all the admitted casualties in a place where it is easier to control. Rarely patients are discharged before the end of the emergency and having received psychological assessment and support. The end of the activation is declared by the hospital command group and the demobilization follows the same flow than the activation backward.

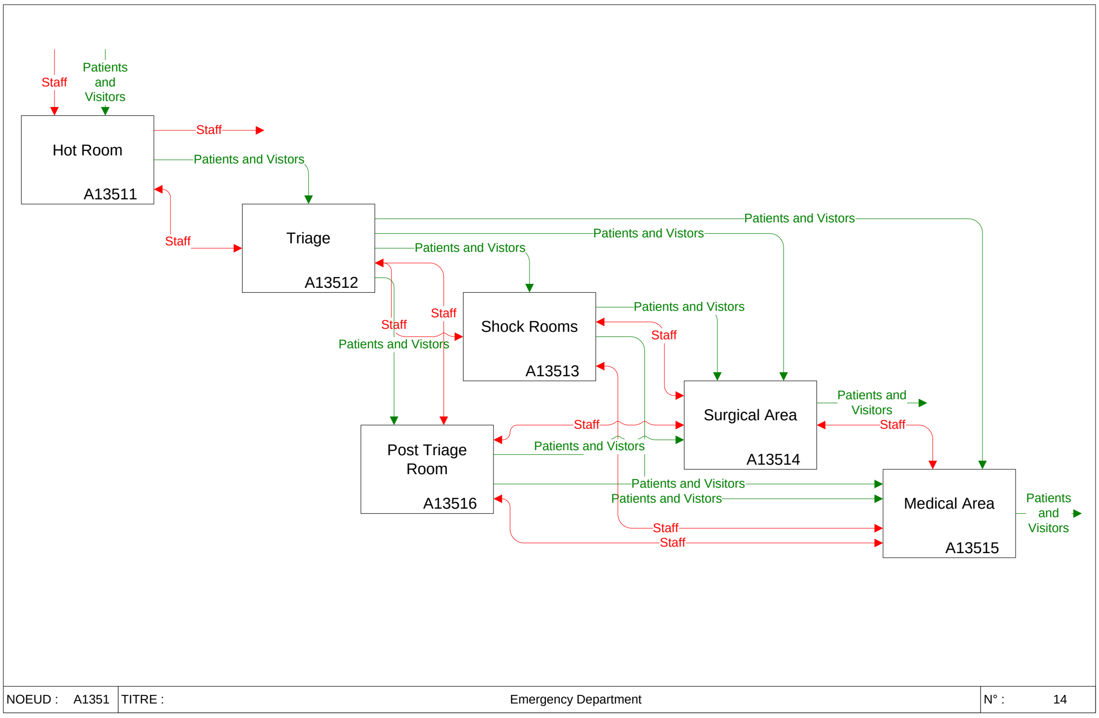

Figure 3: OSR emergency department organization for regular activity

In order to simulate the activation of the external emergency management plan, the regular process of the emergency department (Figure 3) is replaced by the crisis process of this latter (Figure 2), step by step. The changes of organizations (processes) and variations (increasing or decreasing) of human resources, is simulated by flow studies as described later on.

4.2 OSR Internal Emergency Management Plan

The plan is triggered when an emergency occurs inside the hospital. Wherever the alarm of a potentially dangerous event comes from (medical personnel, patients, visitors, automatic alarm system - for example smoke detector) it is processed by the internal security through a single telephone number 7000. The alarm is then forwarded to an emergency team (ET) which has the duty to reach the place of the event and eventually confirms the emergency. In the meanwhile the ED has to try to partition the event with the help of the medical personnel trained for this (for example to put out a fire with the extinguisher). The ET is a technical cell composed by members of the maintenance department (electricians, plumbers…) in house 24/24 and 7/7. If the partition fails again through the 7000 telephone number the emergency direction (ED) is activated. The ED is composed by 2 souls: one technical (a senior technician from the maintenance department) and one medical (usually the senior surgeon on duty); if there is a serious potential danger to people then the decision is made to start the evacuation procedure, belongs to the ED. During the non-working hours the senior surgeon is the only available representative of the ED in house: the initial decisions and leadership of the emergency management belongs to her/him. As we already mentioned, hospital evacuation is a difficult process that requires a robust strategy and a careful execution. The evacuation routes, the type of people (visitors, personnel, patients…), the level of dependence of the patients, the need of continuity of care must be taken into deep consideration. Usually the evacuated people go to prearranged safe areas inside or outside the hospital. The early alert of the EMS (Emergency Medical Service) and of the other potentially involved agencies (Fire Fighters, Police…) is crucial in case of an event that exceeds the ability to cope. Recently the plan for evacuation of the General Intensive Care Unit has been reviewed and tested by a real simulation.

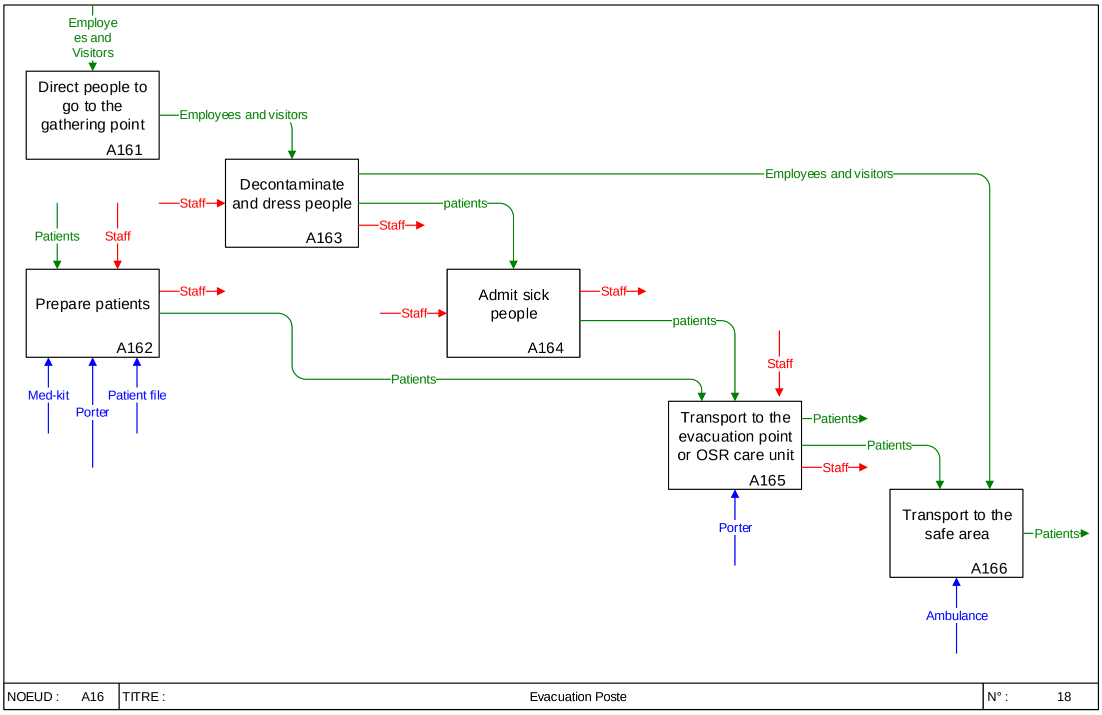

Figure 4: OSR General ICU evacuation

In Figure 4, the patients, visitors and employees, are removed from danger, re-joining a gathering point or being transported to an evacuation point. Regarding patients, a medical team (nurse + porter) is assigned to the patient. Then the patient is evacuated through a safe way to a safe place inside the hospital. At the patient's arrival a new medical team should be ready to receive the hand-over. If there is no possibility to accommodate the patient inside the hospital a transfer to another hospital should be arranged via an ambulance. Regarding employees and visitors, people can be decontaminated and admitted to a care unit if they are sick and they then re-join the patients. EMS is usually in charge of finding destinations and arranging transports for these patients. It is crucial that patients travel with medical records, to avoid misidentification and interruption of care.

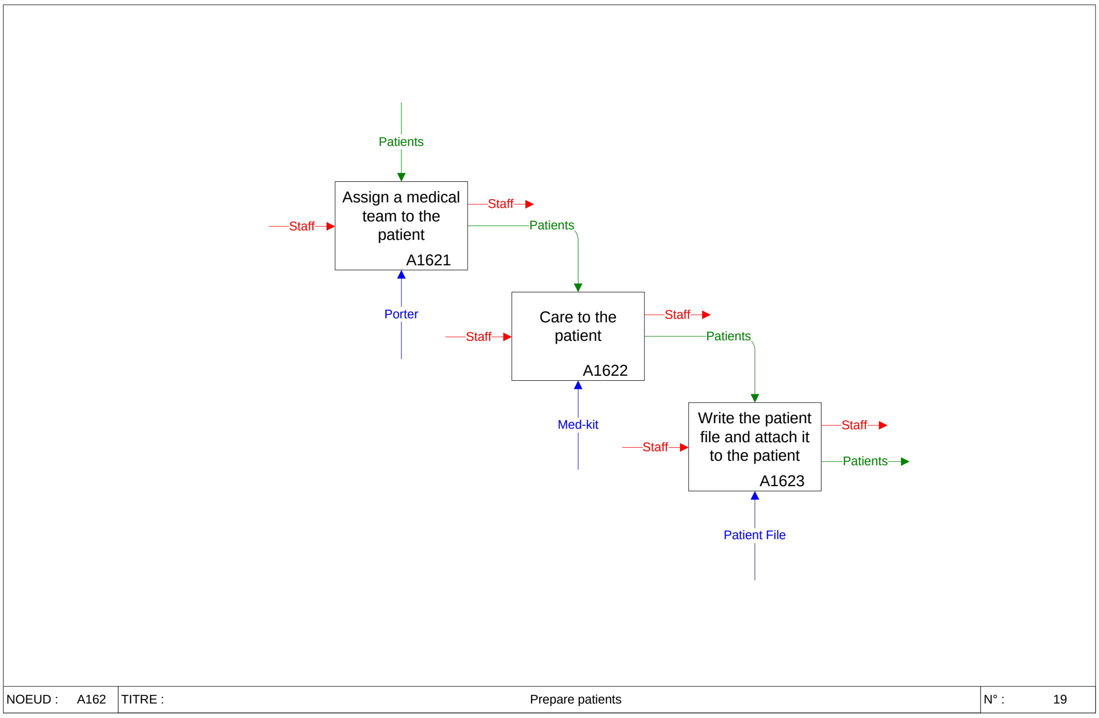

Figure 5: Preparation of patients.

The preparation of patients before evacuation is detailed on Figure 5. First, a medical team composed by a nurse and a porter is assigned to the patient. Second the patient receives the required cares and the patient's state is controlled until it is stabilized and ready for transportation. A patient file summarizes the diagnosis, the care delivered and the patient state.

4.3 Example of early contribution of simulation of a THREATS scenario to OSR emergency management plans

THREAT scenario identification	THREAT scenario description	THREAT scenario contribution to OSR Emergency Management Plans (EMPs)	Strengths of OSR EMPs	Weaknesses of OSR EMPs	Early recommendations
Scenario 1: second strike	**1) A first terrorist strike occurs in Linate Airport; 2) Emergency plan in Linate Airport is activated (EMS); 3) OSR responds with the External EMP for massive afflux of injuries activation and readiness; 4) First patients enters the OSR ED: is a green code arrived by a private car pretending to have been injured in Linate; when assessed shows a bomb-belt and explodes her/himself 5) The ED is damaged; some ED staff is**	**1) The External EMP is activated to face the massive afflux of casualties 2) The Internal EMP is activated to evacuate the ED**	**1) The External EMP is effective in managing the unexpected number of casualties 2) The Internal EMP is effective in evacuating people from the ED**	**1) In the External EMP the terrorist scenario is not taken into deep consideration: there are no specifications on how to increase the security level when casualties come from a terrorist event 2) The Internal EMP does not take into consideration the terrorist scenario: does not consider the case of a dangerous event driven by a direct**	**1) The External EMP should take into full consideration the terrorist scenario: consider to rise the security level of the hospital when casualties come from a terrorist event. For example: prevent private vehicles to enter the ED gate; offload patients out of the ED; set up a security system to check patients for explosives or**

	seriously injured 6) OSR Internal EMP is activated to safeguard the rest of the hospital			terrorist attack; does not consider that the ED is targeted by the terrorist action and becomes unable to lead the Internal EMP	weapons before they enter the ED 2) The Internal EMP should take into full consideration the terrorist scenario, providing strategies for protecting the people from this kind of threats (invacuation, shelter in place, lock down…); the Internal EMP should consider that the ED is targeted by the terrorist action and becomes unable to lead the Internal EMP (second place where to evacuate people, alternative staff to lead the EMP) 3) Implement actions to rise up the level of awareness and preparedness of the personnel against terrorist scenarios

4.4 Early Recommendations for OSR Emergency Management Plans

Even after a very preliminary exam, OSR Emergency Management Plans show evident weaknesses with respect to the ability to adequately respond to a terrorist attack directly or indirectly targeting the hospital; there are two main reasons:

1) both the External and the Internal EMPs do not take into consideration the terrorist threats;

2) the hospital is very vulnerable to intentional acts because it has no effective policy to prevent unauthorized access, being its mission to welcoming people in need of care.

So some early basic recommendations on how to increase the resilience of OSR to terrorist attacks can be made:

1) review the EMPs, both External and Internal considering a terrorist attack as a potential scenario
2) being the open access maybe the most important factor of vulnerability, consider, in case of possible terrorist threats, to implement security measures like restriction of access to the hospital, security check for vehicles and people, “lock down”, “evacuation”, “shelter in place”;
3) promote awareness, training and simulation of potential terrorist scenarios among the hospital personnel to increase preparedness and a security awareness culture

5 Dynamic Simulation: emergency management plans integration

5.1 Extension of OSR dynamic model for emergency management plan integration

Context

The external emergency management plan and the internal emergency management plan, require representing the resources such as physicians, nurses, ambulances and equipment. These resources are limited, and they generate waiting patients for the different activities modelled in the care units processes. So, the time must be represented. The periods represent hours and have been experimented up to 120 units, i.e. 5 or 10 days. We have extended the flow model presented in the first deliverable of the work-package 3, on one hand to several periods, and on the other hand to several patient types (inpatients and outpatients) in order to model different length of stay associated to the patient types. Furthermore, these extensions will allow us to integrate description of particular care units in our extended model. In the absence of a particular scenario study, we focus on the hospital traffic because the most crowded place could be the most vulnerable place. A mathematical model of the problem is described in what follows.

Problem

Parameters:
- N: Number of services/units (number of leaves of IDEFØ's tree, N is equal to 47);
- T: Number of periods (120 hours);
- i, j, k, p, q: Indices;
- H: Length of stay for inpatients;
- L: Length of stay for outpatients;
- Acc(i,j): If there is an access to go directly from unit i to unit j, it is equal to 1, 0 otherwise; The accesses are extracted from the IDEFØ's model (restricted to the physical view, see D 3.1);
- Input(i,p): Number of people (inpatients, outpatients, and visitors) incoming in i directly from outside (entry point) on period p;
- Output(i,p): Number of people (inpatients, outpatients, and visitors) exiting from i directly to outside (exit point) on period p;
- Inp(i,p): number of inpatients (patients which stay at least one night in the hospital) on period p;
- Inp(i,p)=0 $\forall$p=1-H,…,0;
- Outp(i,p): number of outpatients (patients which stay less than one night in the hospital) on period p;
- Outp(i,p)=0 $\forall$p=1-L,…,0.

Variables:
- XG(i,j,p): Number of people going from i to j on period p;
- XR(i,j,p): Number of people returning from i to j on period p.

Basic Model

Objective function:

$$Min\ Z = \overbrace{\sum_{p=1}^{T} \left(\sum_{i=1}^{N} \sum_{j=1}^{N} (XG(i,j,p) + XR(i,j,p)) \right)}^{Traffic} \quad (1)$$

Constraints:

$$\sum_{j=1|j\neq i}^{N} XG(j,i,p)*Acc(j,i) \;-\; \sum_{j=1|j\neq i}^{N} XG(i,j,p)*Acc(i,j)+Input(i,p)$$
$$= \; Inp(i,p)+Outp(i,p) \quad \forall i=1,...,N \quad \forall p=1,...,T \quad (2)$$

$$\sum_{j=1|j\neq i}^{N} XR(i,j,p)*Acc(i,j) \;-\; \sum_{j=1|j\neq i}^{N} XR(j,i,p)*Acc(j,i)+Output(i,p)$$
$$= \; Inp(i,p-H)+Outp(i,p-L) \quad \forall i=1,...,N \quad \forall p=1,...,T \quad (3)$$

$$XG(i,j,p)\geq 0, \quad XR(i,j,p)\geq 0 \quad \forall i,j=1,...,N \quad \forall p=1,...,T \quad (4)$$

Comments:
This linear program minimizes the traffic of the whole hospital over the whole horizon (equation 1). In equations 2, the flow entrances from neighbourhood units, minus the flow exits to neighbourhood units, plus the entrances to i from outside ("Input" data represents the inpatients and the outpatients, visitors are considered as outpatients), are equal to the inpatient absorption by the care unit i (the inpatient admissions are modelled by "Inp" data), plus the outpatient absorption by the care unit i (the outpatient admissions are modelled by "Outp" data). Equations 2 are conservation flow constraints, they model the entrances of the care unit i. Equations 3 are the opposite equations of the equations 2, they model the departures of the care unit i. In equations 3, the flow exits to neighbourhood units, minus the flow entrances from neighbourhood units, plus the exits from i to outside (the inpatient exits and the outpatient and visitors exits are regrouped within the "Output" data), are equal to the previous absorption of the care unit i for inpatients which are now released ("Inp" data represents the previous admissions of inpatients which entered H periods before p, regarding to the length of stay equal to H), plus the previous absorption for outpatients which are now released ("Outp" data represents the previous admissions for outpatients which entered L periods before p, regarding to the length of stay equal to L). The hypothesis that the sum of incoming/leaving people is equal to the sum of inpatients plus outpatients i.e. (∑ Input(i,p) = ∑ Inp(i,p) + ∑ Outp(i,p), ∀p) for hospital entrances and (∑ Output(i,p) = ∑ Inp(i,p-H) + ∑ Outp(i,p-L), ∀p) for hospital exits, are retained. Under these hypotheses, the source flows and the sink flows are balanced.

Solving the multi-period traffic problem for 60 periods (which represents 5 days of 12 hours), it leads to 265 081 decision variables and 5640 constraints. The linear program has been solved with IBM ILOG CPLEX (2015), the computation time is less than 10 seconds and the weekly hospital traffic is equal to 56 086 crossings of patients and visitors over the whole horizon, for a regular week of OSR's activity. The most crowded place has a maximum traffic per hour of 97 patients and visitors. It can be the most vulnerable place.

5.2 Integrating the External Emergency Management plan in OSR dynamic model

Context

This is a raw model of the flows of the emergency department, after the activation of the external emergency management plan, because some data are currently lacking (the pathways of inpatients after the emergency department to OT, ICU…). The hypothesis that the external emergency management plan is activated at period 1 is retained. The inputs of the model are the number of people incoming to emergency department directly from outside. The outputs of the model are the inpatients and the outpatients. We suppose that the inpatients are admitted to a general surgery unit, because the pathways of inpatients after the emergency department are not currently known (next task 3 of WP3). The equations

2 and 3 dedicated to the emergency department and to the general surgery unit must be modified: to conserve the accesses via the emergency department zone if allowed, and to take into account the acute admissions (inpatients from ED), respectively. The outpatients return home directly from the outside exit of the emergency department. The constraints of the emergency department must be added to the basic model. As the weighted of the objective function of the basic model by p, doesn't change the result found because the constraints per period are linked only by parameters, the both objective functions are weighted by p and integrated by a sum. A mathematical model of the EMD is described in what follows.

Problem

Parameters:
N: number of activities (number of leaves of the emergency department tree, it is equal to 5,
T: number of periods (time horizon),
ed: the unit number of the emergency department in the basic model,
gs: the unit number of the general surgery unit in the basic model,
i, j: activities indices,
p, q: period index (hours),
Acced(i,j): If it is equal to 1 there is a successor link to go directly from activity i to activity j, 0 otherwise; the accesses are extracted from the partial IDEFØ's model restricted to the emergency department box in order to face a major external incident, they result from the functional decomposition of the box (see Figure 2),
Acced(0,1)=1 to allow entrances to emergency department from outside, according to Figure 2, the index 0 allows us to represent accesses from outside,
Acced(2,6)=1 to allow exits from emergency department to regular care unit for red patients, according to Figure 2,
Acced(5,6)=1 to allow exits from emergency department to regular care unit for yellow and green patients, according to Figure 2,
Acced(4,6)=1 to allow exits from emergency department to home for green patients, according to Figure 2, the index N+1 enables us to represent accesses to outside,
Input(ed,p): Number of people (Green, Yellow and Red patients) incoming to the emergency department ed directly from outside (entry point) on period p,
D(i): Duration of activity i,
Cap(i,p): Capacity allowed for activity i on period p in terms of number of emergency teams,
Redp: percentage of red patients,
Yelp: percentage of yellow patients,
Grep: percentage of green patients,
With Redp+Yelp+Grep=1,
Greh: percentage of green patients which are hospitalized, Grehp ≤ 1.

Variables:
Inped(p): number of yellow and red patients admitted in emergency department on period p, these inpatients must be later admitted in the care unit gs,
Outped(p): number of green patients admitted in emergency department on period p, they will return home,
XED(i,j,p): Number of people going from activity i to activity j on period p,
WED(i,p): Number of people waiting for activity i on period p.

Model of the emergency department

Objective function:

$$Min\ Z = \overbrace{\sum_{i=1}^{N}\sum_{p=1}^{T}(\mathrm{WED}(i,p)*\mathrm{p})}^{Waiting\ patients} \quad (11)$$

Generic constraints of the process of a care unit:

$$\sum_{j=0|j\neq i}^{N} XED(j,i,p)*Acced(j,i) - \sum_{j=1|j\neq i}^{N+1} XED(i,j,p+D(i))*Acced(i,j) + WED(i,p)$$
$$= \quad WED(i,p+1) \quad \forall i=1,\dots,N \quad \forall p=1,\dots,T-D(i) \quad (12)$$

$$\sum_{j=1|j\neq i}^{N+1}\Big(\sum_{q=p-D(i)+1}^{p} XED(i,j,q)*Acced(i,j)\Big) \leq Cap(i,p) \quad \forall i=1,\dots,N \quad \forall p=D(i),\dots,T \quad (13)$$

$$\begin{aligned}&XED(i,j,p)\geq 0, \quad WED(i,p)\geq 0, \quad Inped(p)\geq 0, \quad Outped(p)\geq 0,\\ &\forall i=1,\dots,N \quad \forall j=1,\dots,N \quad \forall p=1,\dots,T\\ &Inped(p)=0 \quad \forall p=1-H,\dots,0 \quad (14)\end{aligned}$$

Specific constraints of the process of the external emergency management plan (see Figure 2):

$$\begin{aligned}XED(1,2,p) &\leq (XED(1,2,p)+XED(1,3,p)+XED(1,4,p))*\mathrm{Re}\,dp\\ XED(1,3,p) &\leq (XED(1,2,p)+XED(1,3,p)+XED(1,4,p))*Yelp\\ XED(1,4,p) &\leq (XED(1,2,p)+XED(1,3,p)+XED(1,4,p))*Grep\\ \forall p&=1,\dots,T \quad (15)\end{aligned}$$

$$\begin{aligned}XED(0,1,p) &= Input(ed,p),\\ XED(4,5,p) &= (XED(4,6,p)+XED(4,5,p))*Greh\\ XED(2,6,p)+XED(5,6,p) &= Inped(p),\\ XED(4,6,p) &= Outped(p) \quad \forall p=1,\dots,T \quad (16)\end{aligned}$$

Comments:
This linear program minimizes the number of waiting patients (equation 11). A weight p is assigned to the waiting patient numbers in order to minimize the waiting times. In equations 12, the flow entrances from predecessor activities, minus the flow exits to successor activities which will be available "D(i)" periods later, plus the waiting people at the beginning of the period, are equal to the waiting people at the end of the period. Equations 12 are inventory flow constraints. They allow us to express activities in sequence or in parallel and activities dedicated to inpatients or outpatients. In equations 13, the flow exits to successor activities are limited by the activity capacity expressed in number of patients to be treated, taking into account the activity duration equal to “D(i)”. Equations 12 and 13 represent the generic constraints of the process of every care unit, the others equations are specific to the emergency department (see Figure 2). Equations 15 represent the different percentages respectively of red, yellow and green patients. In equations 16, the input flows to the first activity is modelled. They represent the outside entrances directly to the emergency department, these entrances are the only allowed. The dispatching of green patients between inpatients and outpatients, is also specified. The outputs of the emergency department are calculated respectively for the inpatients and the outpatients.

Basic model modification

$$\sum_{j=1 | j \neq ed}^{N} XG(j,ed,p) * Acc(j,ed) \quad - \quad \sum_{j=1 | j \neq ed}^{N} XG(ed,j,p) * Acc(ed,j) \quad = \quad 0$$

$$\forall p = 1,...,T \qquad (17)$$

$$\sum_{j=1 | j \neq ed}^{N} XR(ed,j,p) * Acc(ed,j) \quad - \quad \sum_{j=1 | j \neq ed}^{N} XR(j,ed,p) * Acc(j,ed) \quad = \quad 0$$

$$\forall p = 1,...,T \qquad (18)$$

The accesses via the emergency department are kept. Equations 17 and 18 replace respectively equations 2 and 3 for the emergency unit “ed”.

$$\sum_{j=1 | j \neq gs}^{N} XG(j,gs,p) * Acc(j,gs) \quad - \quad \sum_{j=1 | j \neq gs}^{N} XG(gs,j,p) * Acc(gs,j) + Input(gs,p)$$

$$\geq \quad Inp(gs,p) + Outp(gs,p) + Inped(p) \quad \forall p = 1,...,T \qquad (19)$$

$$\sum_{j=1 | j \neq gs}^{N} XR(gs,j,p) * Acc(gs,j) \quad - \quad \sum_{j=1 | j \neq gs}^{N} XR(j,gs,p) * Acc(j,gs) + Output(gs,p)$$

$$\geq \quad Inp(gs,p-H) + Outp(gs,p-L) + Inped(p-H) \quad \forall p = 1,...,T \qquad (20)$$

The acute patients from emergency department are added to the inpatients and outpatients of the general surgery unit. Equations 19 and 20 replace respectively equations 2 and 3 for the general surgery unit “gs”. The sum of the data and of the variables of the right part of the inequation, is greater than the previous data, but equations 19 and 20 can be respected, on the one hand regarding the relational operator used, and on the other hand because “Output” data and “Input” data can be increased without unbalance the flow problem, these data acting as a dummy sink.

5.3 Integrating Internal Emergency Management plan in OSR dynamic model

Context

This is a raw model of the evacuation flows after the activation of the internal emergency management plan at a given period Pa. The inputs of the model are the number of inpatients and outpatients (visitors and employees are considered as outpatients) of a given care unit k (it could be a set of care units, i.e. a building) to evacuate. The outputs of the model are the inpatients and the outpatients. The inpatients must be admitted in safe care units of OSR or in external hospitals. The hypothesis that inpatients will be admitted in a recovery care unit r which is supposed to be of the same specialty as unit k, is retained in the absence of knowledge of patient pathways. The outpatients return home. The constraints of the evacuation post, must be added to the basic model. The equations 2 and 3 dedicated to the care unit to be evacuated and to the recovery care unit must be modified to take into account respectively the conservation of the accesses via the damaged unit which is supposed to be isolated, and the acute admissions (inpatients) to the recovery care unit. As the weighted of the objective function of the basic model by p, doesn't change the result found because the constraints per period are linked only by parameters, the both objective functions are weighted by p and integrated by a sum. A mathematical model of the problem is described in what follows.

Problem

Parameters:
N: number of activities (number of leaves of the evacuation poste tree, it is equal to 6),
T: number of periods (time horizon),
k: the unit to be evacuated,
r: the recovery care unit,
i, j: activities indices,
p, q: period index (hours),
L: length of stay for outpatients,
H: length of stay for inpatients,
Pa: activation period of internal emergency management plan,
Accep(i,j): If it is equal to 1 there is a successor link to go directly from activity i to activity j, 0 otherwise; the accesses are extracted from the partial IDEFØ's model restricted to the evacuation poste box in order to face a major internal incident, they result from the functional decomposition of the box (see Figure 4),
Accep(0,1)=1 to allow entrances to the evacuation poste from the outside care units for outpatients, according to Figure 4, the index 0 allows us to represent accesses from outside,
Accep(0,2)=1 to allow entrances to the evacuation poste from the outside care units for inpatients, according to Figure 4,
Accep(5,7)=1 to allow exits from the evacuation poste to the safe care units of OSR, for inpatients, according to Figure 4,
Accep(6,7)=1 to allow exits from the evacuation poste to home or the external hospitals, for outpatients and inpatients according to Figure 4, the index N+1 allows us to represent accesses to outside,
Inp(k,p): Number of inpatients admitted in care unit k on period p,
Outp(k,p): Number of outpatients admitted in care unit k on period p,
D(i): Duration of activity i,
Cap(i,p): Capacity allowed for activity i on period p in terms of number of patient treatments,
Sick: percentage of sick outpatients, Sick ≤1,
Pin: patients who can be evacuated in the safe ward, Pin ≤1.

Variables:
Outpev(p): number of outpatients and inpatients evacuated on period p, they will return to home or to an external hospital respectively,
Inpev(p): number of inpatients evacuated on period p, these inpatients must be later admitted in the care unit r,
XEP(i,j,p): Number of people going from activity i to activity j on period p,
WEP(i,p): Number of people waiting for activity i on period p.

Model of the evacuation poste

Objective function:

$$Min\ Z = \overbrace{\sum_{i=1}^{N} \sum_{p=1}^{T} (WEP(i,p) * p)}^{Waiting\ patients} \quad (21)$$

Generic constraints of the process of a care unit:

$$\sum_{j=0 | j \neq i}^{N} XEP(j,i,p) * Accep(j,i) - \sum_{j=1 | j \neq i}^{N+1} XEP(i,j,p+D(i)) * Accep(i,j) + WEP(i,p)$$
$$= \quad WEP(i,p+1) \quad \forall i = 1,...,N \quad \forall p = 1,...,T - D(i) \quad (22)$$

$$\sum_{j=1 | j \neq i}^{N+1} \left(\sum_{q=p-D(i)+1}^{P} XEP(i,j,q) * Accep(i,j) \right) \leq Cap(i,p)$$
$$\forall i = 1,...,N \quad \forall p = D(i),...,T \quad (23)$$

$$XEP(i,j,p) \geq 0, \quad WEP(i,p) \geq 0, \quad Inpev(p) \geq 0, \quad Outpev(p) \geq 0$$
$$\forall i,j = 1,...,N \quad \forall p = 1,...,T \quad (24)$$

Specific constraints of the process of the internal emergency management plan (see Figure 4):

$$XEP(3,4,p) \quad = \quad (XEP(3,4,p) + XEP(3,6,p)) * \text{Sick}$$
$$XEP(5,6,p) \quad = \quad (XEP(5,6,p) + XEP(5,7,p)) * \text{Pin} \quad \forall p = 1,...,T \quad (25)$$

$$XEP(0,1,pa) \quad = \quad \sum_{p=Pa-L+1}^{Pa} Outp(k,p)$$
$$XEP(0,2,pa) \quad = \quad \sum_{p=Pa-H+1}^{Pa} Inp(k,p)$$
$$XEP(5,7,p) \quad = \quad Inpev(p)$$
$$XEP(6,7,p) \quad = \quad Outpev(p) \quad \forall p = 1,...,T \quad (26)$$

Comments:
This linear program minimizes the number of waiting patients (equation 21). A weight p is assigned to the waiting patient numbers in order to minimize the waiting times. In equations 22, the flow entrances from predecessor activities, minus the flow exits to successor activities which will be available "D(i)" periods later, plus the waiting people at the beginning of the period, are equal to the waiting people at the end of the period. Equations 22 are inventory flow constraints. They allow us to express activities in sequence or in parallel and activities dedicated to inpatients or outpatients. In equations 23, the flow exits to successor activities are limited by the activity capacity expressed in number of patients to be treated taking into account the activity duration equal to “D(i)”. Equations 22 and 23 represent the generic constraints of the process of every care unit, the others equations are specific to the evacuation post (see Figure 4). Equations 25 represent the percentages of sick outpatients and of inpatients evacuated respectively to external hospitals or safe care units. The dispatching of patients between external hospitals and OSR’s care units, is also specified. In equations 26, the input flows to the first activities are modelled. It represents the Inpatients and outpatients arriving or staying in the care unit k evacuated at the period Pa. Respectively, the outpatient admissions and inpatient admissions of the evacuation poste, are calculated. Equations 26 define also the number of inpatients sent to the care unit r and the number of outpatients returning to home.

Basic model modification

$$\sum_{j=1 \mid j \neq k}^{N} XG(j,k,p) * Acc(j,k) \quad - \quad \sum_{j=1 \mid j \neq k}^{N} XG(k,j,p) * Acc(k,j) \quad = \quad 0$$

$$\forall p = ta+1,...,T \qquad (27)$$

$$\sum_{j=1 \mid j \neq k}^{N} XR(k,j,p) * Acc(k,j) \quad - \quad \sum_{j=1 \mid j \neq k}^{N} XR(j,k,p) * Acc(j,k) \quad = \quad 0$$

$$\forall p = ta+1,...,T \qquad (28)$$

The accesses via the evacuated unit are kept. Equations 27 and 28 replace respectively equations 2 and 3 for the evacuated unit k which has been isolated.

$$\sum_{j=1 \mid j \neq r}^{N} XG(j,r,p) * Acc(j,r) \quad - \quad \sum_{j=1 \mid j \neq r}^{N} XG(r,j,p) * Acc(r,j) + Input(r,p)$$

$$\geq \quad Inp(r,p) + Outp(r,p) + Inpev(p) \quad \forall p = ta+H,...,T \qquad (29)$$

$$\sum_{j=1 \mid j \neq r}^{N} XR(r,j,p) * Acc(r,j) \quad - \quad \sum_{j=1 \mid j \neq r}^{N} XR(j,r,p) * Acc(j,r) + Output(r,p)$$

$$\geq \quad Inp(r,p-H) + Outp(r,p-L) + Inpev(p-H) \quad \forall p = ta+H,...,T \qquad (30)$$

The acute patients from the evacuation poste are added to the inpatients and outpatients of the recovery unit r. Equations 29 and 30 replace respectively equations 2 and 3 for the recovery unit r. The sum of the data and of the variables of the right part of the inequation, is greater than the previous data, but equations 29 and 30 can be respected, on the one hand regarding the relational operator used, and on the other hand because “Output” data and “Input” data can be increased without unbalancing the flow problem, these data acting as a dummy sink.

6 Conclusions and Recommendations

The results of this deliverable are quite informative and revealing. A shortfall in resilience against a possible terrorist threat in OSR was identified. This is mainly because terrorism is not perceived as a real threat by the hospital and terrorist scenarios are not taken into consideration inside the EMPs. Despite the fact that both Internal and External EMP are quite developed and extensive (as expected for a hospital of this shape, type and function) and seems to be very effective in managing most of the possible emergencies, they appear to fail in handling a direct or indirect terrorist attack targeting the hospital. This reflects the situation of the most similar EU Hospitals according with previous THREATS project deliverables.

From this first overview of OSR in terms of emergency response capability and from a preliminary simulation of a terrorist scenario, it is possible to come up with some recommendations on how to increase OSR resilience to terrorist threats.

1) Review the EMPs, both External and Internal considering the scenario of a terrorist attack.
2) Consider the implementation of security measures like restrictions of access to the hospital, security checks for vehicles and people, “lock down”, “invacuation”, “shelter in place” procedures.
3) Increase the preparedness to handle terrorist scenarios promoting awareness, training and simulations to embed a culture of security awareness within staff.

The THREATS project recognises that recommendations for changes in the emergency procedures would also benefit from the optimisation techniques presented in Section 5. The IDEFØ model and CPLEX software will allow a test of the OSR plans now “as-is” model (D3.3). This may expose more weaknesses, studying and quantifying the impact of a terrorist attack in the actual situation and to suggest countermeasures and solutions to propose a “to-be model” of a better protected hospital.

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