VTOL AIRCRAFT IN DISASTER PLANNING AND MANAGEMENT: A MODEL FOR THE DEFINITION OF A HEMS NETWORK

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Abstract

Rotary-wing aircraft are irreplaceable in carrying out a number of tasks in the civil protection and emergency management fields. These activities are not linked only to medical rescues, but also include all those activities which can best exploit the peculiarities of the VTOL (Vertical Take-Off & Landing) aircraft as compared to ground transportation systems: great operating speed and capability of widespread interventions.

In the present paper a method supporting the decisions taken by disaster planners and managers is set up, which focuses on the quantification of necessary air resources for the management of some probable calamities.

Thus, given a region characterized by a natural and non-natural disaster risk map, given a comprehensive transport system within this region, also characterized by a risk map, given a set of heliports/helipads dislocated on the territory and given a number of available HEMS (Helicopter Emergency Medical Service) rotorcraft, the problem is to assess the adequacy of the VTOL/FATO (Final Take-Off & Landing area) system to overcome a set of possible disasters.

Introduction

It is calculated that in Italy, a country which is vulnerable to seismic events, volcanic eruptions, landslides and flooding, more than 20 million people live in areas at risk. According to current data, in the last century around 120,000 people died due to seismic events alone and in the last 20 years more than 30,000 billion € of damage has been caused by hydro-geological instability [2].

Recent events have turned public attention once again to the problem of how to deal with emergencies and questions regarding the efficacy of prevention measures aimed at minimizing the damage caused by natural calamities. All the main Civil Protection norms for great emergencies have been brought together under Law 24/02/1992 n° 225, which set up the national Civil Protection Service and directly attributed all authority regarding these matters to the Prime Minister, authority which can be delegated also to the Home Minister or the Under Secretary of State for Civil Protection. The Civil Protection Department has been established within the Cabinet Offices having political-administrative and co-ordination, as well as prevision and prevention, functions, while the General Management of the Civil Protection and Fire Services remains the technical-operative branch. Other three central bodies were established by Law 225/92:

1. The National Civil Protection Council, which lays down the preliminary programs for the prevention of great emergencies and plans for emergency situations and the co-ordination of rescue services;
2. The National Commission for the prevision and prevention of great risks (seismic, volcanic, hydro-geological, nuclear, chemical, industrial, ecological, transport, health) which constitutes a kind of permanent great risks observatory.
3. The Working Committee with decision-making functions.

Law 225/92 includes another innovation in the form of health risk, which for the first time falls into the category of risks requiring particular attention and central planning, differing from the other great risks because of the variety of medical-surgical participation foreseeable, which necessitates interdisciplinary programs and research.

This falls into a wider picture of intervention aimed at putting into action Civil Protection projects in order to safeguard the population, economic apparatus, transport and communications, media, etc.

Figure 1 – An AB 412 during a fire-fighting mission

The reply to emergencies evolves in two phases: that of the interventions which take place in order to halt the progress of the disaster (putting out of fires, demolishing and removing dangerous structures, removal of people from dangerous situations) and that of the actual rescue operations (all the operations that permit the medical units to take charge of the victims in order to guarantee their survival and limit the damage following on from their injuries).

Moreover, it is of vital importance for an efficient organization of the transport and moving of victims that all workers present in the Operations Center which interacts with the rescue workers are especially trained for emergency situations. Very often the absence of a direct 'vision' of the scene and how it changes dynamically in the course of time can be critical. It then becomes vitally important, for an optimal organization of the dispatch of suitable rescue services/transport, that the Operations Centre is supplied with a 'photographic' image of the environmental situation, sending images acquired directly at the scene of the disaster to both the Operations Centre and the hospitals involved.

Helicopters in Civil Protection Operations

The fundamental concept in the construction of helipads for helicopters, is to create a versatile complex that can operate around the clock, generally in any weather conditions, with total respect for the norms that control aircraft activity on helipads, raising to the maximum the operating security coefficient which is an integral part of the concept. As laid down by art. 6 of Law n.996 passed 8 December 1970, in areas devastated by a calamity, the rescue work of the Mobile Units is integrated with that of the helicopter fleet of the National Fire Fighters Corp, which has 11 operative Helicopter teams around the country, utilizing the available helipads in the area requiring aid.

Vertical flight aircraft can also be used by the Corps of Foresters to provide a forest fires reconnaissance and sighting service which involves (see Figure 1): reconnaissance work, sighting and notification of fires, transport for the person directing the fire-fighting operations and his/her collaborators for co-ordination work; eventual fire-fighting activities using the bucket or internal cistern as well as the transport of work teams; finally, all other activities forming part of the institutional province of the Corps of Foresters and Environmental Surveillance (CFVA). Fire-fighting activities are always carried out in such a way as to guarantee the maximum speed and to use the maximum efficiency in setting the system in motion, in terms of precision and the quantity of water dropped/time ratio as compared to the distance to be covered, water sources, weather conditions and orographic situation. The vehicle is refueled constantly in order to optimize the performance of a timely standard intervention (a flight time for minor objectives of 15 minutes and a duration of active fire-fighting of about 60 minutes).

Furthermore, the helicopter can also be used by the Civil Protection authorities to carry out on-thespot investigations and monitoring of the front of an eventual stream of lava. By means of thermal surveys from the helicopter it is in fact possible to verify, on the channel feeding any one particular stream, the presence of a series of highly active overlaps that could lead to new overflows from the main channel or provoke further forward movement in apparently very slow channels.

Sometimes, helicopter rescue operations require the use of the winch. This kind of intervention is carried out in ‘slow flight’ situations with a ‘hovering’ phase, that is with a reduced maneuverability of the aircraft with respect to normal flight, accompanied by the typical difficulties of every ‘precision approach’ to a site (rocky walls a few meters from the rotor blades, air currents and wind, clouds that can rapidly cover the scene) with the risk that the rotor stream destabilizes rocks (volleys of stones falling from a height) or blankets of snow (snow-slips and avalanches) or that people who are not fastened to a support or pickaxe are thrown to the ground or are distanced in water.

Helicopters can also be used for intervention in the case of road accidents or, in any case, in areas that are far from hospitals. The first operations of this kind were carried out in the United States.

In short, the capacity for vertical take-off and landing of rotating-wing craft, associated with their flexibility of use, leads to their having a vast range of uses, many of which are linked to public services:

- Emergency missions: HEMS (Helicopter Emergency Medical Services); rescue operations at sea and in the mountains; evacuations, international operations connected with humanitarian works.
- Police and surveillance services: road traffic control and surveillance; urban and border environmental surveillance; marine surveillance both for research and salvage operations and in the fight against drugs and smuggling.
- Environmental investigation and protection: controlling of the lower atmosphere; pollution surveys, data collection, alarm systems, particularly in urban areas and industrial zones; inspection of highly dangerous industrial or energy-producing plants; surveillance of water basins or rivers to avoid flooding or monitor pollution; surveillance and monitoring of forests and fauna; fire-fighting; monitoring of damage caused by disasters.

More particularly, in the case of calamities, VTOL type aircraft are useful for the following kinds of mission, of primary importance [7]:

- transportation of medical teams and supplies to the disaster site. Vertical flight aircraft can transport medical teams and supplies from designated hospitals and/or trauma centers to the disaster site for triage and initial treatment of trauma victims;
- transportation of medical teams and supplies to the affected hospitals: this involves the transportation of medical teams and supplies from pre-designated hospitals, collection points or supply centers to the primary receiving hospital(s) (usually closest to the disaster site or region) that may become overwhelmed with disaster victims;
- transportation of trauma patients: the primary responsibility of HEMS crafts should be the transportation of trauma patients (notice that many emergency plans suggest that the nearest hospitals to the incident be bypassed when helicopters are available, because it reduces the chance of overwhelming the closest hospital with critical care patients);
- transportation of disaster specialists and supplies: vertical flight aircraft can transport disaster specialists and supplies to the disaster site or operations centre where they can contribute most effectively to the relief effort;
- emergency evacuation: in both normal and disaster situations, vertical flight aircraft are used as an alternative to surface-based transport modes (e.g. in a high-rise building fire, they can be used to retrieve fire victims trapped on the roof, or fire fighters can be lifted to the roof for fire fighting and rescue operations);
- fire-fighting: vertical flight aircraft have two primary functions in their roles as fire fighters. First, they are used to spray or drop fire retardants, chemicals or water, on the fire; secondly, they are used to transport fire fighters to sites from where they can fight the fire with conventional means;
- search and rescue (SAR) missions: vertical flight aircraft from the local community should only be used for SAR work in cases of ex-

treme urgency and their efforts should be coordinated by the SAR agency in charge;

and of secondary importance:

- damage survey: when a natural disaster precludes the use of ground transportation, vertical flight aircraft can be an extremely effective means of quickly assessing the extent of the damage so that the authorities can implement plans for disaster relief efforts;
- airborne control and assessment: it may be necessary to use a vertical flight aircraft or an airplane as a mobile aerial platform from which a deputy incident commander can observe and report on disaster response efforts;
- airborne air traffic control (AATC): when more than four or five aircraft are involved in the disaster relief effort, it may be advisable to assign one of the aircraft the mission of airborne traffic controller;
- electronic news gathering (ENG);
- inspection tours;
- hazardous material operations;
- communications support;
- return of personnel and equipment;
- livestock support.

Helipad Network Planning

There now follows a proposed methodology of support, based on a mathematical model, for the planning of helicopter rescue services, which is useful for the positioning of helipads within a vast area.

The method takes into consideration, by means of a risk evaluation procedure, the real or presumed need for intervention within an area, the presence of suitable hospitals and the extension and suitability of the road network in the area, in order to provide an evaluation of the intervention capacity of the system given a certain configuration of the helipad network or some planning indications as to how to create them.

The procedure consists of the following phases:

- subdivision in zones and the analysis of the danger level and need for intervention in the individual zones;
- estimation of mean intervention time;
- optimization model for the positioning of the HEMS operations centers.

Clustering and characterizing the area

The aggregation of the points of the territory in which an intervention by the air rescue system could be necessary is very important, given the nature of the positioning model, which requires a finite number of zones with which to deal.

The territory must, therefore, be subdivided into zones that must be:

- limited enough to consider all the points within them as being equidistant from any other external point of the zone (helipads, hospitals);
- vast enough and therefore, not excessively numerous, so as not to overload the working of the model.

The ideal technique for clustering the territory consists in sub-dividing it according to a square cell grid, whose dimensions meet both the criteria above. In this way, it is possible to make the analysis as detailed as you wish, also considering the computing power available.

Each zone of the territory must then be characterized in demographic, socio-economic, infrastructure and medical terms.

Great importance is given, when evaluating the location of a heliport on one site rather than another, to the possibility that in the course of a year a request for intervention on the part of helicopter rescue services can be made in that generic zone. In other words, apart from the network logic according to which it is best to establish the optimal site for helipads, it is evident that it is better for these infrastructure to be positioned as near as possible to places with the highest concentration of possible requests for assistance.

Such requests would then be classified and ‘weighed’ according to gravity and type, in order to obtain the best picture of the effective necessity for intervention. This information is not easily obtainable in all cases. Besides, in order to effectively represent the level of risk, historical series should be built up, which naturally could not take into account eventual modifications of the socio-economic and natural spheres.

Therefore, it is necessary to arrive at the data by indirect means, through a risk evaluation of each zone. In technical terminology, risk is given by a combination of three elements:

- Hazard (H): A source of potential danger or adverse condition. Hazards include both naturally and non-naturally occurring events that strike populated areas.
- Exposure (E): The number, types, qualities and monetary values of various types of property, infrastructure and life that may be subject to an undesirable or injurious hazard event.
- Vulnerability (V): The extent to which people will experience harm and property will be damaged by a hazard.

If each of these variables is expressed for each of the N zones in which the territory is subdivided it is possible to obtain the risk NR of each of the i zones as:

$$NR_i = H_i \cdot E_i \cdot V_i$$

Naturally this is not the right place to carry out a detailed analysis of the different types of hazard that can affect a certain territory.

As regards our application to Sicily, carried out simply to provide an example, reference will be made only to seismic risk. In this sphere, as for others in the same way, it is possible to refer to the order [14] in which a normalized risk index is defined, which represents the degree of danger linked to seismic events.

As regards the analysis of seismic vulnerability, data is not available and therefore the whole territory under examination is taken as being homogeneous (therefore of no influence).

As regards the exposure, having to calculate a risk index that is representative of the number of requests for relief, it is necessary to take into consideration the following aspects, omitting those linked to the value of the real estate and infrastructure exposed to risk:

- Population (P): the higher the population of an area, the greater its exposure;
- Tourist capacity (T): generally speaking, the greater the tourist capacity of an area, the greater the possibility of there being a need for relief which is not adequately covered by medical structures.

If these two indexes are expressed in normalized terms (growing as the exposure increases), the exposure can be evaluated as:

$$E_i = \frac{u \cdot P_i + v \cdot T_i}{u + v}$$

having weighted the two exposure characteristics differently.

This method is commonly used for those natural and technological dangers not caused by man for which the three variables are independent. Other events can be caused intentionally (e.g. acts of terrorism) or unintentionally (e.g. road accidents) by man.

As far as the former are concerned, all considerations regarding the possibility of an intentional act taking place go beyond the scope of this work. Instead, as regards the others, these represent one of the events in which helicopter rescue operations are particularly advantageous, when they occur at a certain distance from the nearest accident and emergency services.

In order to estimate the risk attached to road accidents, the formula above is not used, and the estimating methods linked to the geometrical and functional characteristics of roads to be found in literature are different, and often, also the predictive ones, founded on a sound analysis of historical data [5] [9].

For our purposes, we can assume that the risk linked to road accidents RR for the zone i is given by:

$$RR_i = NA_i$$

thus obtaining data according to the number of accidents NA which took place in the last year on stretches of road falling within zone i.

Therefore, the total risk linked to zone i is given by the sum, weighted to take into account the different degrees of reliability of the data, of the two risk indexes:

$$TR_i = \frac{n \cdot NR_i + m \cdot RR_i}{n + m}$$

The model

The final result of the characterization process of the area, once all the causes of danger and the relative vulnerability and exposition have been identified for each zone, is a map of the territorial risk, in terms of the possibility of requests for helicopter rescue services. It can be used to give a kind of ‘weight’ to each portion of the territory, to allow for the planning of a network of helipads which takes into account the different distribution of risk over the area.

The working mechanism of the planning model is simple.

For each zone the risk index *TR* and the air distance from all the other zones is calculated. Thus, it is possible to construct a matrix of the distances ***AD*** such that the generic element AD_{ij} represents the air distance between the centers of population of zone *i* and zone *j*. In this way, it is possible to estimate the flight time between the generic zones *i* and *j* as:

$$T_{ij} = at_k + \frac{AD_{ij}}{as_k}$$

Having indicated with at_k the idle time of the vehicle (given by the sum of the preparation time and the take-off and landing times) and with as_k the cruising speed of the vehicle on the departure helipads, located in zone *k*.

Moreover, having the use of a road network, it is possible to construct the matrix of the road distances *RD*, again with reference to the centers of population of the zones.

The zones are characterized by:

- a vector of binary attributes **g** whose g_i element indicates the presence of hospitals having helipads in the generic zone *i*;
- a vector of binary attributes **e** whose e_i element indicates the presence of accident and emergency services in the generic zone *i*;
- a vector of binary attributes **p** whose p_i element indicates the presence of helipads within zone *i*;

The variables of the problem are constituted by the vector **x** whose x_i elements represent the presence, within zone *i*, of a rotating wing craft available for HEMS services.

The system performance indicator is made up of the mean operation time weighted on the basis of the risk index (*WMT*). Given that ART_{hij} is the rescue time in zone *i* with an aircraft situated in zone *h* for final recovery in zone *j*, we have:

$$ART_{hij} = at_h + \frac{AD_{hi} + AD_{ij}}{as_h}$$

And the minimum rescue time $MART_i$ will be given by:

$$MART_i = \min\left(ART_{hij}\right)$$

$$\forall h = 1..N : x_h = 1$$

$$\forall j = 1..N : g_j = 1$$

So, the mean weighted rescue time will be given by:

$$WMT = \frac{\sum_{i=1}^{N}\left(TR_i \cdot MART_i\right)}{\sum_{i=1}^{N} TR_i} \qquad i$$

It is possible to take into consideration the possibility that, in some cases, normal ambulance operations are quicker than using a rotorcraft by introducing, for each zone *i*, the minimum rescue time via land $MGRT_i$:

$$MGRT_i = \min\left(gt_h + \frac{RD_{hi} + RD_{ij}}{gs_h}\right)$$

$$\forall h = 1..N : e_h = 1$$

$$\forall j = 1..N : e_j = 1$$

and therefore:

$$WMT = \frac{\sum_{i=1}^{N}\left[TR_i \cdot \min\left(MART_i, MGRT_i\right)\right]}{\sum_{i=1}^{N} TR_i} \qquad i$$

It can be seen that this latter step is fundamentally important in order not to falsify the optimization results. The zones of the larger urban centers are not good areas for the use of helicopter rescue services, for various reasons, among which the fact that normal ambulance operations are almost always quicker (given the reduced idle times and the shorter distance from the operating centers) and have a lesser impact on traffic and the urban environment.

By means of the proposed model, it is possible to arrive at an objective evaluation, in terms of mean operation time, of any configuration of helipads having a vehicle equipped for helicopter rescue operations. It is, therefore, a planning verification tool.

Moreover, it is possible to carry out an optimization procedure on the system, with the aim of identifying the best configuration of the helipad-network. On this basic scheme, the optimization of the problem can be carried out according to diverse strategies:

- minimization of the mean operation time, given a fixed number of craft equipped for helicopter rescue services *NH*:

$$\min WMT(\mathbf{x})$$

$$\sum_{i=1}^{N} x_i \geq NH$$

- minimization of the craft necessary for the helicopter rescue service given a fixed threshold value of the mean operation time *TT* (if necessary also the maximum time *MT*):

$$\min \sum_{i=1}^{N} x_i$$

$$WMT \leq TT$$

$$\max\left[\min\left(MART_i, MGRT_i : i = k\right) \forall k = 1..N\right] \leq MT$$

- minimization of the combined mean operation time and the number of craft necessary for helicopter rescue services; the formulation is the same as for the first problem, imposing a 'soft' restraint on the number of craft, which allows this latter to be violated imposing gradual penalties on the objective function:

$$\min \; WMT(\mathbf{x}) + \alpha\left[\exp(\beta \cdot \Delta) - 1\right]$$

$$\Delta = \left|\sum_{i=1}^{N} x_i - NH\right|$$

Genetic algorithms. Naturally, as can be seen, we are dealing with a strictly non-linear optimization problem, which cannot be resolved by typical linear programming algorithms.

We are dealing with a complex problem belonging to the set of binary programming problems. The variables are represented by the vector **x** whose *N* elements are all binary. This aspect, combined with the complexity and discontinuity of the objective function, means that the problem cannot be treated with exact analytical algorithms and is an ideal field for the application of genetic algorithms.

Genetic algorithms (GAs) are a generic heuristic technique developed to find quasi-optimal solutions to a problem. They are based on a similar mechanism to that of biological evolution. They start with a population of feasible solutions for a given problem and evolve with the aim of producing ever better populations of solutions, using a highly aleatory mechanism.

The implementation of a GA starts with the coding of the solutions as chromosomes. The classical GA coding is binary, to simplify computer application. The next step is the definition of fitness, the function that measures how good a solution is, compared to the others. The GA evolves in order to maximize the fitness, which is represented either by the objective function or by its reciprocal value, for maximization or minimization problems respectively.

The algorithm starts with a set of *m* solutions, which are randomly generated (population of dimension *m*). The process is recursive, as it transforms the current population of solutions into another set of *m* solutions, by applying some specific operators: reproduction, crossover and mutation.

Reproduction is the construction of a new set of *m* solutions, made up of chromosomes, belonging to the old set, each having a probability that is proportional to its fitness value. After reproduction, the new set is involved in further transformations:

- crossover: two chromosomes called parents, which are randomly chosen, are cut in the same position (which is randomly fixed), and their 'tails' are swapped and re-joined to the new 'heads'. Each of the new strings, called sons, receives part of the genes of one parent and part of the other;
- mutation: it is randomly applied to the population following a fixed incidence rate. It changes the value of a gene (0 to 1 and vice versa) which is also randomly chosen.

To these basic principles different additional techniques are added which require the use of more complex operators, in order to take into consideration the specificity of some kinds of problem.

In our case, the coding of the solutions is immediate, in that we are already dealing with a binary string of *N* dimension.

As regards computational complexity, it should be born in mind that a region like Sicily, having an extension of slightly more than 25,000 sq km, if subdivided into zones of 25 sq km (squares with sides measuring 5 km) can be represented by a string of about one thousand elements, which gives a sufficiently detailed localization for the helipads (1 km is covered in about 15 seconds at helicopter cruising speed) and a number of reasonable variables.

However, suitable processing systems can deal with calculations having a much greater number of variables, especially if they are binary. Furthermore, it is possible to carry out a macro-zone optimization and then further detailed optimizations within each macro-zone. Finally, given the planning nature of the procedure and therefore the dispensability of calculations in real-time, limiting calculation times is not a question of primary importance.

As regards the fitness function, given that we are dealing with a problem of minimization of the objective function (*WMT*), this will be given by the inverse of the latter.

Finally, the restraints are represented by introducing penalties worsening the solutions that violate them so as to make them very poor.

A quick heuristic. To test the accuracy of the proposed genetic algorithm, a simple heuristic technique was set up for the resolution of the model, which we call BAH (Best Addition Heuristic).

This is an iterative process which, starting from a given configuration of established operations centers (which can also be a null vector, starting condition) searches for the sitting of a further operations center in such a way as to minimize the objective function. It consists, therefore, in examining all the possible ‘additions’ and choosing the best. The process can continue in this way until the maximum fixed number of operations centers is reached.

As is evident, the heuristic may not lead to the optimal solution, but can be a good test for estimating the reliability of the genetic algorithm.

An application to Sicily

In order to test the proposed methodology an application on Sicilian territory was elaborated.

Sicily is an ideal field for the application of such a methodology, in particular because it represents a kind of ‘closed system’ with very little interaction with other Italian regions. It is therefore possible, as for other transport spheres, to study the Sicilian helicopter rescue services network, including the smaller islands, independently of the ‘rest of the world’.

The Sicilian regional helicopter rescue service has three operational bases, equipped with helicopter ambulances, sited near the three main hospitals of Palermo, Catania and Caltanissetta. Another helipad with helicopter ambulance, serving the Pelagie Islands, is sited at the airport on Pantelleria.

Moreover, there are a total of 19 helipads distributed around Sicily, assigned to rescue operations, of which 13 are sited at hospitals (including the three above).

For reasons of computational complexity and availability of data, a simplified application of the proposed model was carried out.

As regards the zoning of the territory, instead of the proposed ‘grid’ approach, a zoning on the basis of communes was preferred. To limit the number of variables and, therefore, elaboration times, some communes were united, arriving at a territorial subdivision into N=248 zones.

Furthermore, the application being useful not so much for the positioning of the helipads in Sicily as for illustrating the way the method works, the only risk taken into consideration was seismic risk.

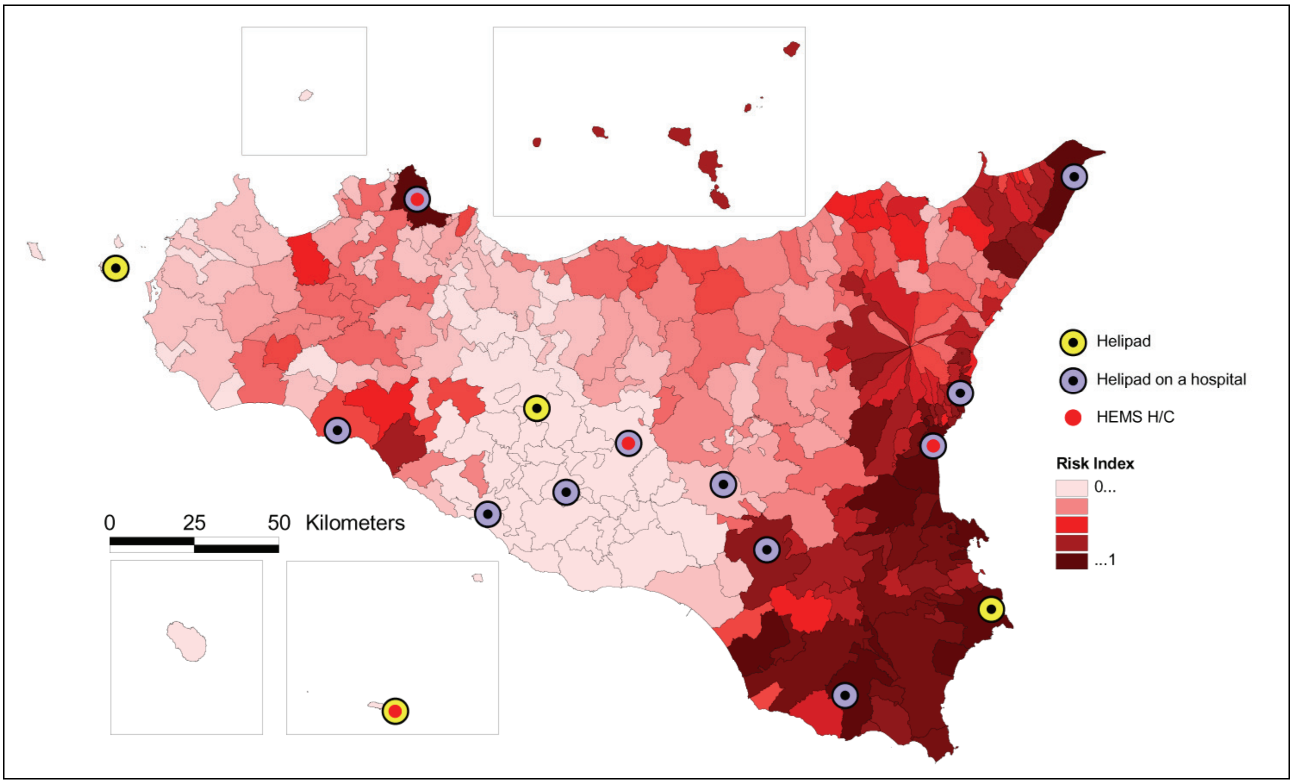

Figure 2 - Seismic risk and existing helipads by zone in Sicily

Proceeding in this way, the result of the territorial characterization procedure, for risk purposes, is the estimate of the *TR* for each zone, which is in any case a normalized index.

As regards the vectors **g**, **e**, and **p**, which are 248-bit binary strings, these were constructed in accordance with the presence of hospitals equipped, or not, with helipads and other generic helipads.

Figure 2 shows the color gradation risk map, the positioning of zones equipped with a helipad, near a hospital or not and the actual helicopter rescue service operations centers.

Using the model it is possible to verify the start situation, by estimating the value of the objective function given the present working conditions of the system. Figure 3 illustrates the territorial distribution of rescue times relating to the current situation, in chromatic scale.

With these conditions, the *WMT* value is equal to 34.5 minutes.

It can be seen how the availability of hospitals equipped with helipads reduces rescue times in the surrounding areas, even if they are located at some distance from the corresponding operations centre.

The first verification of the model was carried out using a potential scenario hypothesis, bearing in mind the general indications of the region integrated with considerations based on engineering 'common sense'. In this way four operations centers in Messina (already planned by the Sicilian Regional Administration), Modica (RG), Trapani and Agrigento were added to those already in existence.

Figure 4 shows the situation as regards rescue times, the *WMT* value being equal to 27.4 minutes, a considerable decrease, therefore, as regards the present situation.

Carrying out an optimization, having fixed the number of HEMS operations centers at three (besides that on Lampedusa, which has very little effect on the rest of the territory given that it is situated so far away), we obtain a *WMT* value equal to 29.4 minutes, about 5 minutes lower than at present, with an intervention time distribution as shown in Figure 5.

As can be seen, the choice of location for the HEMS centers is greatly influenced by risk, that is by the probability of a request for intervention which again, for our application, comes exclusively from seismic risk.

The BAH algorithm, in the same situation, gives a *WMT* equal to 29.4 minutes (a few tenths of a minute more than that of the genetic algorithm).

Launching an optimization, by means of the genetic algorithm, with seven HEMS centers (excluding Lampedusa), we obtain a *WMT* equal to 24.9 minutes, while the BAH algorithm gives a *WMT* value equal to 25.1 minutes.

The results of the optimization model and the *WMT* estimates are shown in Table 1.

	HEMS centers	WMT [min]	difference
present network	4	34.54	
GA optimization	*4*	*29.39*	*-14.9%*
BAH optimization	*4*	*29.45*	*-14.7%*
GA opt. w/1 tiltrotor	*4*	*23.54*	*-37.4%*
tendential network	7	27.43	
GA optimization	*7*	*24.86*	*-9.4%*
BAH optimization	*7*	*25.13*	*-8.4%*

Table 1 – *WMT* assessment and optimization results

Finally, we studied the possibility of equipping one or more HEMS centers with a vehicle which, while having all the maneuverability characteristics of the helicopter also has greater autonomy and speed (tiltrotor).

For example, hypothesizing that the province of Catania was equipped with this vehicle, obliging the model to assign a tiltrotor to only one centre and a helicopter to the other two, the optimal solution would be to position the tiltrotor in Catania and the helicopters in Messina and in Altofonte (PA). In this way, with only three centers (as in the present situation) we would obtain a *WMT* equal to 23.5 minutes, with a decrease in relative terms of almost 40% and in absolute terms of more than 10 minutes.

It is unnecessary to underline the importance of 10 minutes (or even 5) in a rescue operation with lives at stake.

The use of the tiltrotor is, however, only a prospect, given that a version equipped for medical rescue is still not available.

Conclusion

The model that has been set up for the optimal location of the HEMS operations centers network can be used in both verification and planning phases, thanks to the proposed resolution algorithms, or others.

The application has shown how, for problems of limited dimensions, the genetic algorithm is the best solution, obtaining optimal (or nearly) resolutions. Probably, using a ‘grid’ approach with more than one thousand variables, a closed heuristic approach is to be preferred, like the BAH that we propose.

Naturally, the model does not give detailed indications on the precise sitting of the helipads, which is subject to many constraints which it is not convenient to take into account in a model of such vast scale. A subdivision into cells of 5x5 km seems to be sufficiently detailed for a regional study. As the size of the territory studied grows the dimensions of the basic cell must grow within which a further, more detailed, study can then be carried out.

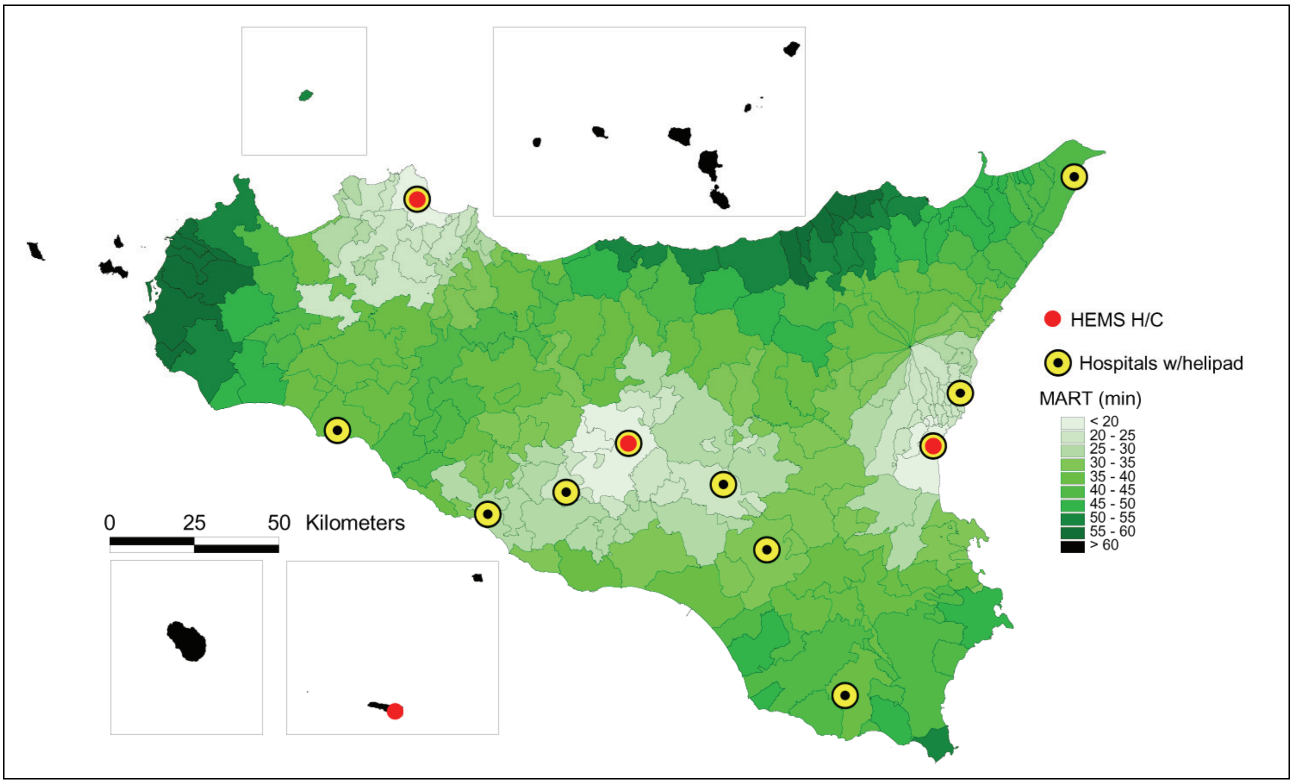

Figure 3 - Rescue times: present HEMS network

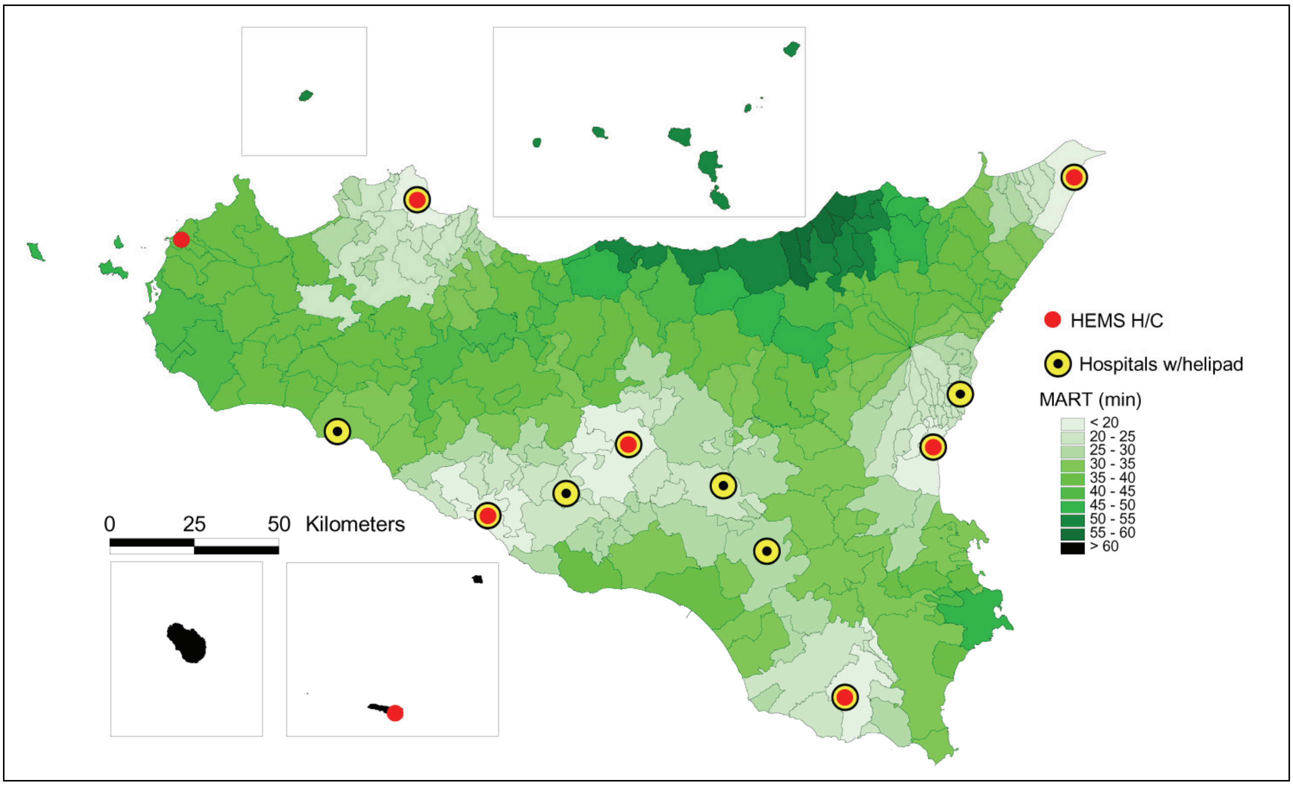

Figure 4 - Rescue times: tendential HEMS network

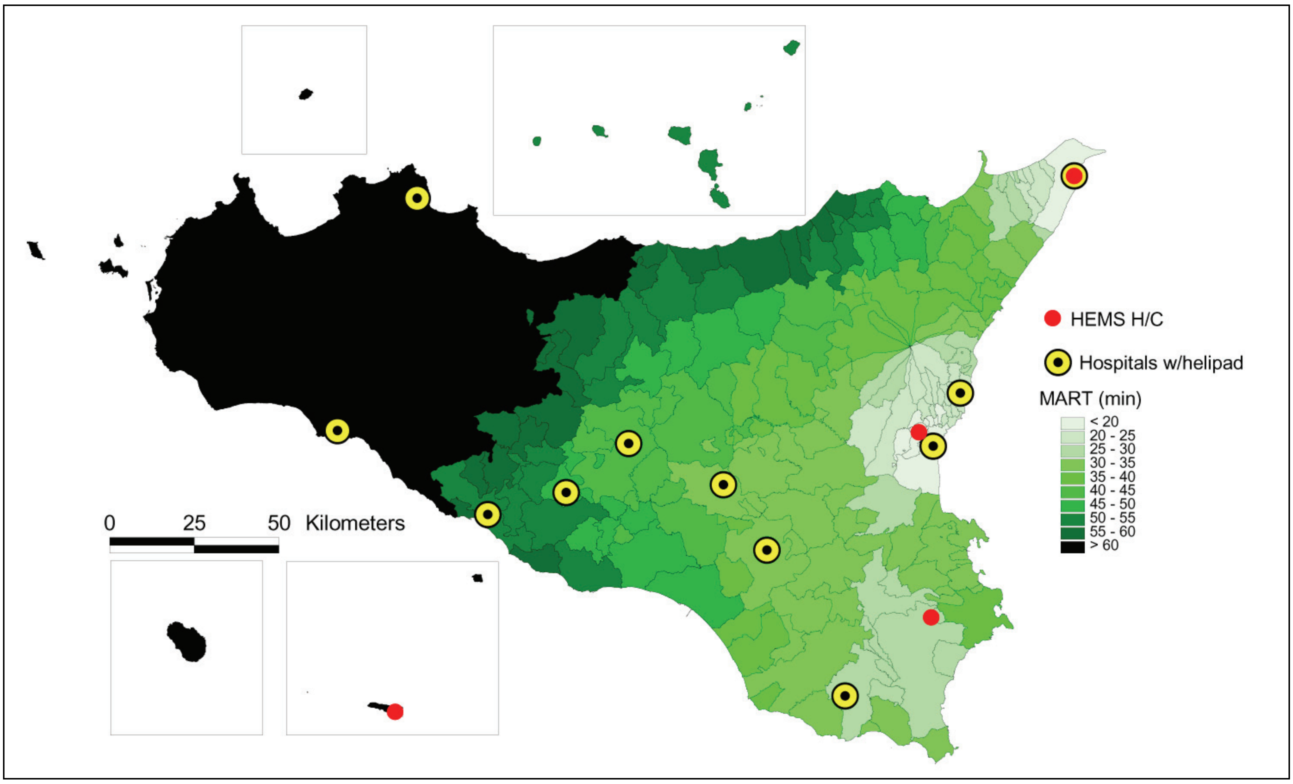

Figure 5 - Rescue times: optimal localization for 3+1 HEMS centers

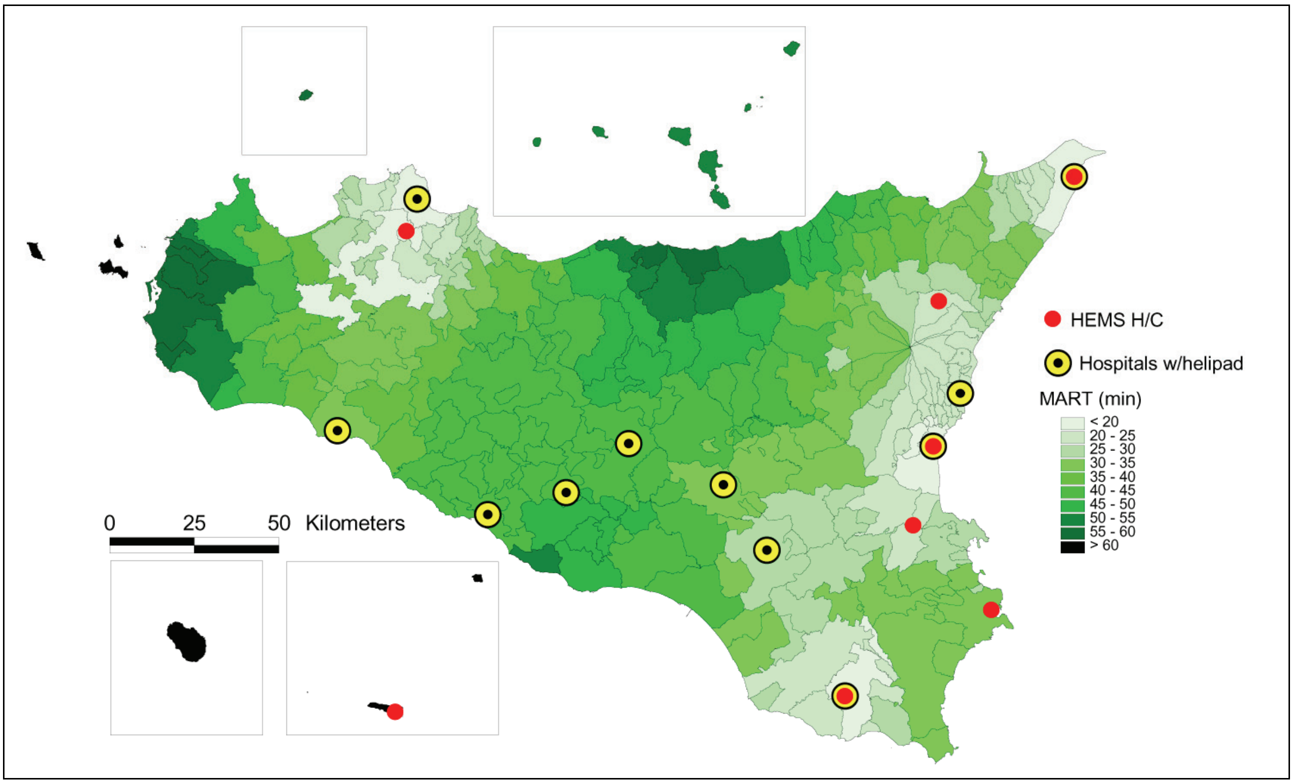

Figure 6 - Rescue times: optimal localization for 7+1 HEMS centers

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