THREATS
Terrorist attacks on Hospitals:
Risk & Emergency Assessment, Tools & Systems

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Decision making tools for mitigation: benchmark proposal; emergency management procedures; mathematical models, and results.

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Executive Summary

Deliverable 3.3 presents the decision making tools for the evaluation of a terrorist attack on a hospital that have been developed for the THREATS project. The reference model for the hospital is OSR in Milan. In order to quantify the impact of a terrorist strike on a hospital, relevant data must be collected, and suitable performance indicators need to be selected. These performance indicators allow a comparison between a hospital's activities in a crisis and during normal conditions. The objective is to let the human decision maker see the effect of the terrorist attack on the hospital and the consequences of choosing certain courses of action. By modelling emergency plans it is possible to help managers in making them more effective in terms of response (Chen, Guinet & Ruiz, 2015). With this in mind, this deliverable synthesizes the work done on tasks 3 and 4 of work-package 3. It includes:

1) Simulation proposals composed of:
    a) Data and Performance indicators. The first are based on collected data (inputs) and the second are calculated from the simulations of terrorist attack scenarios or during normal conditions (outputs). This has been done by taking data from the normal performance of OSR and analyzing them to permit the setting of a baseline of standard performance. It is necessary to generate this information because there is no standard benchmark for them. So, a benchmark has been created.
    b) The simulation tools used to study the impact of terrorist attack scenarios. Various terror attack scenarios were considered, and evaluations for the calculation of various performance indicators were done. The diversity of the terrorist attacks is also required to prove the genericity of our tools, such as the type of attack, the target, the delay of discovery and for recovery, etc.
    c) The simulation produces results of the scenarios of terrorists attacks, using standard emergency management procedures adopted at OSR. The external and internal emergency plans were examined, and modelled by the IDEF0 method. From the latter, some dynamic flow models were created to examine the response against certain terror scenarios. From this it was possible to identify certain "bottleneck" activities, although these were scenario dependent.
2) The vulnerability assessment approach is designed to increase the resilience of hospitals, based on scenario studies, integrating but not limited to the previous decision tools (D3.1). A vulnerability assessment approach was proposed in support for the cost benefit analysis between protected and unprotected hospital in our next deliverable.

From the modelling of the 'as-is' hospital model and the development of the simulation tool it is possible to assess the impact of a terrorist attack on a particular area of the hospital. It is also possible to evaluate different choices for managing a terrorist incident. The modelling tool offers options when the internal emergency management plan is activated and evacuation of an area is required. It calculates how long evacuation will take, demonstrates where the bottlenecks are in the process and what resources are required to reduce the evacuation time. Moreover, the modelling tool enables the human decision maker to calculate the potential loss of life, operational damages to the infrastructure and financial losses as a result of the

decisions made. By running different possibilities through the modelling tool, the human decision maker can devise and refine a more efficient internal emergency management plan. It is therefore a useful tool to mitigate the effects of a terrorist attack against a major hospital that is part of the critical national infrastructure.

1. Available data and Performance Indicators

In the deliverable D3.2, we proposed a generic decision making tool in order to simulate various flow propagation in the hospital (traffic, evacuation, contamination, etc.). To use such a tool, on one hand we have to collect data to feed the inputs of our model, i.e. to define the values of our parameters, and on the other hand to specify some performance indicators to synthesize the results of our simulations, i.e. the values of the output of our model. As our decision making tool represents the map of the hospital (physical model) and the processes of the main critical assets (functional models), two different kind of data must be collected.

1.1 Data for physical model

A terrorist attack is most of the time anonymous before it occurs, and it takes place during the regular activity of the hospital. We collect data from the normal performance of OSR and we analyze it to permit the setting of a baseline of standard performance. These should feed our model and furthermore should allow for the comparison of performance in a crisis situation with standard performance. It is necessary to generate such data because there is no standard benchmark.

In 2014, OSR performed (http://www.hsr.it/chi-siamo/) a total of about:

- 35,000 surgeries,
- 50,950 hospitalizations,
- 895,000 outpatient’s cares,
- And over 63,500 emergency admissions.

The financial turnover for 2013 was approximately €551, 8 million, i.e. €1.5 million per day. If we consider the same activity in 2013 than in 2014, the turnover per patient is €528, integrating all activities with the same weight.

From the 2014 activity, some average data can be proposed:

- The number of outpatients per day is 895 000 / (22 days*10 months) ≈ 4068, also we propose to consider 4000 outpatients per day. We suppose an average length of stay L for outpatients of 2.5 hours ($L \in \{1, 2, 3, \text{and } 4\}$).
- The number of inpatients per day is 50 950 / (22 days*10 months) ≈ 230, also we propose to consider 250 inpatient's admissions per day, and an average length of stay H of 3 days (i.e. 2 nights) regarding to the capacity of 1000 beds and an occupation rate of 75%. The patient admission time and the patient release time is set to 4PM every day, so the length of stay $H \in \{24, 48, 72\}$.
- The number of ED admissions per day is 63 500 / 365 ≈174.
- The outpatients, and the allotment of inpatient's beds per care unit, are detailed from the field, and are presented on Table 1.

The number of studied periods is set to 192 (24 hours * 8 days). Period 1 is the first day on 8AM for simulation.

Regarding entrances and exit possibilities to/from OSR:

- Two buses (925 and 923) and one subway arrive at OSR with a capacity of 100 people each. They are supposed to work 10 hours per day with a frequency of 12 minutes. Their capacities are 3 * 100 * 5 = 1500, i.e. 1500 passengers per hour.
- The public car park has a capacity of 1200 cars. On average, 150 vehicles per hour stay 2.5 hours, with a maximum of 220 vehicles per hour (OSR data on April 2014). We will consider an input flow of 220 vehicles per hour. Regarding the car park dedicated to employees, and based on the data of May 2014, we will hypothesize a flow of 130 vehicles per hour.

INPUT/OUTPUT		OUTPATIENTS		INPATIENTS	
A111	0	A111		A111	47
A112	0	A112		A112	0
A113	0	A113		A113	72
A114	0	A114	800	A114	0
A115	250	A115		A115	0
A116	0	A116	800	A116	0
A121	0	A121		A121	0
A122	0	A122		A122	21
A123	0	A123		A123	44
A124	0	A124	800	A124	0
A125	250	A125		A125	0
A126	0	A126		A126	8
A131	0	A131		A131	53
A132	0	A132		A132	124
A133	0	A133		A133	56
A134	250	A134		A134	0
A135	0	A135	174	A135	0
A136	0	A136		A136	0
A141	0	A141		A141	36
A142	0	A142		A142	6
A143	0	A143		A143	16
A144	0	A144		A144	14
A145	250	A145		A145	0
A146	0	A146		A146	0
A1511	0	A1511		A1511	81
A1512	0	A1512		A1512	48
A1513	0	A1513		A1513	60
A1514	250	A1514	800	A1514	0
A1515	0	A1515		A1515	14
A1516	0	A1516		A1516	0
A1521	0	A1521		A1521	34
A1522	0	A1522		A1522	74
A1523	0	A1523	800	A1523	0
A1524	250	A1524		A1524	0
A1525	0	A1525		A1525	10
A1526	0	A1526		A1526	0
A1531	0	A1531		A1531	0
A1532	0	A1532		A1532	0
A1533	0	A1533		A1533	0
A1534	250	A1534		A1534	0
A1535	0	A1535		A1535	0
A61	0	A61		A61	93
A62	0	A62		A62	50
A63	0	A63		A63	47
A64	250	A64		A64	0
A65	0	A65		A65	8
A66	0	A66		A66	0
People/hour	**2000**	**Patient/day**	**4174**	**Total beds**	**1016**

Table 1: Outpatient and allotment of inpatient's beds per care units

- We will consider a maximum input/output flow of 2000 people and relatives per hour, in order to integrate peak hours.

Table 1 details the entrances (input) and (output) exits of the hospital, the outpatient's admissions, and the inpatient's admissions, per IDEFØ boxes (leaves of the physical model).

1.2 Data for functional models

1.21 External Emergency Management Plan process

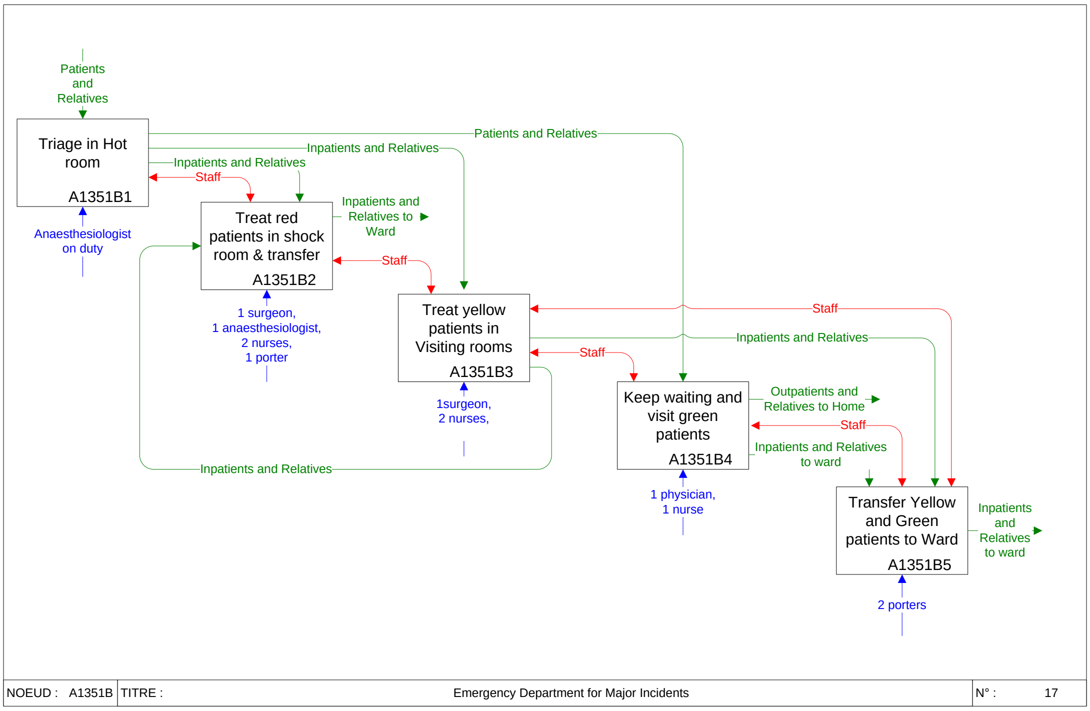


Figure 1: Emergency department organization for external emergency management plan

The external emergency management plan is the emergency organization to manage a massive influx of patients coming from outside the hospital. It replaces the regular activities of the Emergency Department in such situations.

The data for the 5 activities of the External Emergency Management Plan are:

- Triage in Hot room: 1 minute, with the anesthesiologist on duty (Triage Officer: TRO).
- Treat red patients in shock room and transfer: 30 + 30 = 60 minutes, i.e. 15 to 30 minutes per patient for the primary assessment and the stabilization, and 30 minutes per patient for additional tests (CT scan …) and transfer to ICU or OT, with 4 Major Trauma Teams available. Each Major Trauma Team (MTT) is composed of: one anesthesiologist, one surgeon, two nurses, and one porter. The four MTTs in shock room, are supplemented with one radiologist for "Ecofast" (fast scan), and one radiological technician for chest and pelvis X-ray.
- Treat yellow patients in visiting room: 30 minutes per patient, with one junior surgeon, two nurses, and one porter. The team can be supplemented with the

leader of the yellow area team (senior internal medicine doctor on duty), and one radiologist for “Ecofast”. We have a maximum capacity of two teams.

- Visit green patient: 10 minutes per patient with one physician, one nurse, and one porter.
- Transfer yellow and green patients to a ward: 30 minutes per patient, with 2 porters. Each of them can be dedicated to yellow and green patients respectively.

From the data of the Medical Response to Major incident exercises (http://www.macsim.se/), the casualties' flows are spread as above:

- Red patients: 10% fatality rate, 50% are transferred to OT, 40% to another ward;
- Yellow patients: 10% evolve to red patients, 40% are transferred to OT, 50% are directly transferred to a ward;
- Green patients: 40% return home after an accurate secondary survey and the psychological support, 10% are transferred to OT, 50% are directly transferred to a ward;

The arrival of casualties is set to: 4 red patients (20%), 6 yellow patients (30%), and 10 green patients (50%) per hour, i.e. 20 patients per hour.

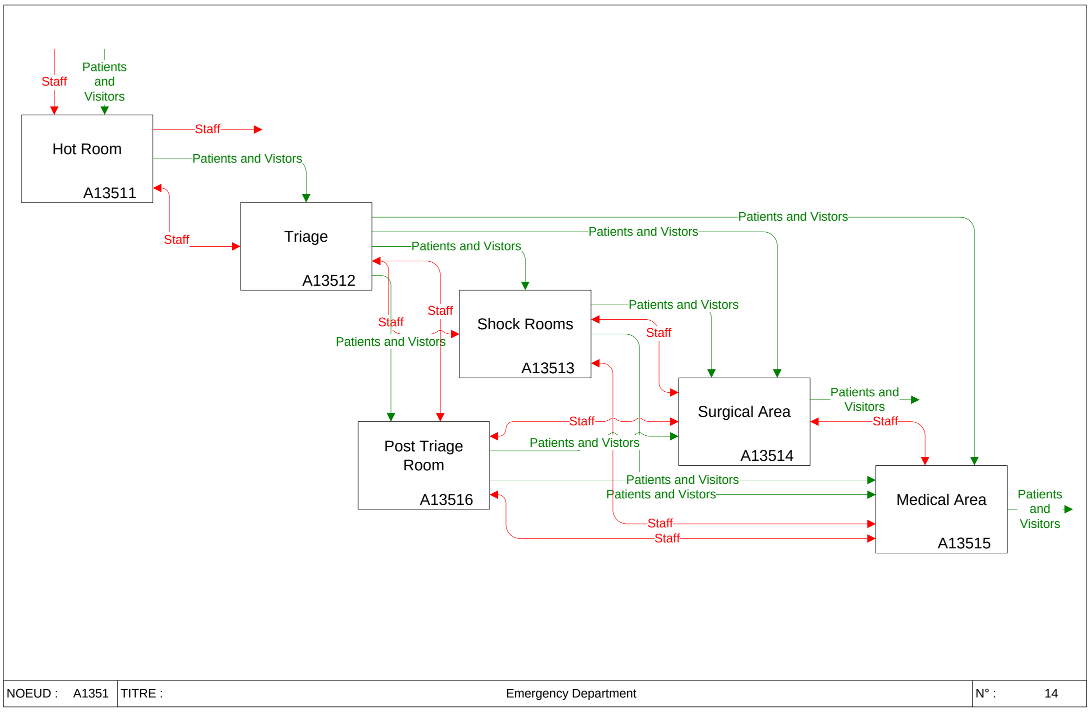


Figure 2: Emergency department organization for regular activity

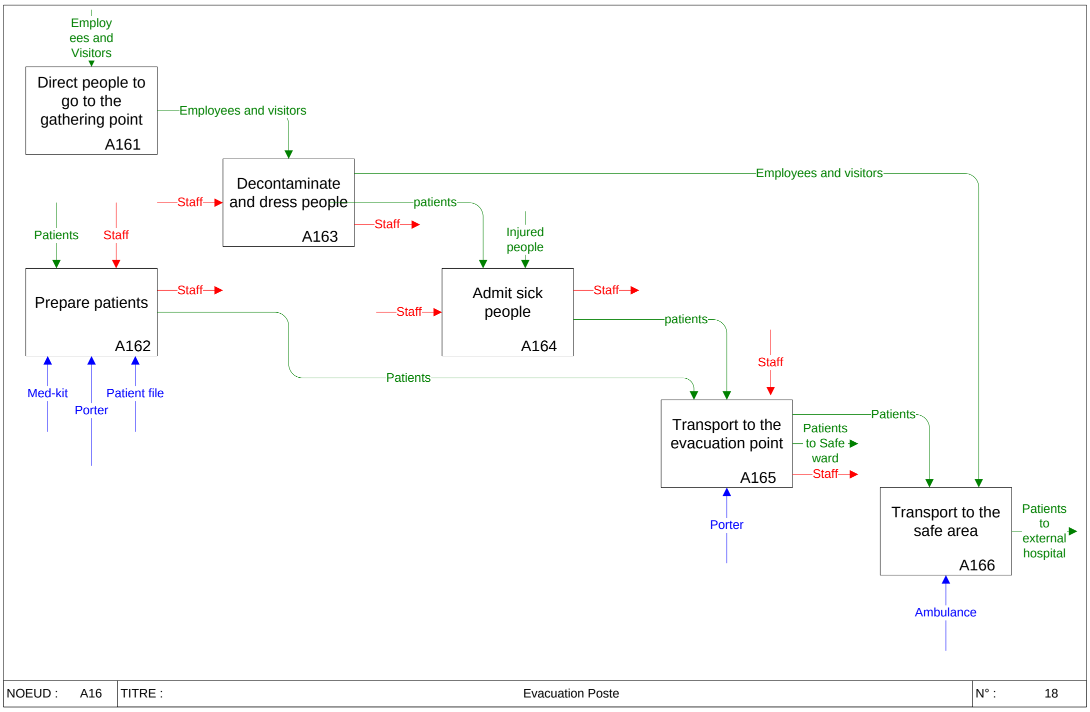
For the regular activity process of the emergency department the data of the activities are the following.

- Hot room admission: 1 minute per patient.
- Triage: 5 minutes per patient, with the triage nurse on duty.
- Shock room treatment: 30 minutes per patient.
- Surgical area treatment: 30 minutes per patient.
- Medical area treatment: 30 minutes per patient.
- Post-Triage regulation: 60 minutes per patient.

In order to switch the activity from regular to the admission of mass casualties, the data for the patient's flows in ED before emergency management plan activation, are spread as above: (the 23 September 2015, 23.00 scenario for regular activity of emergency department, is considered).

- Red patients to shock room: 3 patients cared by 1 team each; they will be transferred to ICU or OT.
- Yellow patients to surgical area: 9 patients cared by 3 teams, 8 will be transferred to a ward and 1 returns home.
- Green patients to medical area: 10 patients cared by 1 physician and 1 nurse, 50% return home, 50% are transferred to a ward.
- A maximum of 6 teams are available for red and yellow patients.

1.22 General Internal Emergency Management Plan process



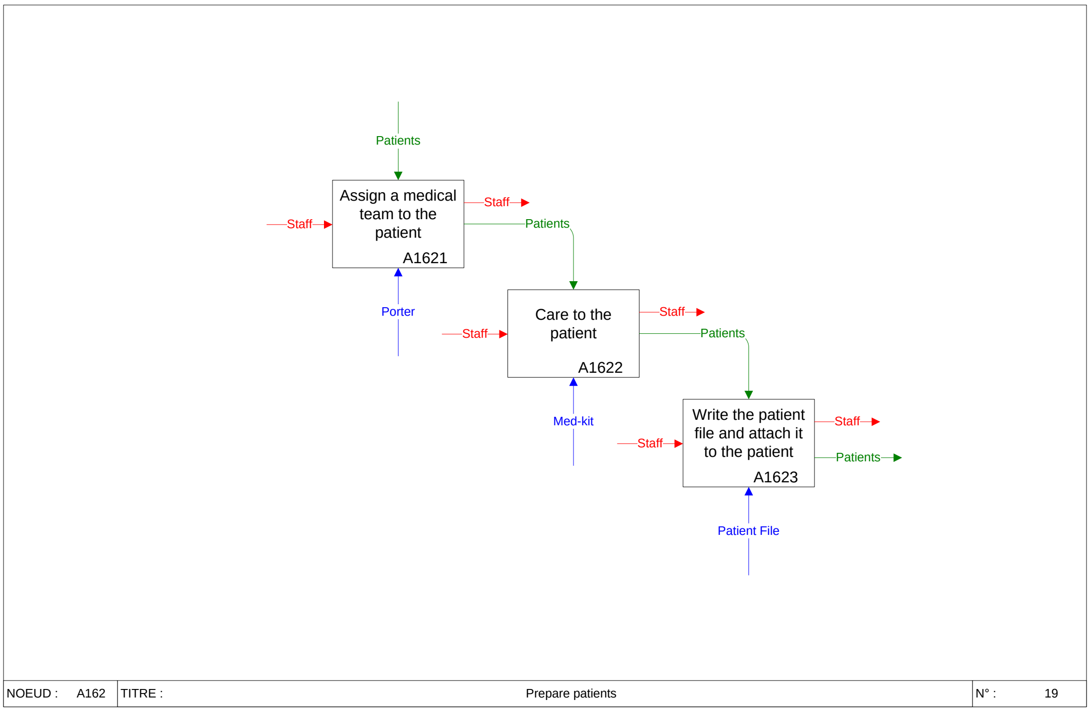


Figure 3: Internal emergency management plan

The internal emergency management plan, is represented as a virtual unit which is located close to the care unit or the building to be evacuated, e.g. for ICU patient evacuation it replaces the regular activity process of ICU. It is called the evacuation unit.

The proposed data for the 6 activities of the Internal Emergency Management Plan are:

- Direct people to go to the gathering point: 15 minutes.
- Prepare patients: 10 minutes, with two nurses or more for 20 patients.
- Decontaminate and dress people: 10 minutes, with one anesthesiologist and six nurses.
- Admit sick people: 10 minutes, with one physician and one nurse.
- Transport to the evacuation point: 20 minutes, with 6 porters.
- Transport to the safe area: 30 minutes, with 6 ambulances.

The number of porters and the number of ambulances are parameters to study, because the efficiency of the evacuation, i.e. the evacuation time, will be a key performance indicator.

1.23 Operating theatre process

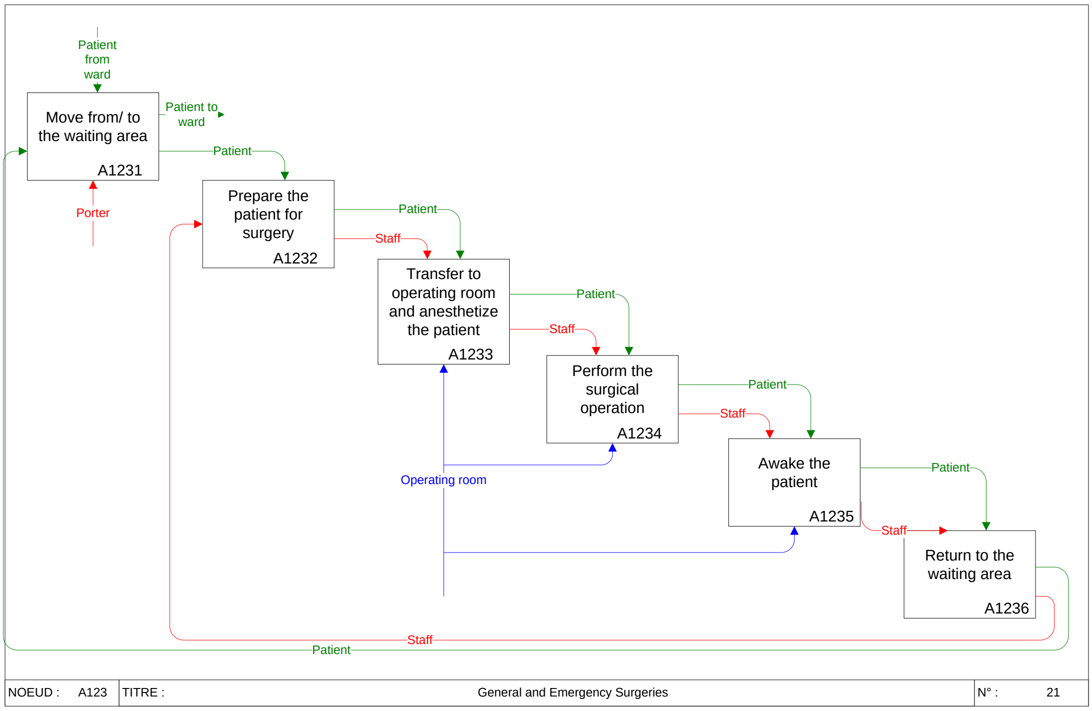


Figure 4: Operating theatre process of General and Emergency Surgeries

Regarding the great diversity of surgeries and of surgeons, the proposed data for the six activities of the operating theatre are mainly collected from the work of Gul et al. (2011). It sets:

- Move from/to waiting area: 20 minutes, with one porter.
- Prepare the patient for surgery: 10 minutes, with one nurse.
- Transfer to operating room and Anaesthetize: 10 to 20 minutes i.e. 15 minutes in average, with one anesthesiologist and one nurse.
- Perform the surgical operation: from 1 hour to 3 hours, i.e. an average of 120 minutes with two surgeons, one anesthesiologist and two nurses.
- Awake the patient: 15 to 30 minutes, i.e. 20 minutes in average, with one nurse and one anesthesiologist.

1.3 Performance Indicators

Some performance indicators are commonly used in previous studies (Abo-Hamad and Arisha, 2013):

- The average waiting time for a care,
- The number of waiting patients,
- The average patient length of stay,
- The resource utilisation rate,
- The pedestrian traffic,
- The most crowded place,
- The number of infected people…

We have selected some indicators per threat scenarios. The equations are expressed regarding to the models of the D3.2 deliverable.

1.31 Second strike

Scenario: 1) A first terrorist strike occurs in Linate Airport (Around 08 am, a bomb explodes in the main terminal killing 10 people and injuring 60 others, similar to the Orly airport scenario in 1983);
2) The emergency plan in Linate Airport is activated;
3) The OSR is alerted in preparation for the eventual massive influx of injuries (around 08.15) and it activates its external emergency management plan (08.15 alarm phase, 08.30 red alert when the first green patients spontaneously arrive);
4) While managing to clear the ED (around 0900 am) from the "non disaster patients", a private car pretending to come from the scene brings a patient to OSR emergency department;
5) The patient is triaged as green and while reaching the green area blows her/himself up revealing to be a suicide bomber, killing/severely injuring some staff, among others the TRO;
6) The ED is in chaos: no leadership, triage and red area are severely damaged.
7) Activation of the Internal emergency management plan and arrival of the Fire fighters to check the security and secure the whole block C;
8) The same strike has been carried out in some other big hospitals in Milano: the emergency management services do not know where to send the severely injured patients and how to rescue the one inside the attacked hospitals.

Regarding to the external emergency management plan, we can calculate the number of treated patients TP (the outputs: $XED(i,N+1,p)$) before the second strike, at period t2, i.e. the time for performing the second strike, skirting the counter-measures:

$$TP = \sum_{p=1}^{t2} \sum_{i=1}^{N} XED\ (i, N+1, p)$$

TP is the sum of patients treated by the last activity of the external emergency management plan, from period 1 until period t2 included.

Regarding to the internal emergency management plan, we can calculate the time ET to evacuate the staff, patients, and relatives after the second strike, i.e. the time for performing the last activity (*XEP(i,N+1,p)*) of the internal emergency management plan for the last casualty:

$$EP(p) = \sum_{i=1}^{N} XEP\ (i, N+1, p)$$

EP is the number of people evacuated for period p, i.e. the number of people treated by the last activity of the internal emergency management plan, for period p.

$$ET = MIN[\ p \mid \sum_{t=p}^{T} EP(t) = 0\ \forall\, p = 1, \ldots, T\ ]$$

ET is the last period when people are evacuated, i.e. the period after which no people is evacuated.

1.32 Structure / facilities damage

Two possible structural or facilities disasters are suggested.

Medical gas scenario: A former OSR maintenance technician was fired by OSR and he has lost his appeal to the court. He works as driver for an external ambulance service supporting the OSR. Being very disappointed by the actions of his former employer OSR, he is approached by a member of an organization (political, religious) and has been convinced to make an attack against the hospital upon payment of an amount of money. Two rudimentary bombs are fabricated, the first bomb is placed in an ambulance in a car-park close to the first medical gas stock, the second bomb placed close to the second medical gas stock. As he detonates the two bombs the OSR has no more O2 flow, except for the few O2 bottles available for emergency. The Internal Emergency Plan is activated for transferring the patients who depend from O2 flow, to external hospitals, under the supervision of the Milan Health Department. No dedicated security lockdown was provided.

Electric grid scenario: OSR is composed of 11 buildings which are supplied by several electric grids (interconnected systems to deliver electricity from public network, each system is protected with a power station using fuel). An electric grid supplies several buildings, and is supplemented by an electricity generator. Grids are interconnected, but the destruction of one of them breaks the connection with the others. A terrorist puts a bomb on the electric grid supplying buildings A to C, because the building C shelters the emergency department. As the bomb is detonated on the morning, no more electricity can be provided to the units of the buildings A to C. Operating rooms must finished their activities with patients manually ventilated. The ICU wards have ventilation equipment with batteries, but they must evacuate their patients. Inpatients in other units must be evacuated to other secured units or to external hospitals, depending on the available beds. The outpatient activities are cancelled and some employees return home.

Regarding to the internal emergency management plan, we can calculate the time ET to evacuate the patient dependent from O2 flow, i.e. the time for performing the last activity (*XEP(i,N+1,p)*) of the internal emergency management plan for the last patient:

$$EP(p) = \sum_{i=1}^{N} XEP\ (i, N+1, p)$$

EP is the number of people evacuated for period p, i.e. the number of people treated by the last activity of the internal emergency management plan, for period p.

$$ET = MIN[\ p \mid \sum_{t=p}^{T} EP(t) = 0\ \forall\, p = 1, \dots, T\ ]$$

ET is the last period when people are evacuated, i.e. the period after which no people is evacuated.

Regarding to the turnover per patient which is equal to 528 Euros and a length of stay of H days, the average turnover loss "LOSS" (operational cost) is equal to:

$$LOSS = \sum_{p=1}^{T} EP(p) * 528 * H/2$$

This scenario could be modified to study a terrorist attack to the electric grid of OSR. The worst scenario leads us to evacuate not only the ICU patients but all the patients from buildings A to C.

1.33 CBRN attacks

Cesium 137 scenario:

1) A few weeks before the attack, one of the staff of the hospital cleaning company reports having misplace/lost his/her uniform containing their personal badge and pass. The company provides a new one.
2) A suicide terrorist expert in nuclear material, wearing a cleaner`s uniform, gets access to the offices where all the nuclear materials are stored.
3) He/she locates the Cesium 137 irradiator and realizes that it is very unprotected.
4) The following night, he/she opens the room with the badge, breaks the steel iron box (with a laser device/acid/oxydric flame) and easily steals the Cesium powder. He/she just wears protective gloves.
5) Then, he/she spreads it in all the rooms of the Emergency department this action takes place during the night because the irradiator room is not frequented during that time. The Emergency department is selected as a target because it is the most crowded area at night time. All the people (patient + staff) of the ED are contaminated. The hospital is informed of the contamination by anonymous telephone call the following day/ .

Bio-Virus scenario:

1) A native Italian affiliated to an international terrorist organization is a medical doctor with a virological back-ground. He/she pretends to be funded by a famous pharmaceutical industry, and approaches the Director of OSR Foundation for a PHD in virology. He/she has been referred to the P3 "SARS" laboratory and works there for a while. He/she has access to the P3 laboratory and to the repository of the SARS virus.
2) One night, he/she takes some material from the SARS vials, and grows up enough viruses;
3) He/she prepares a dispersion solution.

4) Dressed as a cleaner, with enough PPE to be protected but not "unusual", he/she sprays over the surfaces of the primary acceptance central in the time of major influx of patients.
5) All the people passing by the place (almost all the outpatients and the inpatients over 4 hours, regarding to the estimated time for survival of the virus on the surfaces) have contact with the virus.
6) According with rate of infection, 10% of contacts get the infection. Infected people transmit the infection from person to person through air-droplets, 4 days after. Contacts are in the whole hospital (including staff) and out of the hospital through contacts. We can presume that there will be an increased incidence of severe pneumonia inside the most vulnerable people, and then there is an evidence of the same strain of virus at the investigations. No treatment and no vaccine are available. Only the support to vital functions is possible. Then some cases will start inside the medical staff and will be reported in other hospitals. The Preventive Medicine Department will be informed. Quarantine measures and active case finding policies will be implemented. An unusual SARS epidemic will be declared with impact on whole Milano and eventually the need to transfer ICU patients out of Milano and Lombardy region because of shortness of ICU beds. After some time spent looking for the single first case that started the epidemic, an anonymous letter will reach the hospital saying that it was an intentional act, and to substantiate this, recommends a check of the vials inside the P3 lab should be undertaken. The fake PhD student disappears.

A tuberculosis bacteria scenario in the same context will be also investigated in the next deliverable.

We retain the hypothesis that the attempt is done on period t1, and that the contaminated area ca is cordoned off on period t2 (ca could be the most crowded place). The number of contaminated people (human losses) is CP. Human transmission is not considered, because of the incubation duration which is of several weeks, knowing that the studied horizon is 8 days. Nuclear threat is similar than Biological threat. In this last case Cesium 137 powder is spread in the Emergency Department. Several contamination areas can also be considered.

$$CP = \sum_{p \in [t1, t2]} \sum_{j=1 | j \neq ca}^{N} (XG\ (j, ca, p) + XR\ (ca, j, p))$$

CP is the number of people crossing the contaminated area ca, people incoming and outgoing respectively.

1.34 Others scenarios

The scenario of a firearm attack against a VIP, the cyber-attack scenario and the animal activist scenario, have not been selected for simulation at this time, because once the attempt is done no other propagated damage occurs. The counter-measures are the only barrier against such attacks, for a hospital.

1.4 Additional performance indicators

Other performance indicators can be calculated to evaluate the efficiency of a process. We illustrate them with the external emergency management process.

The resource utilization rate UR(i) can be calculated for each activity (where *XED(i,p)* represents the treated patients, and *CAP(i,p)* is the activity capacity). The BR utilization rate for the bottleneck resource of the emergency department is expressed below.

$$UR(i) = 1 - \left(\frac{\left(\sum_{p=1}^{T}(CAP(i,p) - \sum_{j=1 \mid j\neq i}^{N}(XED\ (i,j,p) * Acced\ (i,j))\right)\right)}{\sum_{p=1}^{T} CAP(i,p)}\right)$$

Per activity i, the resource availability rate is equal to the resource capacity minus the used resource, divided by the resource capacity. The rate is calculated for the whole horizon T. The resource utilization rate UR(i) is equal to 1 minus the resource availability rate.

$$BR = MAX[\ UR(i) \mid \forall i = 1, \ldots, N\ ]$$

BR is the resource utilization rate of the bottleneck activity.

The maximum average number of waiting patients MW can be useful to judge the quality or efficiency of a process (where *WED(i,j,p)* represents the treated patients,).

$$MW = MAX\left[\frac{\sum_{p=1}^{T}(WED(i,p))}{T}, \forall i = 1, \ldots, N\right]$$

The average number of waiting patients per period is calculated over the whole horizon T, for each activity. MW is the maximum average number of waiting patients per period, over all activities.

The most crowded area MC during the busiest period is:

$$MC = MAX\left[\sum_{j=1}^{N}(XG\ (j,i,p) + \ XR\ (i,j,p))\ \mid \forall i = 1, \ldots, N;\ \forall p = 1, \ldots, T\right]$$

By calculating the traffic for each area considering incoming and outgoing patients respectively, the area with the maximum traffic MC is the most crowded.

1.5 Objective function to optimize during simulation

$$Min\ Z = \overbrace{\left(\sum_{p=1}^{T}\left(\sum_{i=1}^{N}\sum_{j=1}^{N}(XG(i,j,p) + XR(i,j,p))\right) * p\right)}^{Minimum\ traffic\ to\ reach\ or\ leave\ the\ care\ units} + \overbrace{\sum_{i=1}^{N}\sum_{p=1}^{T}\sum_{k=1}^{N(i)}(WGU(i,k,p) * p)}^{Waiting\ patients\ of\ care\ units}$$

Initially, our first models try to minimize the traffic in the hospital. In the first part of the objective function (i.e. minimum traffic), minimizing the traffic is equivalent to find the

shortest path for all the hospital flows. The weighting by p of the first part doesn't change the results, because finding the shortest path in distance is equivalent to find the shortest path in time, without taking into account traffic congestion characteristics. Regarding to the second part (i.e. the waiting patients *WGU(i,k,p)* for the kth activity of care unit i), we try to treat the patients at the earliest for every activity of each care unit i.
In such a way, we can integrate all the objective functions in a single criterion with the same weight (p), and it can be easily optimized.

Regarding to our indicators:

- Minimizing the waiting patients of each care unit, minimize MW for each care unit, maximize the efficiency of each care unit, i.e. maximize the utilization rate UR(i) for the earliest periods and maximize TP, the number of treated patients in the earliest periods;
- Minimizing the waiting patients of the evacuation unit, minimize the time ET to evacuate the patients from the buildings or services/departments which are out of order;
- Minimizing traffic in the hospital allows us to propose entrances from outside and exits to outside, the closest from/to the care units, i.e. to minimize people crossing in common areas, except if patients must go to a common admission unit for registration; the MC and CP indicators will be minimized;
- As addition operator is commutative, the LOSS indicator is independent of the periods of treatment of patients, it evaluates the cost of the consequences regarding to operational damages…

2. Simulation tools

Considering the IDEFØ model of OSR, the physical view of the hospital model is composed of 12 diagrams of care units and services. The decomposition tree is of 4 levels and has 47 leaves which represent 47 services/units or sets of them. 199 direct accesses between sets of services/units have been modeled. 9 other diagrams of activities allow us to model the processes of the Emergency Department, the Operating Theatre, the Emergency Managements plans…, which define critical assets regarding to terrorist attacks. The physical view shows a picture of the hospital. In order to study the dynamic of the hospital by simulating terrorist attacks, a simulation tool has been designed which requires a limited number of parameters (care unit admissions and care unit discharges). To evaluate the different scenarios of terrorist attacks, we studied the patient traffic in the hospital. First we export from IDEFØ model the different access between the leaves (services/units) of the decomposition tree of the physical view. The result is modeled by a binary matrix where the lines/columns represent the leaves, and the intersections between lines and columns identify the presence (1) or absence (0) of a direct access. This matrix defines a graph and a multi-period flow problem is studied on this graph. In valuating on one hand the patient inputs to the hospital and on the other hand the care units' admissions which are both located at the leaves of the IDEFØ model, the hospital entrance flows can be studied. In defining on one hand the patient exits of the hospital and on the other hand the care units' discharges which are both located at the leaves of the IDEFØ model, the hospital departure flows can also be studied. These two flow problems are connected by the admissions of outpatients and inpatients which stay at the hospital for a given length of stay and will be discharged later. They have been modeled by a linear program. The Cplex solver (IMB ILOG CPLEX, 2015) has been chosen to solve it. In a first section, a linear problem is modelled and in a second section, the benefits of this model are discussed.

2.1 The flow model

2.11 Parameters

- N: Number of services/units (number of leaves of IDEFØ's tree, N is equal to 47);
- T: Number of periods (192 hours i.e. 8 days);
- 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;
- Input(i,p): Number of people (inpatients, outpatients, and relatives) incoming in i directly from outside (entry point) on period p;
- Output(i,p): Number of people (inpatients, outpatients, and relatives) 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;
- Outp(i,p): number of outpatients (patients which stay less than one night in the hospital) on period p;.

2.12 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.

2.13 Model

Objective function:

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

Constraints:

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

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

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

2.14 Comments

This linear program minimises the traffic of the whole hospital over the whole horizon (equation 1). In equations 2, the flow entrances from neighborhood units, minus the flow exits to neighborhood units, plus the entrances to i from outside ("Input" data represents the inpatients and the outpatients, relatives are considered as outpatients), are greater or equal to the inpatient absorption by the care unit i (the inpatient admissions are modeled by "Inp" data), plus the outpatient absorption by the care unit i (the outpatient admissions are modeled by "Outp" data). Equations 2 are conservation flow constraints, they model the entrances of the care unit i. Equations 3 are the opposite equations, 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 exits are regrouped within the "Output" data), are greater or equal to the previous absorption of the care unit i for inpatients which are now released ("Inp" data represent the previous admissions of inpatients which entered H periods before p, according to the length of stay equal to H), plus the previous absorption for outpatients which are now released ("Outp" data represent the previous admissions for outpatients which entered L periods before p, according to the length of stay equal to L).

The dynamic model of the hospital represents 47 units or services modeled by IDEFØ's boxes located at the leaves of the decomposition tree. Solving the multi-period traffic problem for 192 periods which represent 8 days of 24 hours leads to 848 256 decision variables and 18 048 constraints. Considering the data in section 1, the linear program has been solved with Cplex (IBM ILOG CPLEX, 2015), the computation time is around 1 minute and the total hospital traffic is equal to 47 182 crossings of patients and relatives over the whole horizon. The most crowded place has a maximum traffic per hour of 336 patients and relatives. It can reasonably be argued that the most crowded place is also the most vulnerable place in terms of potential injury to people; although note that the most crowded place is not necessarily the most vulnerable in terms of potential damage to infrastructure or services.

Our linear program is a dynamic model of the physical view of the IDEFØ model. Some critical care units have been described following a functional view, they leads to give us a sub-matrix of activity successions ((Accun(j,k)) for each care unit whose activities are described on diagrams. The description of a care unit or an emergency management plan leads us to extend our physical flow model by integrating the resulting care unit linear subprogram. Only a synthesis of the care unit subprogram is shown, for more details the reader will refer to the deliverable 3.2.

As a care unit has internal flows and a limited capacity, the traffic variables XGU(k,j,p) must be defined with the waiting variables WGU(k,p) which represent the inpatients and the outpatients of the care unit who wait for treatment. The inventory flow constraints 5 are added:

$$\sum_{j=0 \mid j \neq k}^{M} XGU(j,k,p) * Accun(j,k) - \sum_{j=1 \mid j \neq k}^{M+1} (XGU(k,j,p+d(k)) * Accun(k,j))$$
$$+WGU(k,p) \quad = \quad WGU(k,p+1) \quad \forall k=1,...,M \quad \forall p=1,...,T-d(k) \quad (5)$$

Given the capacity "Capun(k,p)" of the resources (physicians, nurses, emergency teams…) allocated to the unit activities , some capacity constraints must be added:

$$\sum_{j=1 | j \neq k}^{M} \left(\sum_{q=p-d(k)+1}^{p} XGU(k,j,q) * Accun(k,j) \right) \leq Capun(k,p)$$

$$\forall k = 1,...,M \quad \forall p = d(k),...,T \quad (6)$$

In equations 6, 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(k)”.

Regarding efficiency and quality of care, the number of waiting patients (equation 7) is minimized. A weight p is assigned to the waiting patient numbers in order to deliver the care at the earliest and to minimize the waiting times. For more details, see the deliverable 3.2.

$$Min\ Z = \overbrace{\sum_{i=1}^{N} \sum_{p=1}^{T} (WGU(i,p) * p)}^{Waiting\ patients} \quad (7)$$

2.2 Simulation

Our flow model allows us to evaluate the traffic in all care units and more generally in all areas of the hospital. The impact of bombing attacks in the most vulnerable places (general admission unit), i.e. the most crowded places, can be easily studied considering the traffic calculation. If a CBRN (chemical /biological/radiological/ nuclear) attack can be perpetrated in some areas, we can calculate the number of contaminated people from the beginning period of the anonymous attack until the period of cordoned off the contamination areas. In the case of the activation of an internal emergency management plan for the evacuation of a care unit (e.g. an intensive care unit, following medical gas stock destruction) or a building (e.g. an electric power failure), we can calculate, firstly the number of people to be evacuated, and secondly the time required to evacuate patients, relatives and staff, simulating a virtual care unit process (located to an IDEFØ leaf, i.e. a care unit, or to an IDEFØ branch i.e. a building) which represent the evacuation organization. Some practices can also be investigated such as open space. If we limit the hospital access, we note that the traffic increases in some areas which become more vulnerable.

Regarding the severity criteria, our flow model enables us to calculate the number of deaths or injured people, i.e. the human losses. The infrastructure damages can be indirectly calculated, considering the damaged and contaminated areas or equipment. Knowing the turnover per patient and per day, operational damages can be evaluated considering the number of evacuated people to external hospitals, or considering the number of periods of closure of the care unit (cleaning time, or decontamination time) and its capacity.

3. Scenario studies

The next deliverable which will compare “as-is” systems i.e. without specific protection against terrorists, and “to-be” systems i.e. with counter-measures against terrorist attacks, will be mainly a cost-benefit analysis between this two configurations based on the loss of life, operational damages to the infrastructure, and financial losses as a result. This section is devoted to show some examples about the potential of our flow model in this direction.

3.1 Second strike

For the second strike scenario, there are three steps. First, the regular patients must be treated in the emergency department; second, the emergency department receives the first patients from Linate airport; third, all the patients and staffs must be evacuated out of the emergency department, because of the second strike. Regarding to the scenario simulation, the regular emergency management model, and the internal emergency management model, are used. We suppose that, at period 1, the attack at the airport begins, and there are still 22 regular patients (3 red patients, 9 yellow patients, and 10 green patients) at the emergency department who need to be treated. During the treatment of these 22 regular patients, the emergency department only accepts new patients who are injured by the terrorist attack. At the same time, 10 green patients (a third of the 30 green patients, i.e. 50% of the 60 injured people) by the terrorist attack at the airport, arrive to the emergency department by cars. They are transported to the nearest hospital (OSR) by their relatives going with them to the airport.

We hypothesized that, at the beginning of period 2, there is a second strike at the emergency department. The second strike arrives in the main hall of ED near the waiting room for green patients. The employees who are in hall to receive patients, are killed (the anesthesiologist on duty with one nurse). Red and yellow patients with staff (6 surgical teams: 3 of 5 people and 3 of 3 people) are protected by the walls. Half of green patients and employees (1 physician and 1 nurse) in visiting rooms, are injured. At the beginning of period 2, the numbers of red patients, yellow patients and green patients, are 3, 9 and 20 respectively. The injured staff should be evacuated to other units, as well. So, the total number of people who need to be evacuated is 34 (20+3+9+2=34). Here, the uninjured staff can evacuate the patients and the injured employees. All the evacuated people will be transferred to a safe unit in OSR. The objective of the terrorists is that the ED is out of order, and cannot receive patients from the Linate airport.

Since the resources are enough, at period 7, all the patients have been well evacuated. Figure 8 shows the waiting patients to be prepared and the number of evacuated patients. The horizontal axis represents the periods and the vertical axis is the patients' number. There is no patient waiting for transportation. From this figure, it can be found that the bottleneck activity is "prepare patients" (see Figure 3). From period 4 to period 6, 9 patients (maximal evacuation capacity per period) have been evacuated to other units per period. At period 7, last 7 patients have been well evacuated.

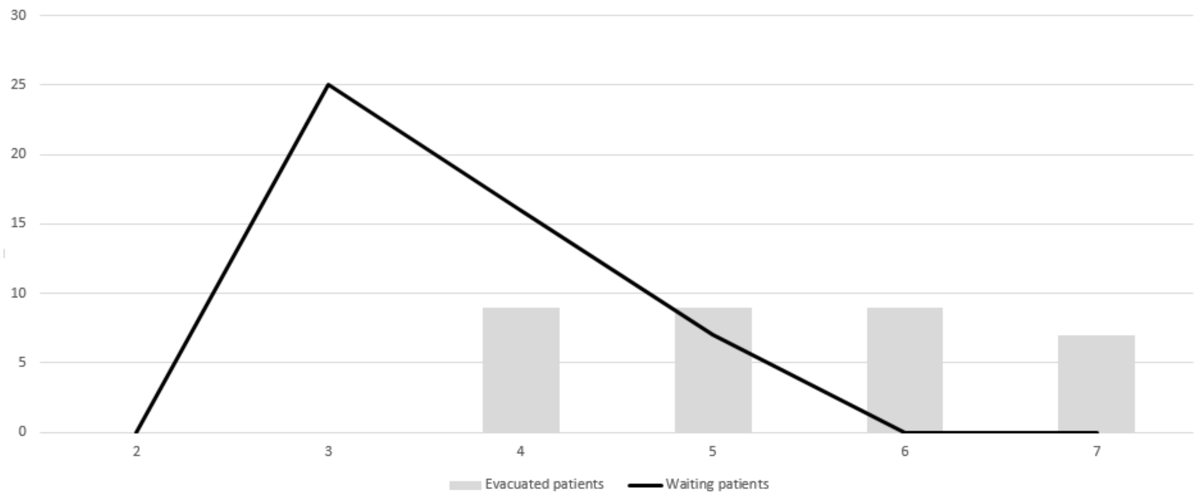


Figure 8: The number of waiting patients to be prepared and the number of evacuated patients

3.2 Structure/ facilities damage

3.21 Electric grid failure

After the electrical failure due to a terrorist attack on an electric grid, all the inpatients in buildings A, B and C should be evacuated, i.e. 18 units should be evacuated. We suppose that the evacuation starts from period 73 (8AM on the third day). The value of parameter 'sick' is equal to 0 (see the flow between A163 and A164 of the internal emergency management plan in section 1.22), because the evacuation cause is an electrical failure. The electric failure takes place on day, and outpatients are delayed or they go back home, employees as well. We suppose that 40% of all the evacuated inpatients will be regrouped in the unit A144 (level 1, building D) before to be dispatched in different wards, and 60% of all the evacuated inpatients are sent to external hospitals. Regarding to the scenario simulation, the physical model of the hospital and the functional model of the evacuation unit are used (see annex 1). The evacuation post is located in the diagram A1 of the IDEFØ model, as a new building.

In total, there are 361 inpatients, who need to be evacuated. In the basic scenario, we use 36 nurses, 18 porters and 6 ambulances to evacuate these 361 inpatients. At period 94, all the people have been evacuated. 21 periods (hours) have been used to evacuate all the people. If we suppose that the turnover of one inpatient is 528 Euros per day, the total loss of patients is 114 365 Euros (114 365=528*361*0.6*H/(24*2)).

Figure 5 presents the number of waiting patients to be transported by ambulances, the number of waiting patients to be prepared by nurses, the number of evacuated patients to other units and the number of patients evacuated to other hospitals. The horizontal axis represents the periods and the vertical axis is the number of patients. From this figure, it can be found that at the beginning of period 74, more than 300 patients are waiting for being prepared. But, all these patients have been well prepared at the beginning of period 80. At the beginning of period 83, the number of patients waiting to be transported by ambulances, reaches the largest. There is no patient waiting for being transported by porters. All the patients who should be transported to other units have been well transported at the beginning of period 82. From the beginning of period 82 to the beginning of period 94, we just transported the patients who should be evacuated to other hospitals. Therefore, we can get the conclusion that the bottleneck activity is “Transport to the safe area” (by ambulances).

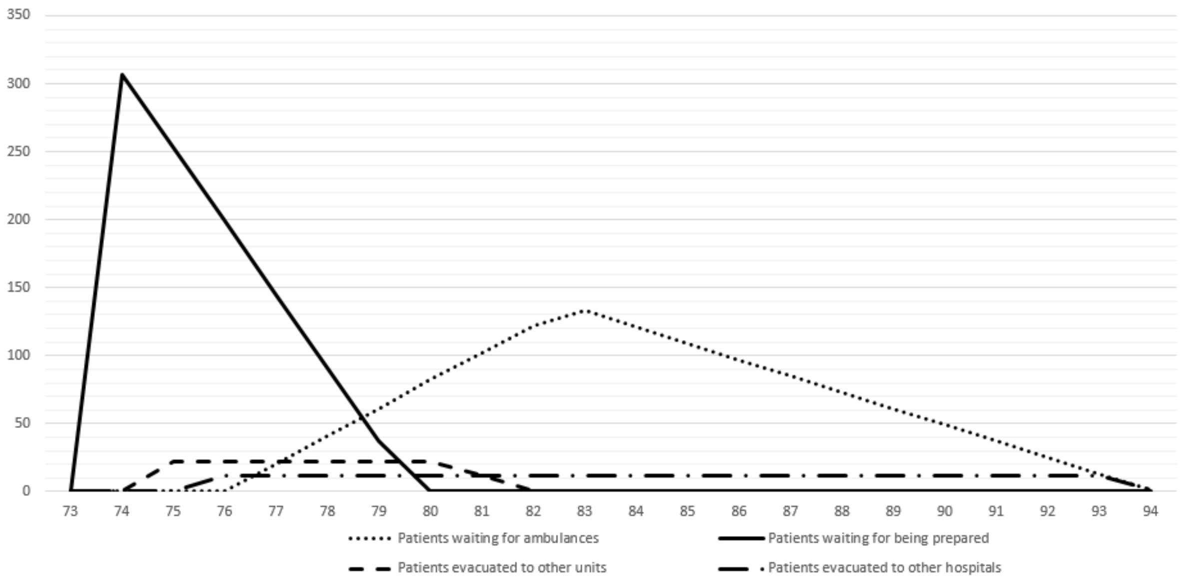


Figure 5: Waiting inpatients and evacuated patients during the evacuation process

The Figure 6 shows the required evacuation time under different capacities of nurses, porters and ambulances. The horizontal axis represents the resource configuration and the vertical axis presents the completion date of the evacuation. This figure is logical and proves the correctness of our model (see annex 3 for more clarity). It demonstrates that doubling the number of ambulances causes a considerable reduction in the required evacuation time: 20 hours (94–74) are required to transport patients with 6 ambulances, and 12 hours (85-74) are required to transport patients with 12 ambulances). Since the bottleneck activity is the transportation of patients to a safe area, it makes sense that increasing the number of nurses and the number of porters will not have a big impact on the used time to evacuate inpatients.

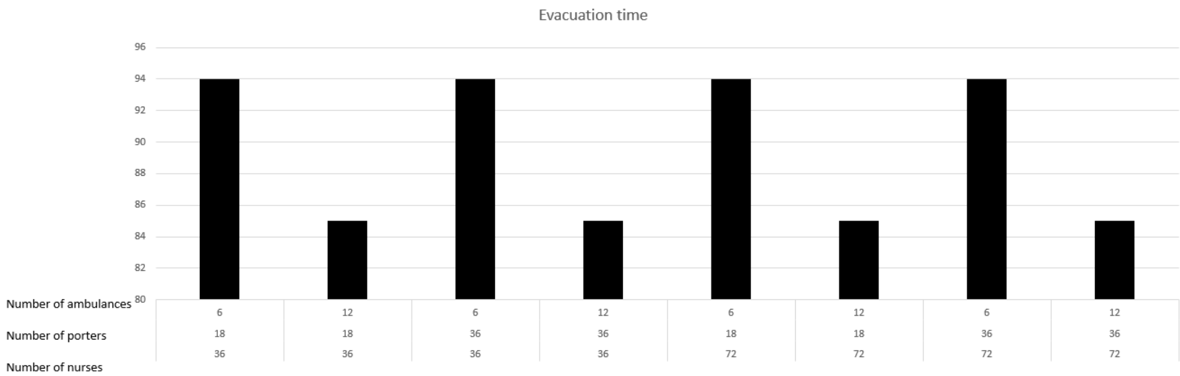


Figure 6: Completion time under different capacities of nurses, porters and ambulances

3.22 Medical gas failure

The terrorist attack begins at day 1 on period 2, and it destroys all the medical gas tanks. Patients from two different kinds of ICU units need to be evacuated: emergency ICU and neuro-surgical ICU. The numbers of patients who need to be evacuated from these two different ICUs are 12 and 16 respectively. The total number of people to be evacuated from ICU is 28. The three main activities to launch are organized in series; they detail the internal emergency management plan supporting hospital evacuation: prepare the patients, transport the patients to the evacuation point or a hospital care unit, and transport the patients to external hospitals. In every ICU, we suppose that 10 minutes are needed to prepare each patient (supply with an oxygen bottle, dress the patient, and attach the medical file) with 2 nurses, under the control of 1 physician and 1 head nurse. To transport the patients to the evacuation point or a hospital care unit, it will take 20 minutes in average depending on accessibility, and one porter with one nurse will be in charge of this transportation. In total, 2 physicians, 8 nurses, and 2 porters will be required. Emergency ICU patients (12 patients) will be evacuated to a hospital care unit where mobile ventilators are available, and neuro-surgical ICU patients (16 patients) will be evacuated to external hospitals. 30 minutes are needed to transport patients to external hospitals, and 4 ambulances are available. All these 28 patients need the oxygen bottles during the evacuation process. Regarding to the scenario simulation, the physical model of the hospital and the functional model of the evacuation unit are used. We suppose that one oxygen bottle can support a patient for two hours. At the period 10, all patients are well evacuated, i.e. 8 hours are required for patient evacuation and a patient needs 4 hours in average to be evacuated. Figure 7 presents the number of patients who are waiting to be prepared in different ICU units. The horizontal axis represents the periods; the vertical axis defines the number of patients waiting to be prepared. After calculation, 56 oxygen bottles (28*4/2) will be needed during patients' evacuation, and 144 oxygen bottles (12*24/2) will be needed for mobile ventilators if tanks are replaced within a day after evacuation. Regarding to the patients waiting to be prepared, the number of required nurses is the focal resource, especially if patients must be manually ventilated. The standard dimensioning of nurses is considered, other nursing resource rates will be considered in the next deliverable.

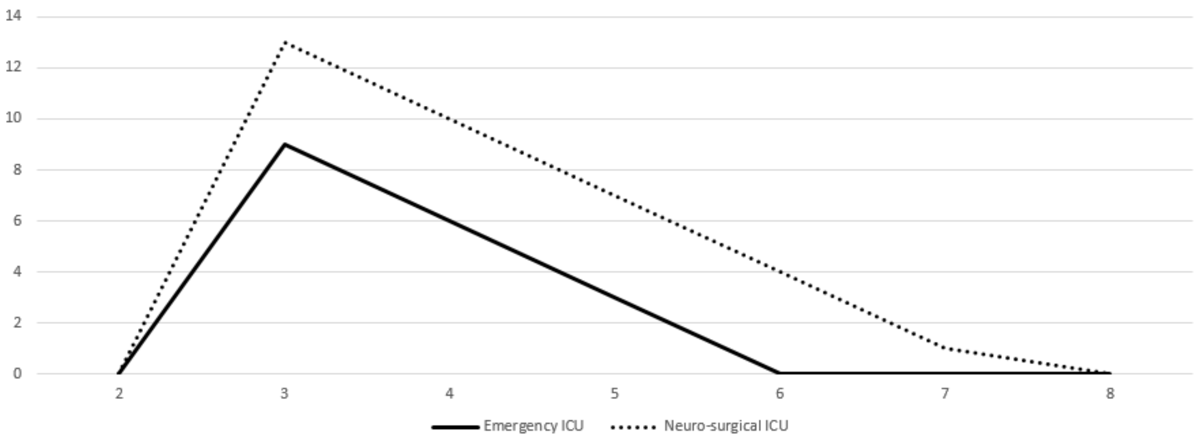


Figure 7: Number of patients waiting to be prepared in different ICU units

3.3 CESIUM 137 threat

We suppose that at period 1, a terrorist stole the CESIUM 137 and he/she spreads this latter in the emergency department. If patients are in contact with CESIUM 137 for at most two hours, they will not be infected. But, if they contact CESIUM 137 for more than two hours, they will be infected. Therefore, we suppose that at beginning of period 5, we detect the CESIUM 137 attack and we try to evacuate the patients and staff from the emergency department to other units. According to the data we got from OSR, we suppose that 22 regular patients are in ED at beginning of period 1, and that 7 new patients arrive in the emergency department per hour (1 red, 2 yellows and 4 greens). So, the patients needed to be evacuated to other units, are 50 at the most (22 + 7 * (5-1) = 50). Because 14 patients have already been treated at the beginning of period 5, the total number of patients that should be evacuated is 36. 28 physicians and nurses should be also evacuated. Therefore, the total number of people that should be evacuated is 64. Regarding to the scenario simulation, the regular emergency management model, the internal emergency management model, and the physical model of the hospital, are used. We suppose that 10 minutes are used for preparing per patient, and 6 nurses wearing protective suits will be responsible for this activity. To transport the patients from the emergency department to other units, it will take 20 minutes, and 3 porters wearing protective suits can be assigned for this activity. At period 14, all the patients can be well evacuated. Figure 9 presents the number of waiting patients to be prepared and the number of evacuated patients. The horizontal axis defines the periods, and the vertical axes the patient numbers. There is no patients who are waiting to be transported. So, the number of the porters is enough. At the beginning of period 13, all the patients have been well prepared. From period 7 to period 13, 9 patients (maximal evacuation capacity per period) have been evacuated to other units per period. At period 14, the last patient has been evacuated to other unit.

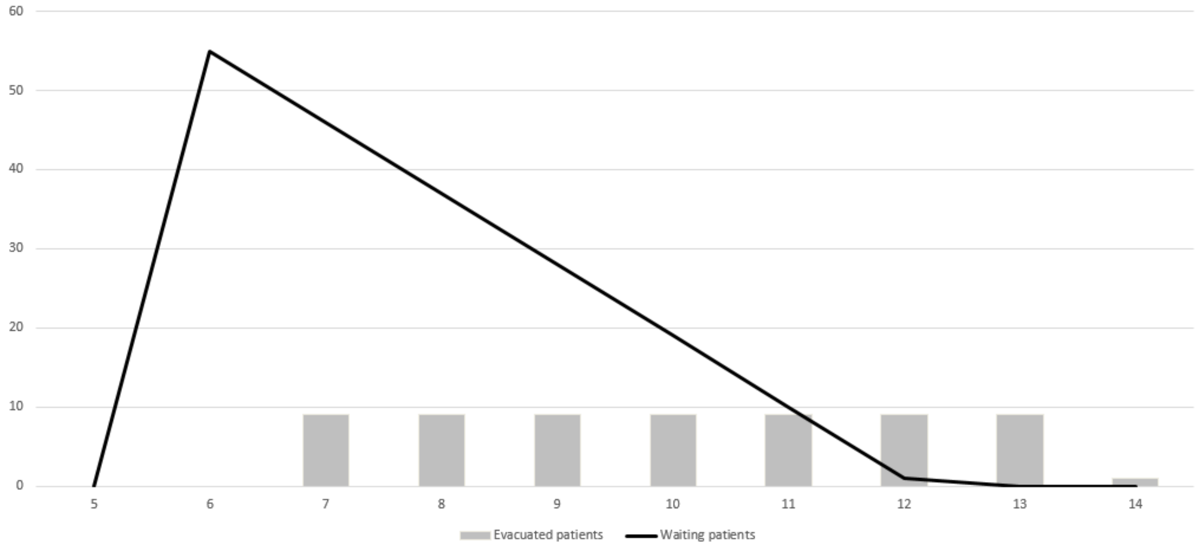


Figure 9: The number of patients waiting to be prepared.

3.4 SARS threat

The Cesium 137 scenario is a CBRN threat which focus on the emergency department and which can be early detected. The SARS scenario targets the whole hospital and beyond the city of Milan, where the attack detection is longer. We suppose that there is a SARS attack at the beginning of period 1, at the admission center of OSR. The virus SARS is transmissible between humans after 96 hours (4 days). Since all the patients (inpatients and outpatients) should go to the admission center first, all the patients have the possibility to be infected. Regarding to the scenario simulation, the physical model of the hospital, is only used (see annex 2). Here, we suppose that 10% of the patients may be infected. From period 1 to period 4, 13416 outpatients and 140 inpatients passed through the admission center. Therefore, the total number of infected patients is about 1356 ((13416+140)*0.1≈1356). At the beginning of period 5, the virus SARS is ineffective because of its lifetime. But the infected inpatients still have the possibility to infect others. Among 1356 infected patients, 14 of them are inpatients. We suppose that 10% of these infected inpatients will infect other OSR patients when they leave the hospital. Based on our basic model, from day 5 to day 8, these inpatients may meet

272 other patients in total. If we suppose that the contamination rate is 10%, the number of second infected patients is about 381 (14*272*0.1=381). In total, the number of total infected patients in OSR, is 1737 (1356+381).

4. A vulnerability assessment approach

A vulnerability assessment framework has been proposed in the deliverable D3.1. We have now instrumented it, and experimented it. It is not the focus of our deliverable, but we must propose a coherent investigation of hospital vulnerability, which integrates our last decision making tools. Our vulnerability assessment approach is composed of 5 steps (see Figure 12). Steps 1 to 3 enable us to calculate the threat likelihood. Regarding the likelihood of the terrorist attacks, it is extremely difficult to find historical data about terrorist events. Some authors propose to consider the ease of causing threats by potential adversaries, to better evaluate the likelihood of terrorist attacks (Wheeler, 2011; Ben Othmane et al. 2015). The ease of causing threats, is based on motivations and capabilities of attackers, and can vary with the attractiveness and the ease of access to the target. Steps 4 to 5 are dedicated to the severity of the hazard. The criteria to evaluate the consequences of a terrorist attack are multiple and concern human lives, infrastructure damages, environmental losses, loss of economic activities… A weighted risk analysis is required (Shahid, 2009).

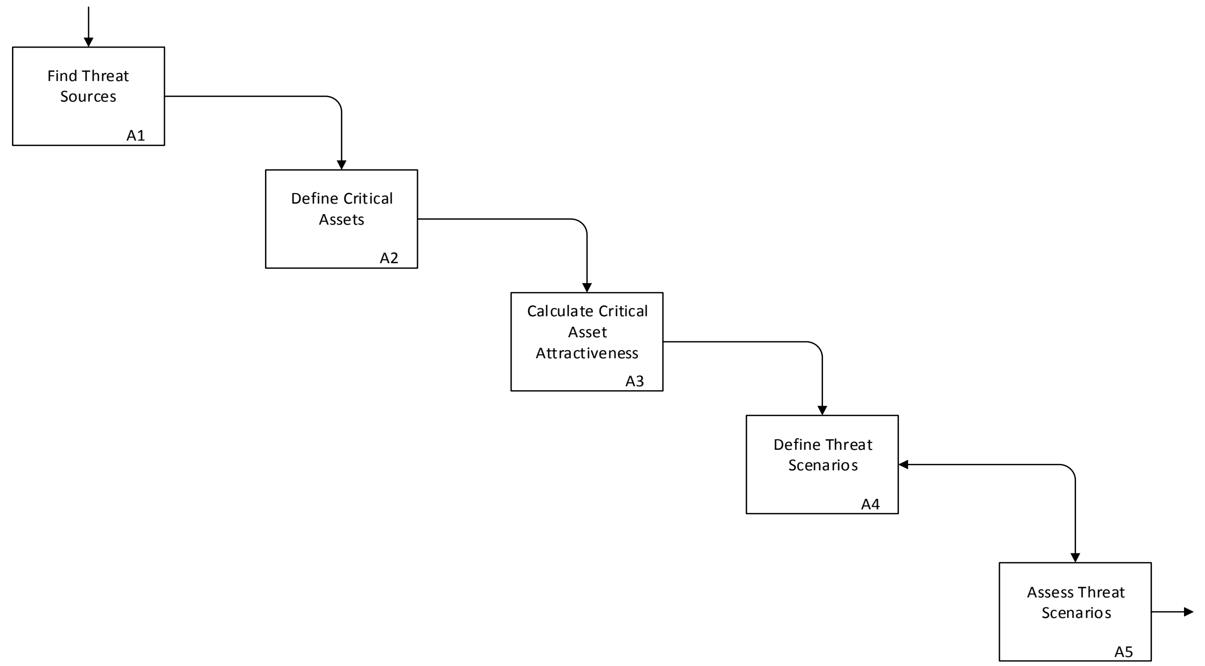


Figure 12: A vulnerability approach

Find threat sources: Reviewing historical data on terrorist attacks, we specify the terrorist profile, their potential actions, their capabilities, their motivation, the threat history…
Define critical assets: Brainstorming on the care units and on the technical units of the hospital, we define and locate the critical assets i.e. the units which are the most likely and the easiest to be exposed to a terrorist threat and which are the most damageable regarding to patients, employees, and the added value, etc. Our IDEFØ model enables us to locate the critical assets.

Calculate critical asset attractiveness: Realize an analysis based on pairing of each critical asset and of each threat source, in order to identify potential vulnerabilities per adversary, and to better evaluate the ease of causing threats per adversary.
Define Threat Scenarios: Based on the attractiveness of the critical assets, the most likely (i.e. the easiest target for the most motivated adversary) scenarios with the worst consequences are constructed, specifying: the terrorist profile, the terrorist action, the hazard release, the type of damages, and the security/safety barriers.
Assess Threat Scenarios: scenarios are simulated to evaluate their consequences, to study possible counter-measures implementation in order to reduce the risk to an acceptable level. The last two steps are repeated until all relevant scenarios are mitigated.

4.1Threat Sources

To define the threat sources, we review the historical data on terrorist attacks (including criminality which could acts as a henchman), and their dynamics. The attacks can occur in similar contexts (same nation, same sector, same social context…) or can occur in different contexts (country at war or not, private/public sector…).

Adversary types	Threat History	Potential actions	Adversary capability	Adversary motivation	Threat ranking: Tr
International terrorists	Missionary hospital, Jibla, Yemen, December 30 2002; The Tikrit, Iraq Hospital Attack, 2011; Christian worship center and hospital, Nwokyo, Nigeria, April 15 2014; Christian hospital, Kabul, Afghanistan, April 24 2014 [Ganor and Halperin-Wernli, 2013]	Armed assault; Hostage/Kidnapping; Bombing and damage/destruction of equipment and buildings; destruction of human life; Release of nuclear or biological or chemical materials; Contamination of humans, equipment, buildings;	High level of organizational support; Good financial backing; Network of members; Highly developed communications capabilities; Weapons and explosives	Adversary is highly motivated (extremist); prepared to die for their cause; Intent to cause maximum damage to hospital assets including loss of lives and economic disruption	**5**
…					

Table 2: the Threat Sources

To evaluate the adversary hazardousness, we propose to use the following criteria: the financial means (F), the knowledge of the system (K), the technology expertise (E), the level of motivation (M)… These criteria will be set from 1 (very low) to 5 (very high). The threat ranking will be measured through a weighted sum and be equal to $Tr = a1 * F + a2 * K + a3 * E + a4 * M$ with $a1 + a2 + a3 + a4 = 1$. The Analytical

Hierarchy Process (AHP) method could be used, in particular to determine the criteria weights a_i, as in the risk management system proposed by Vahdat et al. (2014).

Table 2 presents per terrorist profile, their threat history (context, i.e. location and date of attacks), their potential actions, their capabilities, their motivations, and the threat ranking Tr. If available the threat history could be used to estimate the frequency of the threat occurrences.

4.2 Critical Assets

To identify the critical assets, we suggest a brainstorming on hospital areas/functions (care or technical units) by physicians, nurses and engineers which are more likely to be exposed to a terrorist threat and which have more impact on the hospital activity. This brainstorming is supported by an “as-is” model of the hospital which maps the potential critical assets and their environment. Our IDEFØ model is used for the critical asset identification and location.

To evaluate the criticality of the hospital area/function (called critical asset), the criteria below can be selected: the number of people involved (P), the added value (remuneration of economic activity or chargeback) to hospital (V), and the ease of access i.e. the context (C). The asset severity ranking will also be measured through a weighted sum and be equal to $Ar = b1 * P + b2 * V + b3 * C$ with $b1 + b2 + b3 = 1$ and $V, P, C \in \{1, 2, 3, 4, 5\}$. The AHP method could also be used. Table 3 shows the critical assets of the hospital.

Critical asset	Criticality/Hazards	Asset severity Ranking: Ar
Emergency Department	The emergency department (ED) treats acute patients and then dispatches them to medical and surgical units. It is one of the main entrances to hospital. The Emergency department is the main actor for sustaining emergency management plans.	5
Operating rooms	The operating rooms (OR) are the main tool of surgical activities. They allow also the diagnosis activity of medical activities. The operating rooms are the main source of added values for hospital activities. They are located in several hospital areas.	4
…		

Table 3: the Critical Assets

4.3 Critical Assets Attractiveness as likelihood

We can now evaluate the attractiveness of the critical assets per adversary (i.e. the ease of causing a threat). Table 3 summarizes this information specifying the objective of a potential attack and the Attractiveness Ranking. The attractiveness ranking Lr is function of the criticality of a critical asset and of the adversary hazardousness, It can be expressed as the product of the previous rankings on the interval from 1 to 5, i.e. $Lr = (Tr*Ar)/5$. The higher the attractiveness will be, the more important the likelihood of an attack on this critical asset will be. The attractiveness combines the motivation and capabilities of the adversary and the criticality and ease of access of the target.

Critical assets	Adversary types: International terrorist	Attractiveness ranking: Lr	Adversary types: Domestic terrorist	Attractiveness ranking: Lr
Emergency Department	Major disruption of business activity; The entrance of patients in hospital is affected, several elected activities must be replaced by acute activities coming from Emergency department which is out of order; The emergency management plans become inactive.	5	Major disruption of business activity; The entrance of patients in hospital is affected, several elected activities must be replaced by acute activities coming from Emergency department which is out of order; The emergency management plans become inactive.	4

Table 4: Critical Assets Attractiveness

4.4 Threat Scenarios

Knowing the critical assets attractiveness, we can brainstorm on scenarios of terrorist attacks: the most likely scenarios with the worst consequences are constructed, specifying in Table 5: the terrorist profile, a potential terrorist action, the hazard release, the type of damage, and the existing security/safety barriers. Regarding security/safety barriers, only the existing counter-measures of the hospital are considered. In the next step, some new counter-measures will be proposed.

Scenario Code	Terrorist Profile	Terrorist Action	Hazard release	Type of damage	Security/safety barriers
Second Strike	International terrorist: suicide bomber	1) A first terrorist strike occurs in a close Airport; 2) The emergency plan in Airport is activated; 3) OSR tries to respond with its External Emergency management plan dedicated to massive influx of injuries; 4) First patients enter to the OSR Emergency Department; A green code patient arrived by a private car pretending to have been injured in airport; when assessed, he shows a bomb-belt and explodes himself; 5) The ED is damaged; 2 people	detonation and deflagration of bomb device	human injuries and deaths; destruction of building and facilities;	Hospital Emergency Management Plan; Monitoring of suspect behavior in ED; Procedures for internal terrorist threats and recognition of hazards

		are killed, and some staff are seriously injured. 6) The OSR Internal Emergency Plan is activated to safeguard the rest of the hospital.			
…					

Table 5: the Threat Scenario Generator

4.5 Scenario risk assessment

According to the deliverable D1.4, and based on a set of terrorist scenarios that has been developed, firstly some risk assessment knowledge is required to evaluate the resulting impact of the scenario events, as objectively as possible, and secondly some vulnerability assessment knowledge is needed to understand, to reduce, and if possible to eliminate the resulting impact of adverse events. This step is supported by a linear model which represents the flow propagation into the hospital (e.g., traffic, contamination, evacuation). The linear flow model is solved with the Cplex solver.
The rationale for risk assessment stems out from a set of key functions. The risk assessment serves the purpose to:

- Evaluate and compare terrorist scenarios for differential impacts and severity;
- Rank scenarios for informed selection;
- Inform hospital about major security threats;
- Prioritize major threats and inform decision maker for the need of a cost benefit analysis;

The rationale for vulnerability assessment is based on the objectives of mitigation, preparedness, response, and recovery:

- Choose scenarios of major risk impact;
- Perform sensitivity analysis towards risk reduction by integrating new counter measures;
- Provide hospital with dedicated counter measures to prevent or minimize terrorist events;
- Provide hospital with reliable amendments for its emergency management plans;
- Prepare hospital about emergency management plans for a best resource management.

4.51 Risk assessment

The objective of the risk assessment is to calculate the risk of the different scenarios. The risk assessment approach applied to scenario estimations is based on best practices in hazard matrix applications. Nevertheless an innovation has taken advantage on the one hand of the criteria (adversary capabilities, adversary motivation, criticality of assets, ease of asset access, human losses, infrastructure damages, operational damages, and symbolic damages) used for estimating the likelihood and severity criterions and on the other hand of the quantitative evaluation tool used (the linear flow model). Each terrorist scenario is fully developed, its likelihood (ease of causing a threat, and adversary motivation) as well as its severity (losses and damages) is estimated systematically and deeply. The combination of likelihood and severity shall provide an index representing the best combination of both criteria. The following THREAT Risk Matrix in Table 6 below has been developed. The matrix shows how the risk index shall be calculated on the terrorist scenarios devised in Table 5.

Scenario Number	Description	Likelihood Lr	Human Losses	Infrastructure Damages	Operational Damages	Symbolic Damages	Severity: Sr
1	Second strike	5	3	1	4	5	3.25
2	Attack against VIP	2.4	2	2	2	5	2.75
3	Personal vengeance	3.2	2	2	4	4	3
8	Bacteriological attack	5	3	1	3	5	3
…							

Table 6: THREATS Risk Matrix

The infrastructure damage index is set to: 1 for a single day disruption for one building, 2 for several days' disruption for one building, 3 for several days' disruption for several buildings, 4 for the activity cessation for one building, and 5 for the activity cessation for several buildings.
The Human losses are set to: 1 for 1 killed, 2 for less than 5 killed, 3 between 5 and 15 killed, 4 between 16 and 50 killed, and 5 for more than 50 killed.
The operational damages are set to: 1 for a single service interrupted during one day, 2 for a single service interrupted during several days, 3 for several services interrupted during one day, 4 for several services interrupted during several days, 5 for most services interrupted during several days.
The symbolic damages are based on the reduction of incoming patients after attack. They are set to: 1 for 1% reduction, 2 between 2% and 5% reduction, 3 between 6% and 10% reduction, 4 between 11% and 30% reduction, 5 for more than 30% reduction.
In general the risk model assumed for the matrix in Table 5 above, is the risk of terrorist attack modeled by formula: R = Lr x Sr, where the risk R is the product of the likelihood Lr (i.e., the ease of causing a threat per critical assets, ranking from 1 to 5) and the severity of the hazard Sr (i.e., the impact of the terrorist attack as weighted linear combination of four different severity criteria). In the example presented in Table 6, each severity criterion is supposed to have the same weight so the severity (last column) is calculated as the average of the 4 previous values.

4.52 Vulnerability assessment

The objective of the vulnerability assessment is to reduce the risk of the different scenarios, by defining: counter-measures, disaster (emergency) management plans, and safety practices… Most of the researchers agree on the following four phases to reduce the impact of a disaster (as the result of a terrorist attack): mitigation, preparedness, response, and recovery (Altay and Walter, 2006). The activities of the mitigation and preparedness are the pre-disaster activities, and the activities of the response and recovery are the post-disaster activities. The mitigation phase serves the purpose to minimize the potential number of casualties and reduce the potential losses of property, by acting before that the disaster occurs. The preparedness gets that all relevant stakeholders are ready for the disaster, specifying emergency management plans, and training people according to these latter. The response includes the arrangement of resources and working procedures, according to the emergency management plans to protect the life, property, and environment. The main objective of the recovery phase is to restore activity and reconstruct the resources after the disaster.

The vulnerability assessment investigates on: the implementation of counter-measures at the mitigation level, the use of emergency management plans and the resource dimensioning at the preparedness level, the decision support during the response phase and the recovery measures. For example, an access control can increase the difficulty for an adversary to access a critical asset, and decreases the likelihood of the threat. Or, a biological sensor can reduce the human losses, detecting a human contamination earlier (for instance the detection of Anthrax spores). Emergency management plans organize the use of human, material and information resources to face the disaster in order to minimize the human losses and the damages. They coordinate the stakeholders; they provide behavior procedures for each actor; etc. All these counter-measures, emergency management plans, and safety practices, can be evaluated by our linear flow model (see section 3). Comparing the ‘as-is’ configuration with the ‘to-be’ configuration, a cost-benefice analysis can be made in order to choose the best security and safety barriers and reduce the risk impact to an acceptable level.

5. Conclusion

Our challenge is to design, to develop, and to test decision making tools to reduce the vulnerability of the hospitals. In order to do this we are evaluating the impact of attacks in order to propose counter-measures, emergency management plans, and best practices. Our approach is: firstly based on the estimation of the threat likelihood, secondly focused on the evaluation of the severity of terrorist attack scenarios, and finally dedicated to the study of potential counter measures to reduce the attack impacts. We have chosen a quantitative assessment, based on complex and huge system modeling, and attack simulation by mathematical models.

Hospitals have not yet been first strike targets for major terror attacks in the EU, but the Paris attacks of November 13th 2015 demonstrate that calamitous attacks can occur without a pattern of previous strikes. 130 people were killed and 351 injured in the Paris attacks, which was not predictable from prior history. So, we propose to evaluate the likelihood of threats, on one hand by considering the motivation and capabilities of terrorists and on the other hand by regarding the attractiveness of the targets (critical assets of the hospital) in terms of ease of access and potential damages. Hospitals are human and complex systems, which are organized as open space to facilitate care access to patients. It appears quite difficult to identify their weak points and to estimate the consequences of a terrorist attack without using quantitative tools.

Our approach, firstly estimates the threat likelihood, by finding the threat sources, by defining critical assets, and by calculating critical asset attractiveness per adversary, secondly, by evaluating risk severity, by defining threat scenarios, by assessing the threat scenarios, and by reducing the vulnerabilities by counter-measures implementation. The IDEFØ method is used, to identify all the care units and services which define the critical assets of the hospital. It allows us to produce a hierarchical map of the hospital and to model the processes of the critical assets, i.e. the most accessible and damageable care units or services. By extracting the direct links between care units from IDEFØ model, we can produce a multi-period flow model in order to calculate the traffic in the hospital and show the most vulnerable places, where a terrorist attack can produce the most damages. A linear program allows us to solve this basic flow problem and simulate attack scenarios.

The study of several scenarios highlight that our decision making tools allow us to find the relevant information to evaluate the impact of the attacks (human damages and operational damages). The next step will be to propose counter-measures for vulnerability mitigation and efficient management plan for response to the attack. A set of relevant scenarios based on the attractiveness of the OSR critical assets will be studied, some counter-measures will be proposed and a cost/benefit analysis will be made. It is the main objective of our next deliverable. For non-simulated scenarios, i.e. the scenarios without flow propagation (patients contamination, patients evacuation), some dedicated decision-making tools will be specified in the next deliverable. Our vulnerability assessment method will be integrated in a global audit approach of the hospital vulnerability which is proposed in deliverable D1.6.

6. References

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Annex 1: Evacuation scenarios

```
/*********************************************
 * OPL 12.6.0.0 Model
 * Author: ChenWanying
 * Creation Date: Nov 9, 2015 at 5:39:07 AM
 *********************************************/


/*********************************************
 Parameters
 *********************************************/

 // care unit in the hospital
int N=47;
range rooms=1..N;

// time peiord
int pe=100;
range p=1..pe;

// recover unit and evacuated unit
int recoverunit=22;

// Number of inpatients should be evacuated
int numpa=361;

//Percentage of patients goinh to other hospitlas
float perout=0.6;

// lenth of patients
int H[i in rooms]=...;
int L[i in rooms]=...;

// matric access
int Acc[i in rooms][j in rooms]=...
;
// Number of people going people (inpatients, outpatients, and visitors) incoming in i directly from outside (entry point) on period p t
int Input[i in rooms][t in p]=...;

// Number of people (inpatients, outpatients, and visitors) exiting from i directly to outside (exit point) on period p;
int Output[i in rooms][t in p]=...;

// Number of inpatients (patients which stay at least one night in the hospital) on period p
int Inp[i in rooms][t in p]=...;

//Number of outpatients (patients which stay less than one night in the hospital) on period p;
int Outp[i in rooms][t in p]=...;

// number of activity of evacuation
int Min=5;
range actin=1..Min;

// period to activate the evacuation
int pa=73;

// matric activity evacuation
int Accin[i in actin][j in actin]=...;
```

```
//Capacity and duraing of each activity
int Capin[i in actin]=...;
int Din[i in actin]=...;


/**********************************************
 Variables
 **********************************************/
//Number of people going from i to j on period p;
dvar int+ XG[rooms][rooms][p];

//Number of people returning from i to j on period p
dvar int+ XR[rooms][rooms][p];

// Number of people going from activity i to activity j on period p
dvar float+ XEP[i in actin][j in actin][t in p];

// Number of people waiting for activity i on period p
dvar float+ WEP[i in actin][t in p];

//Patients stay at the same hospital
dvar float+ Inpev[t in p];

//Patients return to home
dvar float+ Outpev[t in p];

//Inter variables for programing
dvar float+ testin[i in actin][j in actin][t in p];


/**********************************************
Objective function
 **********************************************/

//Objection integration of both models, the global model and the evacuation model
minimize sum (i in actin, t in p) (WEP[i][t]*t)+sum (i,j in rooms, t in p) ((XG[i][j][t]+XR[i][j][t])*t);


/**********************************************
Constraints
 **********************************************/

subject to
{

/**********************************************
Global model
 **********************************************/

//Without taking into account the recover unit
// Constraints for XG,
forall(i in rooms, t in p:i!=recoverunit)
  c1:sum(j in rooms:j!=i) XG[j][i][t]*Acc[j][i]-sum(j in rooms:j!=i)
XG[i][j][t]*Acc[i][j]+Input[i][t]>=Outp[i][t]+Inp[i][t];

// Constraints for XR, if the time now is larger than the H[i]
 forall(i in rooms, t in p:t>H[i] && i!=recoverunit)
c2:-sum(j in rooms:j!=i) XR[i][j][t]*Acc[i][j]+sum(j in rooms:j!=i) XR[j][i][t]*Acc[j][i]+Output[i][t]>=Inp[i][t-
H[i]]+Outp[i][t-L[i]] ;
```

```
// Constraints for XR, if the time now is larger than the L[i] and smaller than H[i]
forall(i in rooms, t in p:t>L[i]&&t<=H[i]&&  i!=recoverunit)
c21:-sum(j in rooms:j!=i) XR[i][j][t]*Acc[i][j]+sum(j in rooms:j!=i) XR[j][i][t]*Acc[j][i]+Output[i][t]>=Outp[i][t-L[i]] ;

// Constraints for XR, if the time now is smaller than L[i]
forall(i in rooms, t in p:t<=L[i]&&  i!=recoverunit)
 c22:-sum(j in rooms:j!=i) XR[i][j][t]*Acc[i][j]+sum(j in rooms:j!=i) XR[j][i][t]*Acc[j][i]+Output[i][t]>=0 ;

// Constraints for recovery unit
// Constraints for XG,
forall(i in rooms, t in p:i==recoverunit)
  cr1:sum(j in rooms:j!=i) XG[j][i][t]*Acc[j][i]-sum(j in rooms:j!=i) XG[i][j][t]*Acc[i][j]
+Input[i][t]>=Outp[i][t]+Inp[i][t]+Inpev[t];

 // Constraints for XR, if the time now is larger than the H[i]

 forall(i in rooms, t in p:t>H[i]&& i==recoverunit)
   cr2:-sum(j in rooms:j!=i) XR[i][j][t]*Acc[i][j]+sum(j in rooms:j!=i) XR[j][i][t]*Acc[j][i]+Output[i][t]>=Inp[i][t-H[i]]+Outp[i][t-L[i]]+Inpev[t-H[i]] ;

  // Constraints for XR, if the time now is larger than the L[i] and smaller than H[i]

  forall(i in rooms, t in p:t>L[i]&&t<=H[i]&&  i==recoverunit)
 cr21:-sum(j in rooms:j!=i) XR[i][j][t]*Acc[i][j]+sum(j in rooms:j!=i)
XR[j][i][t]*Acc[j][i]+Output[i][t]>=Outp[i][t-L[i]] ;

// Constraints for XR, if the time now is smaller than L[i]
forall(i in rooms, t in p:t<=L[i]&&  i==recoverunit)
 cr22:-sum(j in rooms:j!=i) XR[i][j][t]*Acc[i][j]+sum(j in rooms:j!=i) XR[j][i][t]*Acc[j][i]+Output[i][t]>= 0;

/**********************************************
Evacuation
 **********************************************/
// Flow constraints
 forall(t in p, i in actin: t<=pe-Din[i]&& i>1&&i<Min)
 cin1:
 sum(j in actin:j!=i&&j<Min) XEP[j][i][t]*Accin[j][i]-sum(j in actin:j!=i&&j>1)
XEP[i][j][t+Din[i]]*Accin[i][j]+WEP[i][t]==WEP[i][t+1];

 // Inter variable calculated
   forall(t in p, i,j in actin: t>=Din[i])
 cintestin:
  testin[i][j][t]==sum(i2 in actin,j2 in actin,t2 in p: i2==i&&j2==j&& t2>=t-Din[i]+1 && t2<=t) XEP[i2][j2][t2]
;

   // Capacity constraints
 forall(t in p, i,j in actin: t>=Din[i]&&i>1&&i<Min)
 cin2:
 sum(j in actin:j!=i&&j>1)  testin[i][j][t]*Accin[i][j]<= Capin[i];

 // Calculate the number of people who need to be evacuated
 XEP[1][2][pa]== numpa;

// Matrix constraints, flow evacuation
 forall(t in p)

  {
    XEP[3][5][t]==(XEP[3][4][t]+XEP[3][5][t])*perout;
    XEP[5][6][t]== Outpev[t] ;
```

```
   XEP[3][4][t]== Inpev[t] ;
 }

}
```

For the date file, we trigger the following files.

```
/*********************************************
 * OPL 12.6.0.0 Data
 * Author: ChenWan
 * Creation Date: Dec 1, 2015 at 8:36:43 AM
 *********************************************/
Capin=[50000 36 18 6 50000 ];
Din=[0 1 1 1  0];

SheetConnection sheet("Accin.xlsx");
Accin from SheetRead(sheet,"Sheet1!B2:F6");

SheetConnection sheet0("ACC.xlsx");
Acc from SheetRead(sheet0,"Sheet1!A1:AU47");

SheetConnection sheet1("Inputdata.xlsx");
Input from SheetRead(sheet1,"Sheet1!B1:CW47");

SheetConnection sheet2("Outputdata.xlsx");
Output from SheetRead(sheet2,"Sheet1!B1:CW47");

SheetConnection sheet3("Inpdata.xlsx");
Inp from SheetRead(sheet3,"Sheet1!B1:CW47");

SheetConnection sheet4("Outpdata.xlsx");
Outp from SheetRead(sheet4,"Sheet1!B1:CW47");

SheetConnection sheet77("Hdata.xlsx");
H from SheetRead(sheet77,"Sheet1!B1:B47");

SheetConnection sheet88("Ldata.xlsx");
L from SheetRead(sheet88,"Sheet1!B1:B47");
```

Annex 2: Global model for hospital traffic

The modeling language used here is OPL 12.6.0.0. The green words mean the comments. The blue words refers to the key words in the OPL language. The black words are the coding.

```
/*********************************************
 * OPL 12.6.0.0 Model
 * Author: ChenWanying
 * Creation Date: Nov 9, 2015 at 5:39:07 AM
 *********************************************/

/*********************************************
 Parameters
 *********************************************/
// Care unit
int N=47;
range rooms=1..N;

// Time period
int pe=120;
range p=1..pe;

// Length duration of inpatients and outpatients
int H[i in rooms]=...;
int L[i in rooms]=...;

// Access matrix
int Acc[i in rooms][j in rooms]=...;

// Number of people going people (inpatients, outpatients, and visitors) incoming in i directly from outside (entry point) on period p t
int Input[i in rooms][t in p]=...;
// Number of people (inpatients, outpatients, and visitors) exiting from i directly to outside (exit point) on period p;
int Output[i in rooms][t in p]=...;

// Number of inpatients (patients which stay at least one night in the hospital) on period p
int Inp[i in rooms][t in p]=...;
//Number of outpatients (patients which stay less than one night in the hospital) on period p;
int Outp[i in rooms][t in p]=...;

/*********************************************
 Variables
 *********************************************/
//Number of people going from i to j on period p;
dvar int+ XG[rooms][rooms][p];
//Number of people returning from i to j on period p
dvar int+ XR[rooms][rooms][p];

/*********************************************
Objective function
 *********************************************/
minimize sum (i,j in rooms, t in p) (XG[i][j][t]+XR[i][j][t])*t;


/*********************************************
Constraints
 *********************************************/
```

```
subject to
{
// Constraints for XG
forall(i in rooms, t in p)
  c1:sum(j in rooms:j!=i) XG[j][i][t]*Acc[j][i]-sum(j in rooms:j!=i) XG[i][j][t]*Acc[i][j]+Input[i][t]>=Outp[i][t]+Inp[i][t];

// Constraints for XR, if the time now is larger than the H[i]
  forall(i in rooms, t in p:t>H[i])
 c2:-sum(j in rooms:j!=i) XR[i][j][t]*Acc[i][j]+sum(j in rooms:j!=i) XR[j][i][t]*Acc[j][i]+Output[i][t]>=Inp[i][t-H[i]]+Outp[i][t-L[i]] ;

// Constraints for XR, if the time now is larger than the L[i] and smaller than H[i]
 forall(i in rooms, t in p:t>L[i]&&t<=H[i])
 c21:-sum(j in rooms:j!=i) XR[i][j][t]*Acc[i][j]+sum(j in rooms:j!=i) XR[j][i][t]*Acc[j][i]+Output[i][t]>=Outp[i][t-L[i]] ;

// Constraints for XR, if the time now is smaller than L[i]
forall(i in rooms, t in p:t<=L[i])
 c22:-sum(j in rooms:j!=i) XR[i][j][t]*Acc[i][j]+sum(j in rooms:j!=i) XR[j][i][t]*Acc[j][i]+Output[i][t]>=0 ;
}
```

For the date file, we trigger the following files.

```
/*********************************************
 * OPL 12.6.0.0 Data
 * Author: ChenWan
 * Creation Date: Nov 9, 2015 at 5:39:07 AM
 *********************************************/
SheetConnection sheet0("ACC.xlsx");
Acc from SheetRead(sheet0,"Sheet1!A1:AU47");

SheetConnection sheet1("Inputdata.xlsx");
Input from SheetRead(sheet1,"Sheet1!B1:DQ47");

SheetConnection sheet2("Outputdata.xlsx");
Output from SheetRead(sheet2,"Sheet1!B1:DQ47");
SheetConnection sheet3("Inpdata.xlsx");
Inp from SheetRead(sheet3,"Sheet1!B1:DQ47");

SheetConnection sheet4("Outpdata2.xlsx");
Outp from SheetRead(sheet4,"Sheet1!B1:DQ47");

SheetConnection sheet7("Hdata.xlsx");
H from SheetRead(sheet7,"Sheet1!B1:B47");

SheetConnection sheet8("Ldata.xlsx");
L from SheetRead(sheet8,"Sheet1!B1:B47");
```

For the OPS setting, we choose the standard one.

Annex 3: Electric grid failure results