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Lifelines in case of Natural Disaster Emergencies

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Executive Summary

Following a natural disaster, a lot of links of the road network may be unavailable or interrupted. Certain segments such as bridges, tunnels or even normal streets may be impossible for vehicles to circulate. This is a result of either the collapse of buildings infrastructure failures, or road network flooding. This degradability creates both inconvenience to local inhabitants and a huge barrier in rescue vehicles.

In order to handle such disasters, emergency areas are often individuated over the territory, close to populated centres. In these areas, rescue services are located which respond with resources and materials for population relief.

A method of automatic positioning of these centres in case of a flood or an earthquake is presented. The positioning procedure consists of two distinct parts developed by the research group of Prof Michael G. H. Bell of Imperial College, London, refined and applied to real cases at the University of Bologna under the coordination of Prof Ezio Todini.

There are certain requirements that need to be observed such as the maximum number of rescue points as well as the number of people involved. Initially, the candidate points are decided according to the ones proposed by the local civil protection services. We then calculate all possible routes from each candidate rescue point to all other points, generally using the concept of the "hyperpath", namely a set of paths each one of which may be optimal. The attributes of the road network are of fundamental importance, both for the calculation of the ideal distance and eventual delays due to the event measured in travel time units.

In a second phase, the distances are used to decide the optimum rescue point positions using heuristics. This second part functions by "elimination". In the beginning, all points are considered rescue centres. During every interaction we wish to delete one point and calculate the impact it creates. In each case, we delete the point that creates less impact until we reach the number of rescue centres we wish to keep.

The proposed technique was applied to the Aquila earthquake in 2009 in Italy, and the flood in the Alessandria Region in 1994. All data was elaborated in the ESRI ArcGIS platform while TeleAtlas™ road network data was also provided by ESRI Italia (dott Pietro Coffaro e dott Fabrizio Pauri). A vast quantity of data was supplied by the Italian National Research Centre - Hydrogeological section of Torino namely CNR - IRPI (Centro Nazionale delle Ricerche - Instituto di Ricerca per la Protezione Idrogeologica del Consiglio) by dr Fabio Luino. The National Institute of Geophysics and Vulcanology of Milan and Rome - Dr Stefano Salvi (namely Istituto Nazionale di Geofisica e Vulcanologia di Milano INGV - Milan) supported the earthquake section of this research.

Executive Summary

In seguito ad un disastro naturale succede spesso che alcune parti della rete stradale siano inutilizzabili o interrotte. Si può avere il danneggiamento di alcuni elementi come ponti o gallerie oppure si può verificare che alcune strade risultino impercorribili a causa del crollo dei palazzi vicini o del loro allagamento Il degradamento della rete stradale costituisce un grande ostacolo ai soccorsi.

Nella gestione di queste calamità si predispongono sul territorio aree di emergenza, in prossimità o corrispondenza dei centri più popolati dei punti di soccorso dove vengono localizzate risorse e materiali per il sostegno alle popolazioni colpite.

Si presenta un metodo di posizionamento automatico di questi centri di soccorso nel caso di un terremoto o di un'alluvione. Il posizionamento avviene eseguendo due proccedure sviluppate dal Gruppo di Ricerca del Prof Michael G. H. Bell dell'Imperial College di Londra e perfezionate ed applicate a casi reali all'Università di Bologna sotto il coordinamento del Prof. Ezio Todini.

Per posizionare in maniera ottimale i centri di soccorso devono essere rispettati alcuni requisiti quali: il numero massimo di centri da posizionare e il numero massimo di abitanti che un centro può soccorrere.

Inizialmente si decidono dei punti candidati all'interno della rete stradale (di solito proposti dal dipartimento locale della Protezione Civile). Si calcolano tutti i possibili percorsi da ogni punto (candidato per diventare punto di soccorso) verso tutti gli altri, utilizzando il concetto dell' "hyperpath" o ipercammino. I costi cosi calcolati rappresentano, in unità di tempo, i tempi di percorrenza. Di fondamentale importanza sono i dati della rete stradale utilizzata. Si utilizzano tutti gli attributi disponibili sia per valutare i tempi di percorrenza ideali sia per stimare i possibili ritardi che sono dovuti al verificarsi dell'evento stesso.

In una seconda fase si usano i tempi individuati per decidere in modo euristico quali siano le posizioni migliori dei punti di soccorso. Questa seconda parte della procedura funziona per "eliminazione". All'inizio tutti i punti sono considerati come possibili punti di soccorso. Si prova ad ogni iterazione ad eliminare un punto di soccorso e si calcola il costo di rimozione

Si elimina sempre il punto caratterizzato dal mnimo costo di eliminazione e si procede fino a raggiungere un numero di punti di soccorso pari a quello desiderato.

La tecnica descritta è stata applicata alla Provincia dell'Aquila per il terremoto del 2009 e alla zona di Alessandria per l'alluvione del 1994. Tutti i dati sono stati elaborati all'interno della Platform ESRI ArcGIS e le reti stradali TeleAtlas^{TM} usate sono state fornite da ESRI Italia (dott Pietro Coffaro e dott Fabrizio Pauri). Una vasta quantita di dati è stata fornita dal CNR - IRPI (Centro Nazionale delle Ricerche - Instituto di Ricerca per la Protezione Idrogeologica del Consiglio) di Torino (dott Fabio Luino). Per la parte dei terremoti c'è stato il supporto dell'Istituto Nazionale di Geofisica e Vulcanologia di Milano INGV - Milano e Roma (dott Stefano Salvi).

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Chapter 1

Introduction

Natural and technological disasters (International Federation of Red Cross and Red Crescent Societies, 2011) keep on imposing very high tolls on human kind (Centre for Research on the Epidemiology of Disasters, 2011). In 2010 385 natural disasters have been recorded, causing more than 297,000 fatalities and US$ 123.9 billion of damages. In 2010 an earthquake in Haiti (12 January) resulted in 222,641 deaths; floods and landslides in China (May to August) affected more than 145 million people; an earthquake of magnitude 8.8 on the moment scale (27 February) cost Chile US$ 30 billion (Guha-Sapir et al., 2011).

The individuation of natural hazard prone areas, permits a comprehensive defend actions organization from the part of civil protection department (both national and local). Such natural disasters may include geological, hydro geological, geomorphologic, geophysical, etc interest.

Natural hazard phenomena manifest periodical impact. The goal is to capture their rhythm although intensity may vary from time to time. Furthermore natural hazards lead to actual disasters only when the natural event impacts on a vulnerable environment. Vulnerability can be reduced by the adoption of emergency management measures before, during and after the occurrence of adverse events. Comprehensive Emergency Management considers four stages in dealing with adverse events: mitigation, preparedness, response, and recovery (Green III, 2002). Systematic reviews of research on optimization of disaster management activities are provided by Altay and Green III (2006) and Caunhye *et al* (in press). The latter classifies the research on the logistics of humanitarian relief chains – crucial in the preparedness and response phases – into two categories: 1) facility location; 2) relief distribution and casualty transportation.

We present a method to locate repositories of resources for humanitarian relief chains (referred to as “terminal points” in the following) to face emergencies generated by natural disasters such as floods. Both the demand points (referred to as “population centres”) and the candidate locations for terminal points coincide with the nodes of a transport network which can be degraded by the disaster. It is assumed possible to estimate for each link the maximum additional cost (or delay) caused by the damages generated by the disaster. The problem is formulated as a two stage optimization problem: The primary problem is a capacitated p-median problem in which the location of p rescue centres is sought which minimizes the overall weighted best-worst cost between rescue centres and population centres

Global warming

Global average temperature rises are evident in most people's experience. Rise in the average temperature of Earth's atmosphere and oceans is commonly known as Global warming. Earth’s surface average temperature increased almost 0.8°C over the past 100 years, while 0.6 °C of this warming occurred over the last three decades. This phenomenon is very likely caused by the emission of greenhouse gases from human activities (e.s. deforestation and burning fossil fuels). Actually, 97–98% of climate researches support the outcomes of the Intergovernmental Panel on Climate Change, on the tenets of Anthropogenic Climate Change (ACC) (William R. L. Anderegg, James W. Prall, Jacob Harold, Stephen H. Schneider, 2010). However there are a few climate scientists sceptic about this issue (Arrhenius, 1896) (Page, 2007) (Berkeley Earth Team, 2011) (Kai-Uwe Eichmann, 2011).

However it is very important that 97% of active climate researchers agree with the Intergovernmental Panel on Climate Change executive summary. Should we note that Global climate is a very complex system, processes are diverse and cover many fields.

There is no doubt that humans are altering the climate, but the implications for regional weather are less clear. No computer simulations exist in order to give a conclusion about a given snowstorm or flood due to global warming. But with a combination of climate models, weather observations and a good dose of probability theory, scientists may be able to determine how climate warming changes the odds. Nonetheless, this poses significant risks for a range of human and natural systems. And these emissions continue to increase, which will result in further change and greater risks.

An increase in global temperature causes sea levels rise and changes the amount and pattern of precipitation. The insurance industry has long worried about increased losses resulting from more extreme weather. It is not yet certain, if put the blame on climate change, may give the answer. Indeed it may take long time to prove (Schiermeier, 2011) but somehow it is the case to take this matter into consideration when it comes to talk about flooding issues.

Figure 1-1 Global warming for flooding

Resilience and Vulnerability of transport networks

Investigation of short to medium term operational vulnerability and resilience of transport networks analysis is commonly accepted as a very important step to reduce the catastrophic impact of natural disasters. This may also include identify longer term network adaptation issues raised by climate change if this is not addressed.

We can reach somehow the concept of vulnerability through bibliography of the last ten years. Berdica (2002) presents a detailed terminology for vulnerability. Vulnerability should focus on the impacts of the different threats to the network and not on the threats themselves. However a generally recognized definition for resilience is not recognised. Yet there have been identified some key properties that have been used to gauge the resilience of a transport network by Murray-Tuite, P.M. (2007) and reported by Christopher Mason., 2010

- Redundancy. In the transport network there are some similar one to each other components, from the functionality point of view that can serve the same target and therefore the system does not fail when one of its components fails (there may be available more than one paths to go from one place to another).
- Diversity. There may be different functional components so as to be protected against various threats (there must be different travel modes to go from one place to another).
- Environmental Efficiency. For a sustainable transport system, capacity constraints may produce less impact to itself due to environmental reasons.
- Autonomy. Different components of the transport system should be able to operate independently. In such way, one components failure, would not cause the failure of others. (Eventual efficiency of the transport system be in case of electricity power cut).
- Strength. The robustness of a transport systems against an incident (the "magnitude" of a natural hazard the system may afford).
- Adaptability. The flexibility of the transport system to adapt to changes. This may include the capacity to change through different experiences (different traffic conditions in the same area).
- Collaboration. Different components of the transport system share the same information or resources are shared (adaption of the same plans in case of an emergency and the ability or responsibility for different system operators to communicate).
- Mobility. Users of the transport system should be able to arrive to the desired destination in an acceptable time.

- Safety. The transport system should be robust enough so as protect travellers in case of an unexpected hazard and not expose them to additional risks.
- Recovery. The transport system should be able to quickly recover up to a reasonable level after the occurrence of a routine incident.

Chapter 2

Emergency Management

Emergency management is the generic term of a multidisciplinary field. It generates strategies and processes used to protect critical assets of an organization from hazard risks that can cause events like disasters or catastrophes. It is also responsible to ensure the continuance of an organization within their planned lifetime. Comprehensive emergency management can be defined as the preparation for and the carrying out of all emergency functions whether natural, technological, or human caused. It includes more than one components in order to be prepared for each hazard considering all hazards, its phases and its impacts.

Catastrophes, Emergencies or Disasters, are not linear fields; they are discrete issues causing different problems that require distinct strategies of response. These differences need specific planning and management activities for their relevant crisis groups both quantitatively and qualitatively (Quarantelli, 2000).

Emergency Management is considered strategic and not tactical process. As a result it is very often treated by the highest level management in an organization. It has no direct power generally, but corporate as a coordinating or advisory function to ensure that all elements of an organization are emphasised on the desired target. Effective Emergency Management is firstly based on the integration of emergency plans at all levels of a certain organization. After that is very important to ensure that each level of the specific organization is capable to apply the decisions taken under crisis state, be responsible enough to manage the emergency, receive additional resources and assistance from the upper levels when needed.

Last but not least, Emergency Management has a certain hierarchy led by a specialist normally called Emergency Manager. He is in charge of creating the framework within which communities reduce vulnerability to hazards and cope with disasters.

In summary, Emergency management has a certain definition, Vision, Mission and Principles (IAEM, 2007) . Emergency management is the managerial function in charged to create the lines within which communities reduce vulnerability to hazards and cope with disasters. It's vision is to promote safer communities with the capacity to cope with hazards and disasters. Its mission is to protect the community by coordinating all necessary activities capable to mitigate against, prepare for, respond to, and recover from threatened or actual natural disasters, acts of terrorism, or other man-made disasters.

A successful Emergency manager must be Comprehensive, Progressive, Risk-Driven, Integrated, Collaborative, Coordinated, Flexible and Professional based on, training, experience, ethical practice, public stewardship and continuous improvement (IAEM, 2007).

The Phases of emergency management

Comprehensive Emergency Management includes four distinct phases based on local and economical conditions. Namely these four phase s are Mitigation, Preparedness, Response and Recovery. All four phases highly depend on the long term work on infrastructure, public awareness and even legal and justice issues.

In United states Emergency Management is mainly driven since 1979 by the Federal Emergency Management Agency (FEMA). FEMA is a government institution that deals with all phases four phases of natural and technological disasters as well as terrorist actions etc

In Europe natural and technological disasters are organised by the Civil Protection Departments different for every country. Organization and functional standards vary from country to country since there does not exist a main driven organization to generally provide the guidelines for mitigation, preparedness, response and recovery.

Italian Civil protection is one of the most effective organizations in Europe that cover all four phases of Natural disasters in the Italian territory.

Mitigation

The first phase of emergency management analyzed is mitigation which in general deals with the prevention of hazards before these, are developed into disasters. This phase efforts to reduce life and property loss by preventing the impact of disasters. There are plenty of mitigation activities which achieve to calculate the risk over certain natural or man-made disasters and provide a methodologies to reduce it. Such information can be provided by Risk analysis foundations and flood insurance that protects financial investment. Mitigation analysis phase differs from the other phases of emergency management in the sense that it mainly focuses on long term studies for reducing or eliminating risk. Mitigation strategies can then be implemented as part of the recovery phase, if applicable following a disaster.

Mitigation measurements may apply either structural or non structural units. Technological solutions are generally used for structural measurements when we have to deal with flood levees or building retrofitting for earthquakes. Non structural measurements instead, often deal with legislation, land-use planning (for example create non essential land such as parks to be used as floodplains) and insurance.

Many times there has been stated that the most cost-efficient method for reducing the effect of hazards is through mitigation. However this is not always the most suitable solution. Strategies included in this phase include regulations regarding evacuation plans, sanctions against those who refuse to apply decided regulations (for example mandatory evacuations), and communication of risks to the public. It is also possible that some structural mitigation measurements may harm the ecosystem.

A precursor to mitigation is the identification of risks. Physical risk assessment refers to identifying and evaluating hazards. The hazard-specific risk (Rh) combines a hazard's probability and effects.

Determination of Hydrogeological Risk and Loss

In analytical terms, hydro geological risk is expressed in the following equation. This equation connects hazard, vulnerability to the exposed value (the value exposed to the risk):

Risk = hazard x vulnerability x exposed value

"Hazard" term expresses the probability that in a certain zone is verified a damaging event of a certain intensity during a certain period of time (this period of time is referred to as "return time"). Hazard therefore function of the frequency of the event. In certain cases when we mainly deal with floods it is possible to calculate an acceptable approximation of the return period. For other hydro geological risks, such as certain types of landslides, such estimation is way more difficult to obtain.

Vulnerability instead, indicates the attitude of a certain "environmental component" (such as human population, buildings infrastructures, services, etc) to support the effects in an intensity bases, due to the event itself. Vulnerability expresses the level of loss of a certain element or a series of elements as a result of the verification of a stated "magnitude" expressed in a scale from zero (no damage) to one (absolute destruction). The exposed value (or exposition) indicates the element that has to support the event. The event can be expressed either form the presence of human lives, or from the value of natural and economical resources exposed to a certain danger.

The product Vulnerability x Exposed value thus indicates the consequences deriving from humans in terms both of human loss and damages in building and in general infrastructures or the producing system. The risk expresses therefore the expected number of human loss, human injuries, property loss, economical activity loss natural recourses loss due to particular harmful event; in other words risk is the product of the probability of occurrence of a certain event with the event's dimension itself.

Determination of Seismic Risk and Loss

For the occurrence of an earthquake the standard definition of risk is the same. However Risk and loss are described separately. Seismic risk is thus the probability or likelihood of damage and consequent loss to a given element at risk, over a specified period of time.

It is important to note again the distinction between risk and vulnerability. Risk combines the usual losses from every level of hazard severity, taking also into account their occurrence and probability, while an element's vulnerability is usually stated for a given hazard severity level (Coburn et al. 1994).

Loss is defined as the human or and economical results of an individual damage, along with injuries or deaths, the costs of repair, or loss of profits. The distinction between risk and loss many times is not clear and always generated based on their definition; these two terms are very often used equally. Taking into consideration that the standard definition of risk is a probability or likelihood of loss (from zero to one) it may be more appropriate to express risk as

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability}$$

On the other hand loss depends on the value of the exposure at risk, given by

$$\text{Loss} = \text{Hazard} \times \text{Vulnerability} \times \text{Exposure}$$

As a result, while seismic hazard is genuinely a product of natural processes, seismic risk and loss depend on the vulnerability and societal exposure in terms of the infrastructure environment, human population, and value of processes.

Preparedness

The term Preparedness deals with the way we change our behaviour in order to limit a disaster's impact to ether individuals or organizations. This includes an eterne cycle of, evaluating, , monitoring, planning, training, managing, equipping, exercising, creating and improving actions to guarantee efficient organization and the connection of all available capabilities of concerned organizations to either protect or create resources against natural or manmade disasters but even terrorist actions or other causalities that may create human and natural inconvenience.

An emergency manager, for the preparedness phase, needs to focus on the development of emergency plans. During effective Risk management, there are counted individual risks as well as are organised specified activities. In such way are created the necessary capabilities, needed to implement such plans. Common preparedness measures include:

- Communication plans with clear process and terminology.
- Efficient maintenance of emergency services and continuous training and updating of qualified personnel, including mass human resources such as community emergency response teams.
- Continuous tests and development of early warning methods. This would include determination of emergency shelters (such as rescue centres or terminal points) and efficient evacuation plans.
- Relief supply chain which includes inventory of the target zone, streamline, food and medicine supplies and equipment.
- Take advantage of and gather together specific organizations, trained volunteers and local communities. Emergency operator professionals are immediately overpowered after mass emergencies so responsible trained and organized volunteers are very valuable. There exist organizations that provide spontaneous trained volunteers such as the "Red Cross" and "Community Emergency Response Teams". Red Cross's emergency management system has received high ratings all over the world.
- Last but not least, another key issue of the preparedness phase of emergency management is "casualty prediction", which is the study of the loss we can expect due to a certain event in terms of deaths or injuries. "Casualty prediction" may form

an opinion to planners about the required resources needed so as to respond to a particular sort of event.

As long as planning phase lasts, Emergency Managers should be both flexible, and all encompassing. They should carefully recognize both exposure and risks the of the regions they are responsible for, and be eligible to employ unusual or unconventional systems of aid. Depending on the category of the emergency service that can be applied to a region, municipality or even a certain private sector, emergency services can immediately be consumed and overcharged. Mutual aide compromises between nongovernmental organizations, which offer desired resources, and rescue groups is important to be distinguished in the first stages of planning process and applied with uniformity.

Response

In the response phase we can individuate the mobilisation of all available emergency services needed which would be naturally pat of the first services to respond at the disaster zone. This is possible to include emergency vehicles of fire-fighters, ambulances or even police and army forces. Civilian emergency resources apply to the first wave, or core emergency services. In the case where military operations are needed a Disaster Relief Operation is conducted. When this occurs it is very often the case where a non combatant evacuation may follow. Several secondary emergency services may participate such as specialist rescue teams.

When an emergency plan is efficiently structured, the coordination of rescue teams is less hard to handle. There are times where search and rescue teams (Search And Rescue -SAR teams) have to react at a very early stage. This depends on injuries supported by the victims, weather conditions, victims possibility to escape from the disaster area or access to air and water. The majority of victims affected by a disaster may pass away within 72 hours within the impact if not helped.

From the organization point of view, a comprehensive response to a significant disaster (which could be ether a natural disaster -man-made- or a terrorist) is mainly based on the existing processes and systems of the actual emergency management structure. This may include a Response Plan and the Incident Command System.

Both agility and discipline are needed in responding to a disaster. An efficient leadership also needed in order to onboard and built a quick coordination and solve problems as they grow over the first responses. The suitable leader, together with the responsible and trained team have to work together and implement an already robust emergency plan for the specific needs of each disaster.

Recovery

The goal of the recovery phase is to rebuilt, reconstruct and renovate the area affected by the disaster to its prior condition. There are certain directions people should follow in order to facilitate recovery. This may include health and safety guidelines, maybe clean a damaged home and rebuilt it safer for the future, take certain precautions while going back home or even ask for assistance. More generally re-employment, and repair of all essential infrastructure. Other human aspects after a disaster is cope with the emotional effects of a disaster, help children or others cope with such feelings over recovery.

Main efforts should focus to build a better and more robust environment aiming to reduce the pre-disaster risks organically in the community and infrastructure. A very significant aspect of effective recovery efforts is taking advantage of the instructions given and maybe the opportunity implement discrete measures and keep in mind that disasters (especially natural disasters) have a period of return and thus it is very likely to happen again. This is why measurements need to be taken as soon as possible in order to avoid more severe consequences. Citizens of the affected area are more likely to accept more changes when a recent disaster is in fresh memory.

There are three general phases that take place during recovery after a natural disaster. Both actions and timing vary respect to the severity and the nature of the disaster. The first phase deals with direct actions taken to reduce life-threaten hazards and prepare short-term repairs to critical lifelines. The second phase consists of the preparation of social needs during the reconstruction of damaged infrastructure. This phase may last several weeks, months or even a couple of years. The third phase consists of implementing all reconstructions of damaged buildings and other facilities or infrastructure as well as the continuation of normal financial and social life in the community. This may also include a review of pre-disaster status. This third phase may last way long tame, may in fact continue for some years.

Chapter 3

The concept of the hyperpath

Introduction

The problem of searching a route in a network that consists of links and nodes is mostly encountered by transport engineering. However it is very often computer sciences and (or) operational research that deals with searching problems and thus problems such as minimization, maximization or capacity of a denoted value. The network, or in other words the directed graph, represents in our case a street map where the links are different road elements (roads, bridges, tunnels) and the nodes are the junctions.

There has been proposed a lot of network searching techniques in the past and thus a lot of research to form a search tree, beginning from a certain origin and arriving to the desired destination. There are algorithms seeking to find the optimal route in a certain network (with respect to the criterion to be optimized) and others that guarantee to find any possible available solution. The first ones are called optimal and the second ones heuristic.

The concept of the hyperpath derives initially from a specific field of transport engineering known as transit assignment (Spiess and Florian, 1989; Nguyen and Pallotino, 1988) and consists of a number of paths, any one of which can be used as optimal. It comes along a strategy that allows the traveler to reach his destination in the minimum expected cost in terms of reliability. When it comes for the traveler to decide which path to choose for a certain destination, he chooses the first attractive line that comes first which most of the times this is the most frequent one.

For example when arriving at a bus stop or a train station there are often a number of alternatives available and most of the times the choice depends on the bus or train that happens to arrive next. Under this rule and assuming that public services arrive with given frequencies it is possible to know the optimal attractive lines of a certain train or bus station. Under this point of view Spiess and Florian (1989) proved that the hyperpath can be found, minimizing the expected travel times by resolving the linear problem that comes along. This problem is solved using an algorithm that recalls Dijkrtra's algorithm for shortest paths initializing it from the target.

In this part are shortly described some of the most famous and commercially used shortest path methods that along with digital maps and satellite locationing have made possible the development of affordable car navigation systems very popular in the markets of the developed and developing countries. Indeed shortest path methods have been able lately to calculate alternative routes that take into consideration time spent in congested zones.

Notation and Definitions

We report in this section some basic issues for the solution of the arguments stated in this chapter.

Optimization

Optimization is the selection of one or a number of solutions that are the best among other available alternatives. It refers to the solution of a problem that minimizes or maximizes a real function, choosing real or integer variables from the defined domain. In other words, it means discovering "best available" values of some objective function given a defined domain, including a variety of different types of objective functions and different types of domains.

More specific, for a given function $f(x)$, $\forall x \in A \subset R$ minimization is condition in which for an element x_o is $f(x_o) \leq f(x)$ and maximization is a condition in which for an element x_o is $f(x_o) \geq f(x)$.

Linear Programming

A linear programming problem is a maximizing or minimizing optimization problem with a linear objective function subject to linear constraints and a number of nonnegative restrictions upon the decision variables. The constraints may be equalities or inequalities.

The standard form of a linear program is the following:

$$Minimize \sum_{j=1}^{m} c_j x_j$$

Subject to

$$\sum_{j=1}^{m} a_{ij} x_j = b(i) \qquad \text{For all } i = 1,....,m$$

$$x_j \geq 0 \qquad \text{For all } j = 1,.....,n$$

Constraints have to be no negative and the objective function is better to be stated in the standard form (and not in Maximization form).

The most significant method for solving linear programming is the simplex method developed in 1947 by Dantzing in order to solve several military planning problems (Ahuja et al, 1993). This method is able to maintain a basic feasible solution at every step. Once we have this basic solution, the method applies the optimality criteria in order to test the optimality of the current solution. If the last does not fulfill the condition an operation said pivot operation is performed to create another structure with the same or lower cost. This process is repeated until the point that the actual basic feasible solution satisfies the optimality criteria.

Duality theory

Every linear problem has closely related another linear programming problem that together defines the duality theory. The first linear programming problem is called primal problem, the second closely associated to the primal problem is called dual problem. In other words the duality principle states that optimization problems may be viewed from two perspectives: the primal problem or the dual problem.

Assuming that the linear program is in the following form

$$Minimize \sum_{j=1}^{m} c_j x_j$$

Subject to

$$\sum_{j=1}^{m} a_{ij} x_j \geq b(i) \qquad \text{For all } i = 1,....,m$$

$$x_j \geq 0 \qquad \text{For all } j = 1,.....,n$$

We insert a variable $\sigma(i)$ for the formulation of the dual problem which is:

$$Maximize \sum_{i=1}^{n} b(i)\sigma(i)$$

Subject to

$$\sum_{i=1}^{n} a_{ij} \sigma(i) \leq c_j \qquad \text{For all } i = 1,....,n$$

$$c(i) \geq 0 \qquad \text{For all } j = 1,.....,m$$

It can be noticed that the dual of the dual problem is again the primal problem. If any possible solution of the dual problem is σ and if any possible solution of the primal problem is x, then $\sum_{i=1}^{n} b(i)\sigma(i) \leq \sum_{1}^{m} c_j x_j$. This states the weak duality principle. Instead, if the primal problem, has a finite optimal solution so does the dual problem and vice versa. In this case they share the same objective function and this states the strong duality principle.

Lagrangian formulation

In mathematical optimization, the method of Lagrange multipliers (named after Joseph Louis Lagrance) provides a strategy for finding the minimum/maximum of a function to constraints.

Before explaining the hyperpath algorithm we present briefly two other algorithms that played pivotal role for the calculation of shortest paths performed in road networks.

Diksta algorithm

Dijkstra's algorithm was developed by the Dutch mathematician Edsger Dijkstra in 1956, is the most famous shortest path algorithm. It is categorized as optimal which means it finds shortest paths from the source node to all other nodes. Every node is being labeled according to its distance from the source node and this guarantees that this node is not going to be visited again. It makes optimal choices at every step so it can be terminated at any time and gives the results already calculated.

The algorithm is being initialized by giving a label of zero (distance) to the source node and a label equal to ∞ for every other node temporarily which is going to be replaced by the permanent label that indicates the distance of every node selected from the source. At every interaction the algorithm breaks ties arbitrarily by selecting the node with the minimum temporary label, calculates the distance and replaces it with the permanent label (distance). As soon as all nodes are marked as permanent the algorithm terminates.

This algorithm is precise and accurate but it results inefficient for the long running time because of the space it needs to explore. There have been a lot of implementations on Dijkstra algorithm .The most famous solution was given using heuristics and generate A* algorithm some years later.

A star algorithm

The A* algorithm (Hart, Nilson, 1968) is an implementation of Dijkstra's algorithm that uses a heuristic estimating function to reduce the search area. If this function does not overvalue the actual length of the distance, the algorithm results very efficient.

An unsuccessful heuristic function chosen may increase the running time or may not find a solution at all. For this reason the success of A* is heavily depended on the correct choice of the heuristic function. Very often, this function is the Euclidian – airline distance from any node of the network to the destination node.

The algorithm holds two sets, the "open" list and the "closed" list. The "open" list contains all the nodes that may be expanded, whereas the "closed" list contains all the nodes that have already been expanded. For initialization, the "open" list contains just the initial node, and the "closed" list is empty. At every step, when a node is examined is being moved from the "open" list to the "closed" list. For each node n is calculated the evaluation function

$$f(n) = g(n) + h(n)$$

Where $g(n)$ is the cost or reaching node n from the source node
$h(n)$ is the heuristic estimate distance from node n to the target node

Hyperpath

The concept of the hyperpath as already introduced, emanates from the field of transit assignment and is a number of routes any of which may be optimal. The algorithms briefly explained in the beginning of this chapter, as well as a large number of algorithms proposed before the formulation of Spiess and Florian (1988) led directly to a computational procedure without a model stated. Spiess and Florian developed a model and provide an algorithm to solve the linear program proposed.

We report the Spiess and Florian linear program and solution algorithm considering a road network consisting of a set of links A and a set of nodes I. The arcs represent the roads and the nodes represent the intersections of the network. We recognize two types of links: the ones leading out of a certain node A_i^+ and the ones leading into a certain node A_i^- (**Error! eference source not found.**). A link can also be indicated as the pair of nodes that connect, so $a = (i, j)$ is the arc that connects nodes i and j.

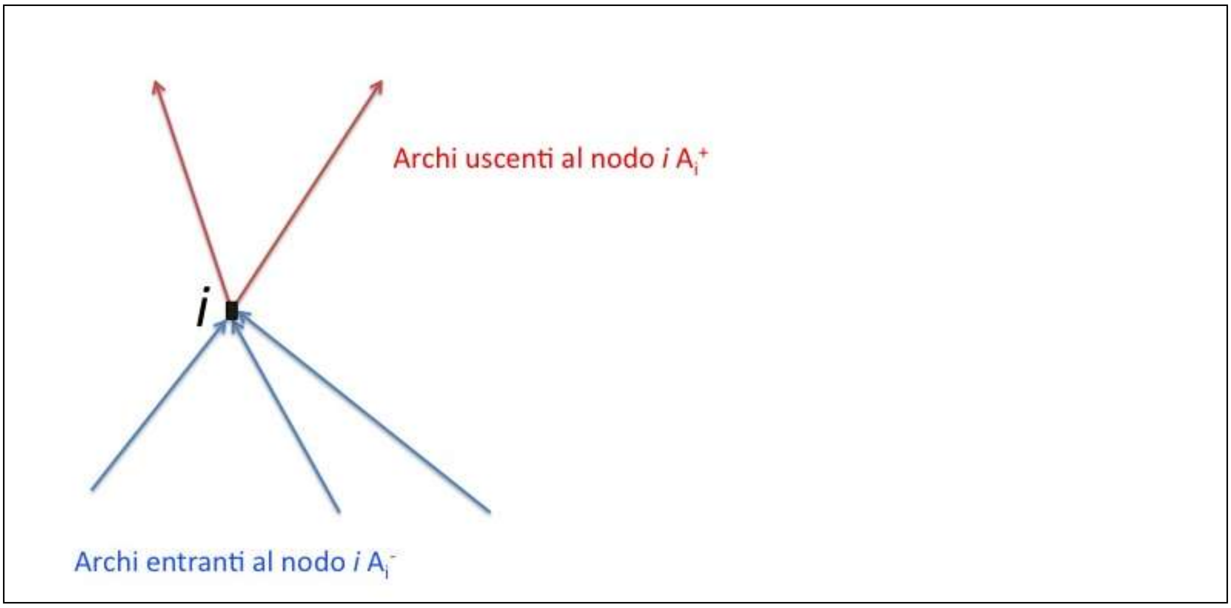


Figure 3-1 illustrated in blue the links out of node i A_i^+ and in red the links into node i A_i^-

To every road element is assigned a service frequency which inverse indicates the waiting time at every link of the vehicles that use it. We could briefly explain better in this way:

- Suppose that a link (ideally without delays) could be crossed in a certain time c_a
- If I have disturbs I spend more time to traverse this link
- The difference between the ideal time c_a and the one with disturbs is indicated as delay d_a
- This disturb could be seen as if someone (ex a policeman) stopped me in the beginning of the intersection (node) time equal as the difference mentioned above (d_a) and after this, I continue without disturbs crossing the link in ideal time c_a
- The time I spend because of the policeman is defined as *waiting time* of the link
- The inverse of this time is the frequency of service[1].

In order to understand better the concept of the service frequency and the waiting time we could make the following example: If you place yourself at the beginning of a node and you count the number of vehicles that traverse a certain link in a minute, the number you obtain is a frequency, the inverse of which indicates the mean time that passes from the cross of one vehicle to the next one. If a lot of vehicles cross (high frequency) means

[1] The inverse of a time is always a frequency and the inverse of a frequency is always a time. A high frequency indicates little time while little time indicates high frequency.

the time of traverse between one vehicle and its successor is little (little time). If the frequency is low, means that a lot of time passes between the cross of one vehicle and its successor. You can now remember, as said before, to the policeman that stops the vehicles at the beginning of the link and understand that the high frequency means that the policeman maintains the vehicle for very few time. Low service frequency means that the police officer maintains the vehicles for a lot of time so there is a lot of time that passes between the cross of two continuous vehicles.

To sum up, a link without delays has a low waiting time (almost nothing) and a high frequency, almost infinitive (dividing to zero obtains infinity). A link with a lot of delays has low service frequency. If vehicles do not cross the link means that there is zero service frequency

The proposed adaption of the algorithm being risk averse, takes into consideration the worst exposure to road link delay and its service frequency is $f_a = 1/d_a$. It is assumed that one is interested to use all available paths so as to be less exposed to link delay.

Another key concept for the proposed algorithm is the risk at every node or the expected node delay. The scope of the driver is to avoid the risky parts (maybe the intersections full of traffic). At every intersection or node i is associated a value w_i that indicates the grade of risk exposure to delays. Under a very conservative adaption (or pessimistic point of view) is assigned the maximum delay $d_a = w_i$ to the links out of node i. The higher value w_i has the riskier the node i is (in the sense of serviceability and thus waste of time) and as a result better to avoid.

Using the following notation the hyperpath from source r to target s is the following linear program:

$$Minimize_{p,w} \sum_{a \in A} c_a p_a + \sum_{i \in I} w_i$$

Subject to

$$\sum_{a \in A^+} p_a - \sum_{a \in A^-} p_a = g_i \quad i \in I$$

$$p_a d_a \leq w_i \qquad a \in A_i^+ \qquad i \in I$$

$$p_a \geq 0 \qquad a \in A$$

Notation

A: Links of the network
I: Nodes of the network

A_i^+: Links outwards from node i
A_i^-: Links inwards to node i

H: Selected links of the hyperpath

c_a: Travel time on link a without delay
p_a: Usage probability of link a
d_a: Maximum delay on link a

w_i: Maximum delay at node i
u_i: Minimum travel time from node i to target s
h_i: Potential at node i with respect to source r
N: Large size number for computation needs

Briefly the solution of the above problem (Spiess and Florian algorithm) is reported here and explained later:

1. Initialization	$u_i \leftarrow \infty,$ $i \in I - \{s\}$ $u_s \leftarrow 0$ $f_a \leftarrow 1/d_a$ if $d_a > 0$ Else $f_a \leftarrow N$ $f_i \leftarrow 0, i \in I - \{r\}, y_r \leftarrow 1$ $L \leftarrow A$ $H \leftarrow \emptyset$
2. Select link a	Find $a = (i, j) \in L$ such that $u_j + c_a$ is minimum $L \leftarrow L - \{a\}$

3. Update node i	If $u_i \geq u_j + c_a$ then
	If $u_i = \infty$ and f_i =0 then
	$\beta \leftarrow 1$
	Else
	$\beta \leftarrow f_i u_i$
	$u_i \leftarrow (\beta + f_a(u_i + c_a))/(f_i + f_a)$
	$f_i \leftarrow f_i + f_a$
	$H \leftarrow H + \{a\}$

4. Loading	If $L = \emptyset$ or $u_j + c_a > u_r$
	Go to step 3
	Else
	Go to step 1
	For every link $a \in A$
	If $a \in H$ then
	$p_a \leftarrow (f_a / f_i) y_i$ and
	$y_j \leftarrow y_j + p_a$
	Else
	$p_a \leftarrow 0$

The hyperpath between the source r and the target s can be determined as the minimization of the following expression:

$$\sum_{a \in A} c_a p_a + \sum_{i \in I} w_i$$

This is nothing different from the expected time to conclude the calculated route. p_a Is the probability that a certain link *a* may be used; being a probability it is expressed as a number between 0 (impossible to happen) and (certain to happen).

$$p_a \geq 0 \quad a \in A^2$$

For the minimization the expression of the objective function has to follow the condition (constraint):

$$p_a \cdot d_a \leq w_i \quad a \in A_i^+ \quad i \in I^3$$

Which means that for all links a out of node i in exam (and for all nodes of the network analysed) is guaranteed that the use of a link is inversely proportional to its maximum delay. It is being recalled that, if a link is selected to take part in the hyperpath, then its probability p_a is over zero, otherwise, if not selected, p_a is zero.

The last constraint to the objective function is the following:

$$\sum_{a \in A_i^+} p_a - \sum_{a \in A_i^-} p_a = g_i \quad i \in I^4$$

---

[2] First constraint of the objective function
[3] Second constraint of the objective function

This relationship is equal to 1 when the node i is the source node *r*; results instead -1 when i is the target node. In all other cases g_i is always zero. The significant of this expression is that the sum of the probability of the links out of a node i is equal to the probability of the links into i and both sums have to be equal to 1.

This equation can result simpler than it seems. Assuming that an event is certain when the probability is 1 and impossible when the probability is 0 we can make the following thoughts: If a node is connected to the path assuming you have A_i^- (i is the target node) in the network, there is for sure the possibility you can reach the target (so you have possibility 1). So, summing all p_a of links into the target node the possibility to arrive there has to be equal to 1 since there in no point in going nowhere else once arrived to the destination. The same thing works for all links out of a node i A_i^+ and thus the origin node. If a node is connected to other links out of i, then the probability to be able to leave this node is sure so the sum of all p_a in this case is 1. We have the same probability to reach or leave a node once we have links out of node i. This is how we can now tell that the difference g_i between the two sums (the one for all links into node i A_i^- and the one for all links out of node i A_i^+) is zero. We talk about sum because is performed an "OR" execution. For example if my desire is to know the probability to arrive to a node i that has three links leading to it with p_a 0.5, 0.25 e 0.25, the answer I seek to have is "Which is the probability to arrive to node j through any of the links, link 1, link 2, link 3". In statistics the keyword is "OR" and mathematically becomes a sum.

[4] Third constraint of the objective function

After that being stated, we can now see the Flow Chart of the proposed algorithm. This algorithm is working outwards from the target so we depart from the destination s and we come back to find the starting point r . This means that I have to pass through from s all links (A_i^-) coming to the node in exam. The algorithm results iterative (repetitive) which means it has to execute a certain operation more times until it satisfies certain conditions (explained next), that means that arrived in convergence. Any iterative algorithm respects the following layout:

1. Initialization of some criteria,
2. Execution of an operation that is being repeated more times,
3. Control after every interaction of the point 2 if arrived in convergence,
4. If arrived in convergence results are being saved. If not you return to point 2

In our case we depart from the target s and the variables are being initialised in the following way:

$$u_i \leftarrow \infty,\ i \in I - \{s\},\ \mathrm{u_s} \leftarrow 0$$

This means that we assign at all nodes of the network except from target s value u_i equal to infinity. In other words we initialize the time that remains for the arrival to the destination from every ode i which in the beginning is a big number since we do not have an indication about the remaining time at this point. This value (u_i) for the source node s is zero.

Then known the delay of every link service frequency is being calculated (as explained before):

$$f_a \leftarrow 1/d_a \ \text{ se } \mathrm{d_a} > 0 \ \text{ o } f_a = N \ \text{ se } \mathrm{d_a} = 0$$

More specific service frequencies are assigned to the links as maximum delays: if there is no delay (in other words the delay is zero), we have the problem that dividing to 0 we get infinity ($1/0=\infty$). This is a problem because counts with infinity give infinity. In these cases we introduce a big number (in our case N) that replaces infinity when necessary.

It is also assigned:

$$f_i \leftarrow 0,\ i \in I$$

This frequency f is referred to the node i and not the link a. So for every node i we have a service frequency which is going to be updated during various interactions.

It is also assigned:

$$y_i \leftarrow 0,\ i \in I-\{r\},\ \mathrm{y_r} \leftarrow 1$$

Every node i has a value of y_i equal to zero apart from the source node *r* which will have a value equal to 1. This value is going to be explained afterwards.

We also initialise two sets: *L* and *H*. *L* in the beginning maintains all links of the network (is the same as the set *A in the beginning*), while *H* for initialization is empty.

Step 1 (initialization) is now concluded. We continue describing all operations executed in repeated mode (step 2) until the point of convergence. This is called iteration as said before.

During iteration is selected a link $a=(i,j)$ not yet examined among all these links that lead to the node selected. That link belongs to the L set explained before. At the first interaction is selected the shortest link that leads to the target node. This link $a=(i,j)$ shall connect a node i to the target node ($j=s$).

The selected link is removed from the *L* set and added to the *H set*. Remaining travel time u_i is then updated from the node i to the destination j in the following way:

$$u_i = c_a + d_a = c_a + 1/f_a$$

This means that the predicted to arrive at the destination node is the "ideal" time (without delay) c_a to cross the selected link plus the maximum delay that one can find on this link d_a.

The algorithm continues to return to step 1 until all links have been selected and *L* is empty or $u_j + c_a$ is larger than u_r. During the first interaction it is difficult for *L* to be empty; as a result it returns to interaction selecting another link connected either to the node i already in exam or another "new" node not yet under exam. A formal and more correct expression of how the system works is explained later.

Variables and controls that take into consideration that e certain node has been examined are needed. In the beginning, all nodes during initialization step report a value of u_j equal ∞ and a value f_j equal to zero. For the "best" link $a = (i, j)$ is verified that:

$u_i \geq u_j + c_a$ (u_i Is from now on called acceptation standard)

If the node analysed has never been examined, u_j is still equal to infinity, so the above condition is for sure verified. In such case we also have $f_j = 0$ in initialization. For $u_j = \infty$ and $f_j = 0$ we set:

$$\beta = 1$$

In contrary, if the node has already been examined but we still have $u_i \geq u_j + c_a$ we set:

$$\beta = u_i \cdot f_i$$

Variable β is used to carry out the update of the node automatically. The acceptation standard not only permits to verify if a certain node has already been analyzed, but also, modify the node's values, only if the added link permits a reduction of the forecast time to reach the target s from the node under exam i If the acceptation standard is not satisfied, the selected link is removed from the L set and added to the H set and the algorithm searches for another link leading to i among the ones not yet examined (that take part of the L set). The update now uses the following rule using β value:

$$u_i = \frac{\beta + f_a \cdot (u_j + c_a)}{f_i + f_a}$$

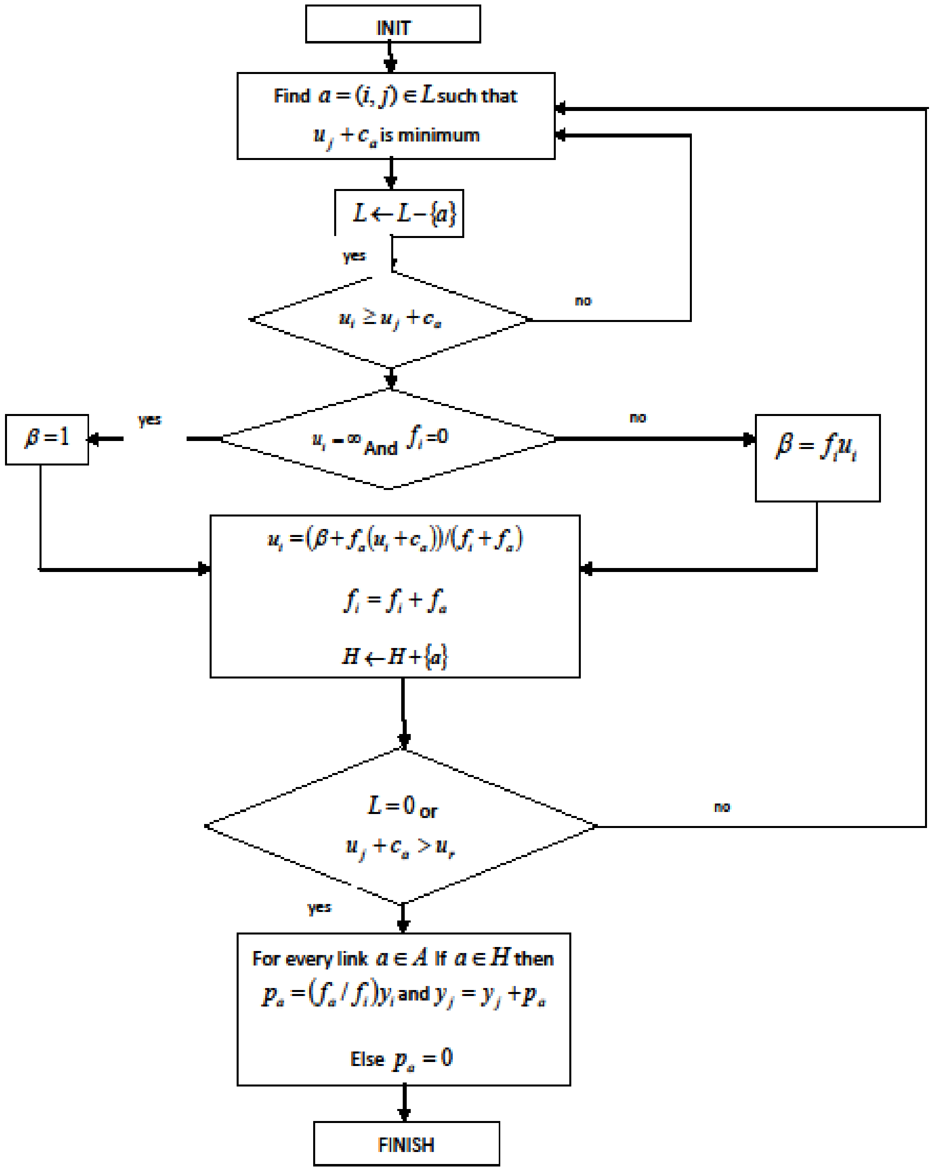
For $\beta = 1$ and $f_i = 0$ things are quite simple:

$$u_i = \frac{\beta + f_a \cdot (u_j + c_a)}{f_i + f_a} = \frac{1}{f_a} + u_j + c_a = d_a + u_j + c_a$$

While if I have already used node i and values u_j and f_j have to be updated I use the condition $\beta = u_j f_j$ (with * are indicated the updated values):

$$u_i^* = \frac{f_i \cdot u_i + f_a \cdot (u_j + c_a)}{f_i + f_a}$$

$$f_i^* = f_i + f_a$$



Flow chart of the Spiess and Florian algorithm (1989)

Chapter 4

Facility location concept

Facility location, also known as location analysis, is a branch of operations research and computational geometry concerning itself with mathematical modelling and solution of problems concerning optimal placement of facilities in order to minimize transportation costs, avoid placing hazardous materials near housing, outperform competitors facilities, etc.

Location problems deals with the problem of sitting a set of supply facilities to serve a given demand so as to optimize a certain objective function. The literature on location analysis is very large: Already three decades ago an international bibliography mentioned more than 1,500 references (Domschke and Drexl, 1985). Therefore in the following description of problems only seminal papers are referred to. ReVelle and Eiselt (2005) and ReVelle *et al* (2008) constitute recent and insightful starting points to approach the field. Location problems are defined either in *d*-dimensional real spaces and or in networks. Both classes include continuous and discrete problems: In continuous problems there is no constraint on the location of the facilities, in discrete ones only a limited number of potential locations are considered.

Three main families of network problems can be identified according to the objective of the optimization: *minisum*, *minimax* and *coverage*. The aim of *minisum* problems is to localize a set of supply facilities and to assign them a set of demand points so that the total cost of connecting demand and supply is minimized.

Different constraints give rise to different problems: In *p*-median problems the location of *p* facilities is sought that minimize the weighted distance of the facilities from a set of *n* demand points (Hakimi, 1964, 1965; ReVelle and Swain, 1970). In the simple plant location problem (SPLP, also known as uncapacitated location problem – ULP) the objective is to minimize the weighted distance between supply and demand but the number of supply facilities is endogenous (Balinski, 1965).

In the capacitated plant location problem (CPLP) capacity constraints on the facilities are considered. To the class of *minimax* problems belongs the *p*-centers problem, whose objective is to minimize the maximum distance between the demand nodes and the supply points to which they are allocated (Kariv and Hakimi, 1979). A third family of location problems arises around the concept of covering: A demand point is covered by a supply facility if their distance is smaller than a threshold value. In the location set covering problem (LSCP) the objective is to minimize the number of facilities needed to fully cover the demand (Toregas et al., 1971).

In maximum covering location problems (MCLP), a limit on the number of supply facilities exists and the objective is to maximize the covered demand (Church and ReVelle, 1974). The location of emergency services can give rise to different kinds of problems depending on the service under planning and on the existing constraints: To mention only some of the most recent references, *minisum* approaches are used when the overall or average accessibility is crucial, e.g. in facing floods (Chang et al., 2007), in positioning emergency vehicles on urban networks (Geroliminis et al., 2009), in locating strategic national stockpiles (Jia et al., 2007b), in deciding on facility location and on acquisition and stocking of commodities for disaster response (Rawls and Turnquist, 2010) . Location of sites for homeland security (Bell et al., 2011) and facilities for general large scale emergencies (Huang et al., 2010) have been studied through *minimax* location problems, which can be seen as aiming to maximize the lowest level of service provided by the system.

Covering approaches are very common in emergency facilities location models: e.g. maximal covering has been pursued in dealing with humanitarian relief chain (Balcik and Beamon, 2008) and medical supplies for large scale emergencies (Jia et al., 2007a).

A higher degree of uncertainty in demand of services and availability of resources makes problem solving more challenging in the field of the emergency logistics than in that of the ordinary logistics (Balcik and Beamon, 2008; Sheu, 2007). Non-deterministic location problems have been studied both in contexts in which the probability distributions of the quantities involved in the optimization are known (*stochastic optimization problems*) and in cases in which no information on probabilities is available (*robust optimization problems*). *Robust optimization* seems to be more suitable in dealing with natural disasters, for which no reliable probability distribution of damages usually exists. In *robust optimization* the objective is typically to minimize the cost or the regret in the worst situation, but also different concepts of robustness have been developed. Both *best-worst*[5] and alternative models are presented and discussed by Snyder (2006), which remarks that the *best-worst* cost approach is reasonable in facing emergencies where a high performance is required from a system in the worst situation. *Best-worst* location problems are difficult to be solved, thus exact solutions to *p*-median problems using this approach have been provided only for networks with special structures or for single supply facility cases. Heuristic solutions are available for general formulations. In most models uncertainty is related to link costs and node weights.

The method we propose deals with the former source of uncertainty. Theoretical contributions to *best-worst p*-median problems under similar assumptions have been given by Averbakh (2003), Burkard and Dollani (2001), Chen and Lin (1998), Serra and Marianov (1998), Vairaktarakis and Kouvelis (1999). All these studies focus on regret minimization in 1-median problems on trees. Recently Nikoofal and Sadjadi (2010) proposed a mixed integer

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Robust optimization problems tackled trying to optimize the system performance in the most adverse case are referred to as "minmax" problems by Snyder (Snyder, 2006). Here "*best-worst*" has been preferred to avoid confusion with the family of problems to which the *p*-center problems belong. Note that in the context of robust optimization, *p*-center problems can be dealt with a *best-worst* approach (Averbakh and Berman, 1997; Averbakh and Berman, 2000).

linear formulation of robust *p*-median problems which allows for different levels of the conservatism regarding the link lengths, whose intervals of values are assumed known.

Most location problems on general networks are NP-hard and many research efforts have been put in place to develop tractable and reasonably approximate solution methods (ReVelle et al., 2008). It has been shown that *p*-median problems can be solved in polynomial time if *p* is fixed or the graph is a tree (Garey and Johnson, 1979). Several approaches have been brought forward to solve *p*-median problems: enumeration and heuristics, linear programming relaxations, meta-heuristics and approximation algorithms (Reese, 2006). Greedy (Kuehn and Hamburger, 1963), Alternate (Maranzana, 1964) and in particular Vertex Substitution (Teitz and Bart, 1968) heuristics have proven to be very popular and numerous improvements and hybrid formulations have been brought forward. In the Greedy heuristic a solution is searched by iteratively modifying the set of candidate facility locations so that the change in the goal function is optimized. This can be done following an Add or a Drop procedure (Sridharan, 1995). In the latter case the search starts locating a facility at each potential site and progressively removes facilities (until the solution set contains *p* nodes) so as to minimize the increase of the objective function (Feldman et al., 1966). Improvements to the Drop procedure for non-capacitated problems have been proposed by Whitaker (1981) in which at each iteration *k* facilities are eliminated and *k*-1 reintroduced.

Simple Plant location Problem

In the Simple Plant location Problem, sometimes also referred to as incapacitated facility location problem, the number of facilities to be located is treated by the problem itself. It is assumed that each facility has unlimited capacity.

The general formulation for the Simple Plant location problem is

Min $z = \sum_{ij} c_{ij} x_{ij} + \sum_{i} f_i \; y_i$

Subject to

$$\sum_{j \in J} x_{ij} = 1 \quad i \in I,$$

$$x_{ij} \le y_j \quad i \in I \;\; j \in J$$

$$y_i - x_{ij} \ge 0 \quad i \in I, j \in J$$

$$y_j = \begin{cases} 1 & \text{Facility is located at node j} \\ 0 & \text{Otherwise} \end{cases}$$

$$x_{i,j} = \begin{cases} 1 & \text{Facility i supplies demand at facility j} \\ 0 & \text{Otherwise} \end{cases}$$

$$x_{ij}, y_i \;\in \{0,1\}, i \in I, j \in J$$

c_{ij} Cost of supplying customer i from j

f_i Cost of establishing a facility at i

Capacitated plant location problem

In the Capacitated plant location problem it is assumed that each facility has limited capacity. These problems are mostly solved by Lagrangian relaxation methods or the matrix column generation method.

Let $I = \{1,...i\}$ give potential facility locations providing a service of a certain value or producing a product of a certain value. Let $c_i \geq 0$ be the establishing cost of the location among the $i \in I$ potential facility locations provided and $V_i \geq 0$ V the value of the produced service or product.

Let $J = \{1,..., j\}$ assign users that require service. For each pair *i, j* let $g_{i,j} \geq 0$ be the production and transportation cost and $g_{i,j} \geq 0$ the value of service (or product) created in facility i directed to the user j.

Then we have

$$y_j = \begin{cases} 1 & \text{Facility is located at node j} \\ 0 & \text{Otherwise} \end{cases}$$

and

$$x_{i,j} = \begin{cases} 1 & \text{Facility i supplies demand at facility j} \\ 0 & \text{Otherwise} \end{cases}$$

Then the Capacitated Facility Location Problem may be written

$$\sum_{j \in J} p_{ij} x_{ij} \leq V_i y_i \quad i \in I$$

$$\min \left\{ \sum_{i \in I} c_i \, y_i + \sum_{i \in I} \sum_{j \in J} g_{ij} x_{ij} \right\}$$

$$\sum_{i \in I} x_{ij} = 1 \quad j \in J$$

$$x_{ij}, y_i \in \{0,1\}, i \in I, j \in J$$

Location set covering problem

The location set covering problem treats the location of minimum possible facilities. This should ensure that demand points do not exist outside the maximum distance that a facility serves. When solving the set covering problem over a range of values it is possible to produce a cost effectiveness curve between the maximum service distance and the distance from a facility.

The only decision process used in the location covering problem is the number of facilities in terms of a cost factor. In this way (isolating a discrete number of facilities) it is possible to give the solution for many real world formulations.

The examination of the cost effectiveness curve shows that for a certain number of facilities there may be more than one solutions that fulfill coverage requirements. When there are specific numbers of facilities, it is possible to take the solution that uses the maximum service distance.

Maximum covering location problems

The maximum covering location problem is stated as the "Maximize coverage (population covered) within a desired service distance S by locating a fixed Number of facilities" (Richard Church, Charles ReVelle, 1971). In the same paper the problem is designed as the "Maximal covering location problem with mandatory constraints" stated as locating a fixed number of facilities in order to maximize the population covered within a certain service distance S, while maintaining mandatory coverage within a distance T (T>S).

The solution techniques to solve such Maximum covering location problems consist of Heuristic approaches or linear programming. We only name two heuristic approaches to solve such problems. These are the Greedy Adding Algorithm (GA Algorithm) and the Greedy Adding with Substitution Algorithm (GAS Algorithm). These two methods cannot however guarantee a global optimality solution.

If we consider a network of nodes and arcs the mathematical formulation of the maximum covering problem is:

Maximize $z = \sum_{i \in I} a_i y_i$

$\sum_{j \in N_i} x_i \geq y_i$ For all $i \in I$

$\sum_{i \in J} x_i = P$

$x_j = \begin{cases} 0 & \text{Service located at node } \boldsymbol{i} \\ 1 & \text{otherwise} \end{cases}$ For all $j \in J$

$y_i = \begin{cases} 0 & \text{Population served at node } \boldsymbol{j} \\ 1 & \text{otherwise} \end{cases}$ For all $i \in I$

I : Set of demand nodes

J : Set of facility sites

S : Distance beyond which a demand point is considered uncovered (S value can be chosen differently for each demand point)

d_{ij} : Shortest distance from node i to node j

N_i : $\{ j \in J | d_{ij} \leq S \}$

a_i : Population to be served at demand node i

p : Number of potential facilities to be located

Chapter 5

The mixed strategy

Both hyperpath and facility location concept are involved so as to provide a mixed strategy. The problem is solved in two steps. First we use all possible routes to calculate minimum paths. Then, according to the rescue centres or terminal points we wish to use (exact number of rescue centres or terminal points), we locate them along the road network in basis of the risks the driver may find ehen he seaks to reach his final destination.

Description

The algorithm was initially developed to optimize a rescue plan towards populations hit by a natural disaster such as an earthquake. However it seems that it applies more to the flood problem following reasonable implementation steps showed later. The principal target is to individuate along the road network optimum, valid places in which to locate centres of human relief against a natural disaster. In such centres, there have to be enough necessary supplies in order to support the total number hit by an earthquake.

More specific along the road network, close to the areas hit by the natural event, there are individuated specific nodes where population is supposed to be located. Those nodes (or points) are referred to as population centres and with each one of them, there are associated attributes, such as the number of inhabitants each population centre has, specifically called his. Those represent exactly the set of nodes from which we will select our potential rescue centres. At the end of the execution of the algorithm, some population centres become rescue centres, which means that corresponding to these points there are resources predisposed to rescue all populations hit by the natural disaster.

The optimization of the rescue plan, apart from the indication of rescue centre locations, also calculates which population is assigned to each rescue centre as well as a list of possible paths which vehicles can use in order to connect rescue centres to population centres.

We note that we individuate a list of paths or routes because we calculate all possible paths from a rescue centre to a population centre. Very often it is proposed that only one route be calculated, the shortest one, independent of the risks a driver may find along his trip. This list of paths, namely haperpath, which emanates from the field of transit assignment of transport engineering, is a set of routes any of which may be optimal. Using the haperpath as the approach to the solution, for the treated problem we offer valid alternatives in case part of the road network may become unusable. The selection of these paths is calculated on a probabilistic basis seeking in each case to select the next link by minimizing the risk the driver might be exposed to.

In order to correctly execute the algorithm there are some constraints which need to be respected. First and foremost, the number of potential rescue centre locations need to be determined beforehand. Secondly, each rescue centre needs to have limited capacity, which is specifically stated. This means that we have determined the maximum number of people that each rescue centre can support (zr value), at initialization. Last but not least, each population centre has to be assigned to one and only one rescue centre while one rescue centre can serve more than one population centre.

Implementation steps

In order to efficiently apply the proposed procedure in the case of flood it was necessary to proceed with some modifications and see the problem from a different point of view as well as involve a different phase of emergency management. In the case of flood, in fact, we consider an evacuation plan, initially before the arrival of the flood wave, rather than a rescue plan. We could also consider both an evacuation plan (for the mitigation and preparedness phase of emergency management) and a rescue centre location plan so as to reach populations hit by the flood after the flood wave has passed (relief phase of the emergency management).

In order to correctly state an evacuation plan, starting from the problem already described, we need to replace rescue centres with terminal points and optimize the flow from population centres to the related terminal points. In these potential terminal point locations, all responsible citizens who decide to follow the instructions provided by the local civil protection may have to spend a long period of time away from the disaster zone. These potential terminal point locations have to be already stated beforehand, by the local civil protection department, responsible for the area referred to.

We still have to individuate specific points (nodes) where population is concentrated. These nodes are referred to as population centres. Furthermore, we add a set of nodes which are candidate locations to become terminal points. In contrast to what we propose for the earthquake problem, only some of these later nodes described, can be selected as potential terminal point locations. Naturally, it is impossible to locate terminal points, where population centres are located for flood responses. This is what we propose for the earthquake rescue centre location problem: rescue centres, which have the role of terminal points in cases where we need to evacuate before a flood emergency, cannot be in the area where flood waters may appear. They have to be away from the crisis area, at a 'dry' secure place.

For an emergency evacuation plan before a flood, terminal-rescue locations are particular population centres that have no permanent inhabitants in the sense that no population intends (or needs) to leave that place during flood evacuation. This means that we set value hs equal to zero. Population centres are treated in a particular way as well; they do not have rescue capacity, which means that we assign a null value to zr attribute. This value indicates the number of people each rescue centre can support. In this way we can apply the same macro-methodology to treat both floods and earthquakes during different phases of emergency management.

In conclusion, within this work, we propose an evacuation plan during the preparedness or mitigation phase of emergency management. Experimentally, we suggest a rescue plan, after an earthquake which applies to relief phase of emergency management.

Results however are completely different when we treat a flood emergency compared to a post earthquake emergency. In the first case, we refer to citizens who seek to leave population centres in order to reach terminal points. In the second case, rescue vehicles take advantage of the haperpath concept in order to use all possible paths to reach populations affected by the consequences of a vulnerable earthquake zone.

Chapter 6

Flood responses

We propose here a method for the positioning of terminal points organized to gather people after emergencies generated by floods. The demand points are referred to as “population centers”. The candidate locations for terminal points coincide with the nodes of a transport network which can be blocked homogenously by the disaster. A flood model (like the one generated by Francesco Dottori called CA model) can make possible the estimation of the maximum additional cost (or delay) for each link caused by the disaster. The problem is formulated as a two stage optimization problem: The primary problem is a capacitated p-median problem in which the location of p rescue centers is sought which minimizes the overall weighted best-worst cost between population centers and terminal points. In the secondary problem the *best-worst* cost between each pair of terminal points and population centres is worked out as the payoff of the mixed strategy Nash equilibrium for a non-cooperative zero sum game between citizens seeking to reach terminal points and node-specific evil entities able to spoil a single link at each node.

General Description

We consider a road network composed of a set of links $a \in A$ that represent the streets and a set of nodes $i \in I$ that represent the junctions of the network (Figure 6-1). Among these nodes *i* we identify a subset $R \subset I$ of nodes where we consider the location of points referred to as terminal points of the network and a subset $S \subset I$ of nodes where we consider the location of points referred to as population centers.

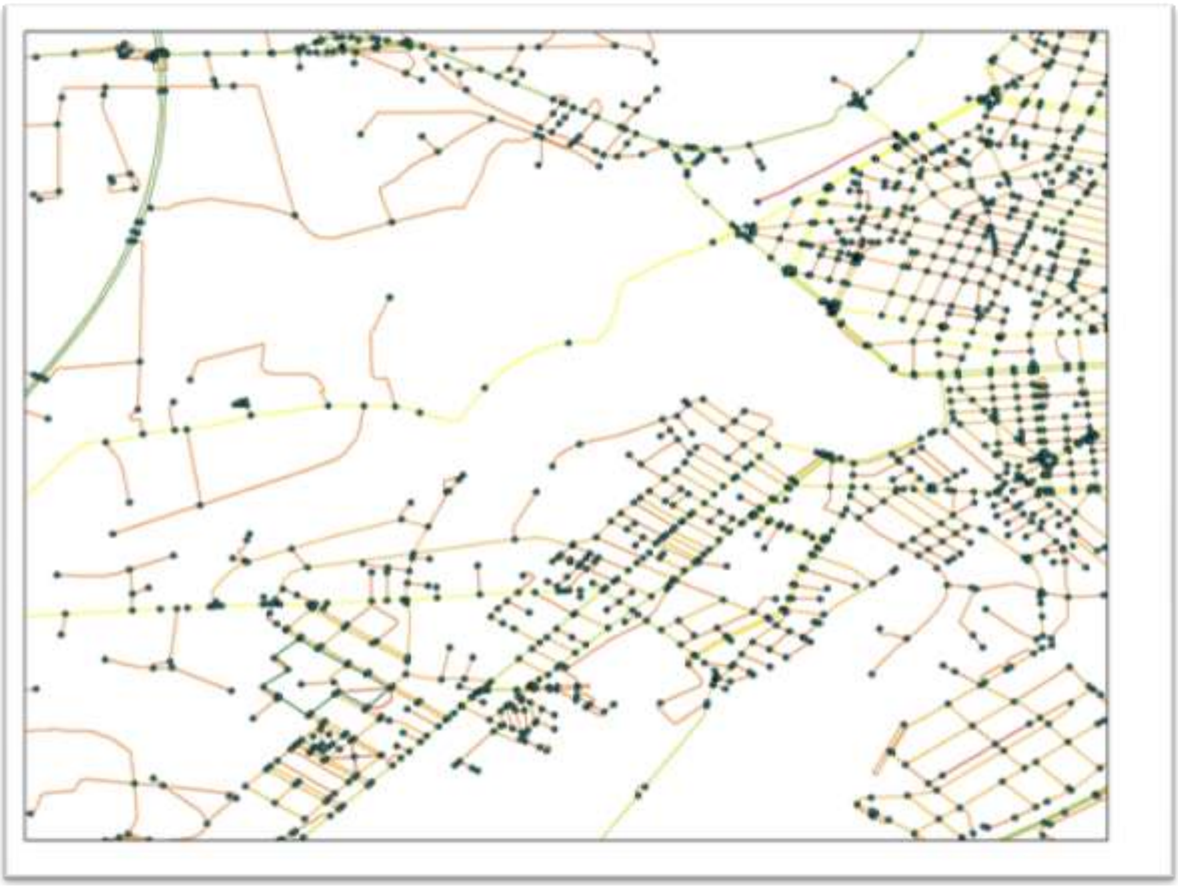


Figure 6-1 TeleAtlas™ sample map - representation of a road network. The nodes are the junctions and the links are the streets of the transport network

In the proposed system, we assume that the population exposed to the catastrophe is located at a subset of nodes *S*, referred to as *population centres*. We also assume that local civil protection has proposed possible locations referred to as *terminal points*. We wish to reach these nodes from rescue centres. This study examines the case where rescue centres have an upper limit on the population each can cover and resources are sufficient for only *m* rescue centres, where *m* is sufficiently large to cover the entire exposed population. The problem is to find the best subset of nodes $R \subset S$ at which to locate the *m* rescue centres. We then describe below three possible ways to solve this problem according to the time local civil protection has decided to communicate the state of emergency; a lot of time before the mass of water is about to arrive, during the emergency state or after the catastrophe, considering that both rescue vehicles have to circulate and, when possible, stranded civilians need to find another place to stay until the complete recovery of the district.

We assume that every link has a cost of use c_a before the catastrophe. Before, during or after the catastrophe, there is an additional cost of d_a calculated differently depending on the time local civil protection decides to announce the state of emergency. Yet, we are almost certain as to which links are degraded. We estimate the process of the links degradation using a flood inundation we describe later. Suppose we are seeking to access rescue centre *r* from node *s*. We assume that upon exiting any node *i* en route to *r* one link is degraded. Given the additional costs for these links when degraded, we seek the set of potentially optimal paths from node *i* to destination *s* for the worst case set of link failure probabilities. The set of potentially optimal paths between rescue centre *r* and destination *s* is referred to as a *hyperpath*. Given the worst case link failure probabilities, we calculate link usage probabilities, which minimise the expected hyperpath cost, u_{rs}, and then use the expected hyperpath cost for determining the optimal deployment of rescue centres.

More specific, Figure 6-5 describes the input data the proposed system needs. A street map where the streets are represented as links and the junctions as nodes Figure 6-5 (a) , a subset of nodes where population is located Figure 6-5 (b) and a subset of nodes where terminal points are located Figure 6-5 (c). The system, first calculates all possible paths the civilians can use during the evacuation plan we propose. It then identifies the optimum terminal points, among the ones the local civil protection district has proposed, they can use according to the actual state of the flood status. We distinguish three different possibilities of flood emergency according to the time the alarm may be communicated to civilians.

The terminal point location problem is divided into two problems which may be solved separately. First, the minimum hyperpath costs are found from each population centre to all terminal points. We create a matrix in which are captured the hyperpath costs in travel time units from each population centre to all terminal points. Then this matrix is used to solve the rescue centre location problem which has two sets of decision variables, namely **x,** which represents the decision to supply a given population centre from a given rescue centre, and **y**, which represents the decision to locate rescue centres at given nodes. The constraints ensure that each population centre is covered by one and only one rescue centre and that the maximum population that a rescue centre can cover is not exceeded.

The degradability of the network means that travel costs are not known with certainty but estimated with several methods we describe later. We assume that upon arrival at every node en route to a destination the preferred exit link from that node may be degraded or indeed blocked. For link a, d_a measures the degradability of the link which is stated as high (almost infinity) when the link is partly or completely blocked or has various values according to the actual state of the flood and the time it is estimated to arrive. Where this is low, the incentive for finding an alternative route is correspondingly low. A very large value for d_a would correspond to the case where link a is very likely to block soon (e.g. in less than five hours time) therefore the driver is exposed to high risk and an alternative must be used. Using various techniques to decide if a link may be open or closed at a certain time, we can be almost certain of the level of degradation of the link. This delivers the set of paths from each origin to each destination that may be optimal if one and only one link exiting each node is degraded as well as the expected travel time corresponding to pessimistically estimated link failure probabilities.

So far, we have described some main input values we use to calculate the emergency paths: c_a which captures travel time of link a in travel time units and d_a calculated in the same travel time units, which captures the additional delay on a certain link ɑ caused by several reasons. This can be generated as the evacuation time estimate which is the time required to move the population at-risk out of the evacuation area. This has to take into consideration also human factors such as mobilization time and evacuation response as well as human psychological states during an emergency. In this study, we calculate delay travel time

The method used to calculate a vulnerability index for each link was based on developing indicators for the blocked passage due to the time the water is expected to arrive at a certain link. Furthermore, the capacity of the road network is also considered by following the multinet TeleAtlas™ street classification and the speed limit of each link.

There are also other important attributes that we take into consideration. Firstly, the maximum capacity each terminal point can support (z_r) since in maximum covering location problems (MCLP), a limit on the number of supply facilities exists and the objective is to maximize the covered demand (Church and ReVelle, 1974). Secondly, we set the number of people each population centre has. This is all public information provided by local government offices.

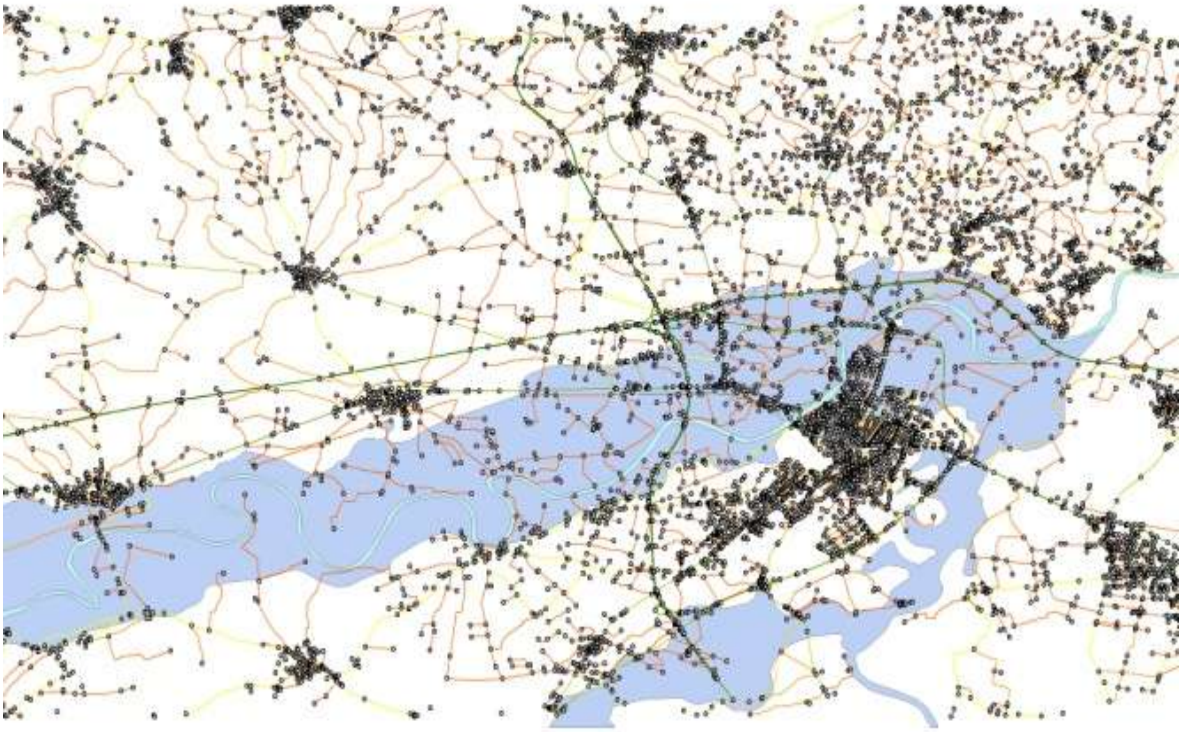


Figure 6-2 (a) Sample of a street map (TeleAtlas streetmap), a representation of a road network

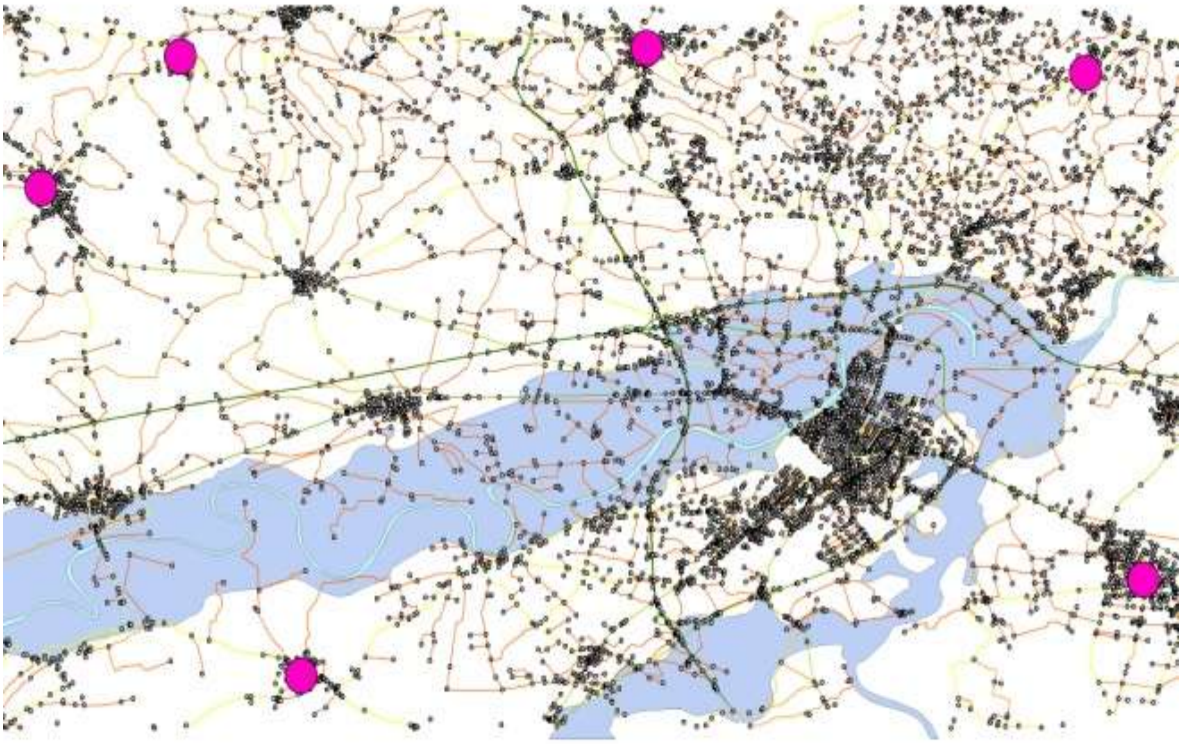


Figure 6-3 (b)) Terminal points: purple points represent terminal point locations

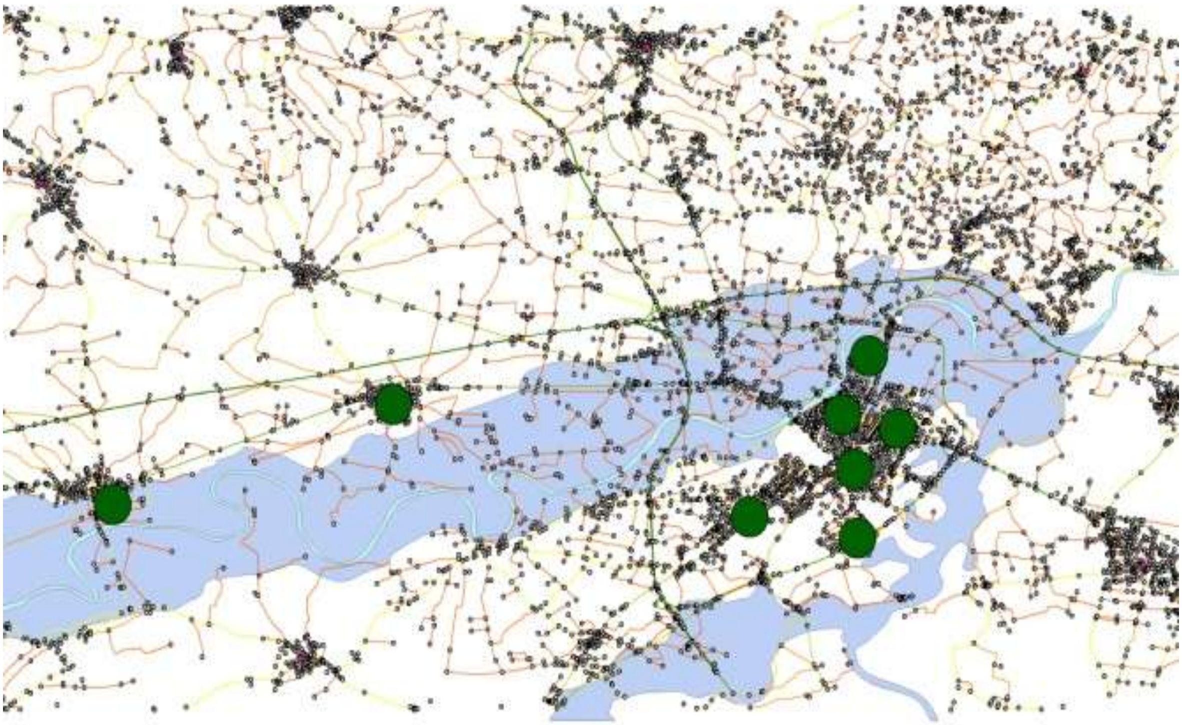


Figure 6-4 (c) Population centers: green points represent population centre locations

Figure 6-5 Input data for the proposed system, (a) Sample of a street map (TeleAtlas streetmap), a representation of a road network, (b) Terminal points: purple points represent terminal point locations, (c) Population centers: green points represent population centre locations

Cellular automata Flood Propagation Model

The inundation model we use to identify beforehand the roads that may be closed in the course of flood waves is the Cellular Automata 2D Model produced by F. Dottori, E. Todini., 2011. This is a model based on the cellular automata approach and improved through the implementation of two techniques; an inertial formulation for the computation of discharges, originally developed for the LISFLOOD-FP model by Bates et al. (2010); and the incorporation of a local adaptive time step algorithm, based on a technique originally presented by Zhang et al. (1994).

A cellular automata is a discrete choice model (i.e. when individuals have to select an option from a finite set of alternatives). This great chapter of methodologies apply to a lot of disciplines such as mathematics, physics, complexity science, theoretical biology, computability theory, microstructure modeling as well as fluid dynamics phenomena such as debris flows (D'ambrosio et al., 2003)

More specifically, this model describes the physical dynamic systems in a discrete way regulated only by local laws. Generally, it is made of a regular grid and can be in any finite number of dimensions. Every cell is in the state "on" or "off" in respect to its properties."Neighborhood" is defined as the neighbour cells which are usually the cells that include a certain cell. Initially it is assigned a condition for every cell after selecting the initial state and then, following a fixed rule, generated mainly by a mathematical function, the new state of each cell is produced depending on the actual condition both of itself and the "neighborhood" - the neighbour cells. The updating rule of every cell does not change over time.

This model uses the macroscopic cellular automata approach to represent flood plain inundation events where diffusion phenomena are dominant. The macroscopic CA approach partly differs from the classical CA approach structure described so far. Every single cell represents a volume of fluid to which the momentum and continuity equations may be applied. The cell lattice forms a grid of polygonal elements of either regular or variable shape and dimension, which represents the topography of the study area.

The adopted computational scheme can be described through the finite volume schematization. According to Garcia-Navarro and Murillo (2010), considering a single finite volume we can consider the following equation

$$\frac{\partial W}{\partial t} + \nabla F = S$$

Equation 1

Notation

W : conservative variables
t : time
F : flux function
S : source term

Following a two dimensional cell-centered finite volume scheme, Equation 1 is integrated in a volume or grid cell Ω:

$$\frac{\partial}{\partial t}\int_{\Omega} W d\Omega + \int_{\Omega} \nabla F d\Omega = \int_{\Omega} S d\Omega$$

Equation 2

In the CA model scheme originally proposed by Dottori and Todini(2010)

W : the volume of water, V, stored in a cell
F : total discharge Q between cell *i* and the adjacent cells m, per unit width
Taking into consideration this notation Equation 2 gives the solution at cell *i* at time level *t+Δt.*:

$$V_i^{t+\Delta t} = V_i^t + \Delta t \sum_{j=1}^{m} Q_{i,j}^t + q^t$$

Equation 3

Δt : time step in use
q : total discharge entering or leaving the domain through the cell *i*

The integration in time is obtained with the Euler explicit scheme, following the CA rule that the overall system state depends only on the previous time step.

If we consider two adjacent cells i and j, discharge Q is calculated using the momentum equation leaving, in time and space, the variation of velocity along the relevant direction:

$$Q_{i,j} = \frac{b h_m^{5/3}}{n}\left(\frac{H_i - H_j}{\Delta x}\right)^{1/2}$$

Equation 4

H_i : water stage in level *i*
H_j : water stage in level *j*
Δ*x* : distance between centroids of the two cells
B : width of the contact face
N : Manning roughness coefficient
h_m : arithmetic mean between water depths in the two cells

We note that the proposed computational scheme is equivalent to a pipe network, where nodes represent the cells and the links represent contact faces. In this way, any generic 2D flow breaks up into 1D flow components through the links. The momentum equation is integrated along the link direction Δx being a vector with x and y components. Every flux component is then decoupled from the others , in a way that Equation 4 can be solved separately for every link.

The final CA model we used, inspired by cellular automata approaches, resembles various modelling techniques especially the part of the storage cell approach. The most commercially popular models based on this technique are LISFLOOD-FP (Hunter et al., 2005) and FLO2D (FLO-2D Software Inc., 2007). They both perform flux computation through the decoupling of x and y flow components. LISFLOOD-FP uses Equation 4 for discharge computation while FLO2D uses the full dynamic momentum equation.

However, we suggest the use of this flood model for a number of reasons. Firstly, the introduction of a tool, namely "pre-processor" that allows the use of regular grids derived from digital elevation models (DEM), as well as polygonal grids from TIN files. The code structure (that requires this special tool mentioned above) allows within the same model the use of both regular and irregular mashes. From the users point of view and for the needs of this study, this method is very efficient. Secondly, the similarity of the computational scheme to a pipe network gives an advantage to the computational scheme of the structure of the code; node and link elements all share computational information. This leads to major code efficiency. Last but not least, focusing on the flux computation between cells, different formulations for computing the friction slope along the links were considered and tested for use in the CA model.

Evacuation plans

Emergency evacuation is the immediate and rapid movement of people away from the threat or actual occurrence of a hazard. Examples range from the small scale evacuation of a building due to a bomb threat or fire to the large scale evacuation of a district because of a flood, bombardment or approaching weather system. In situations involving hazardous materials or possible contamination, evacuees may be decontaminated prior to being transported out of the contaminated area.

Static pre-flood evacuation

In this paragraph is described an emergency evacuation plan is described in which it is assumed that the state of emergency has been announced in time and thus citizens have all available time to evacuate the city. At this particular stage all streets are open and there are no streets closed because of the flood.

We first solve the secondary minimisation problem which finds the hyperpath costs from all origins referred to as "population centres" to each destination referred to as "terminal points" for the network under the state of emergency. In Figure 6-12 we present a detailed representation of all optimal paths from all six population centres to one terminal point respectively.

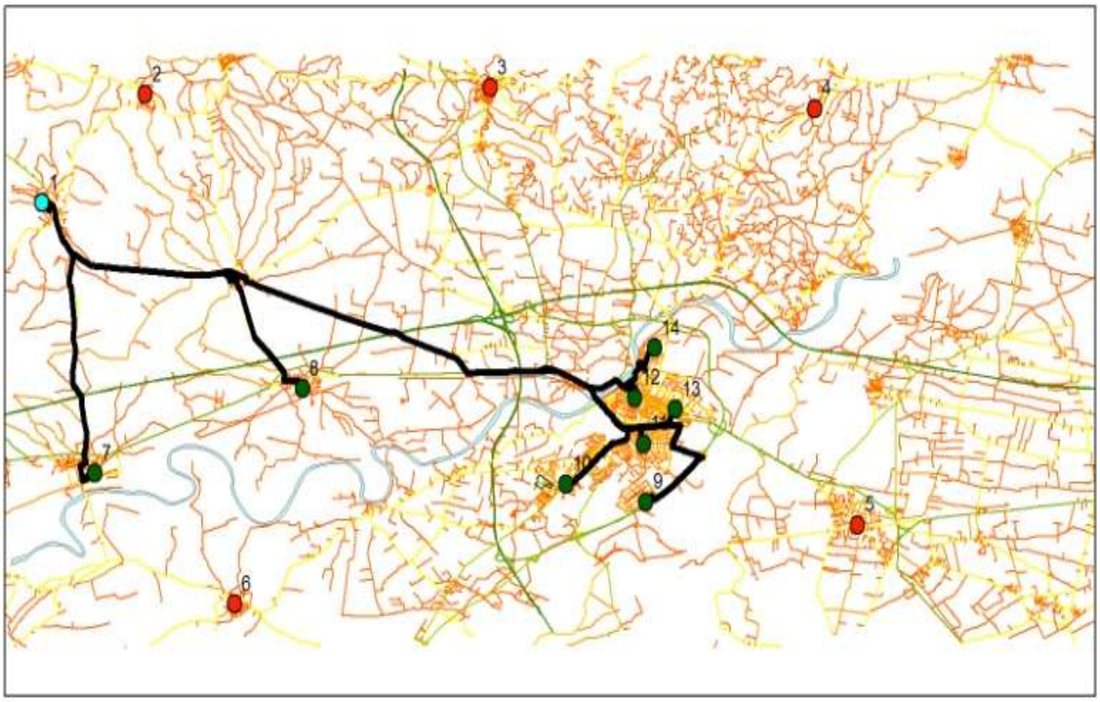


Figure 6-6 (a)Demonstration of all available paths from each population centre to terminal point No "1"

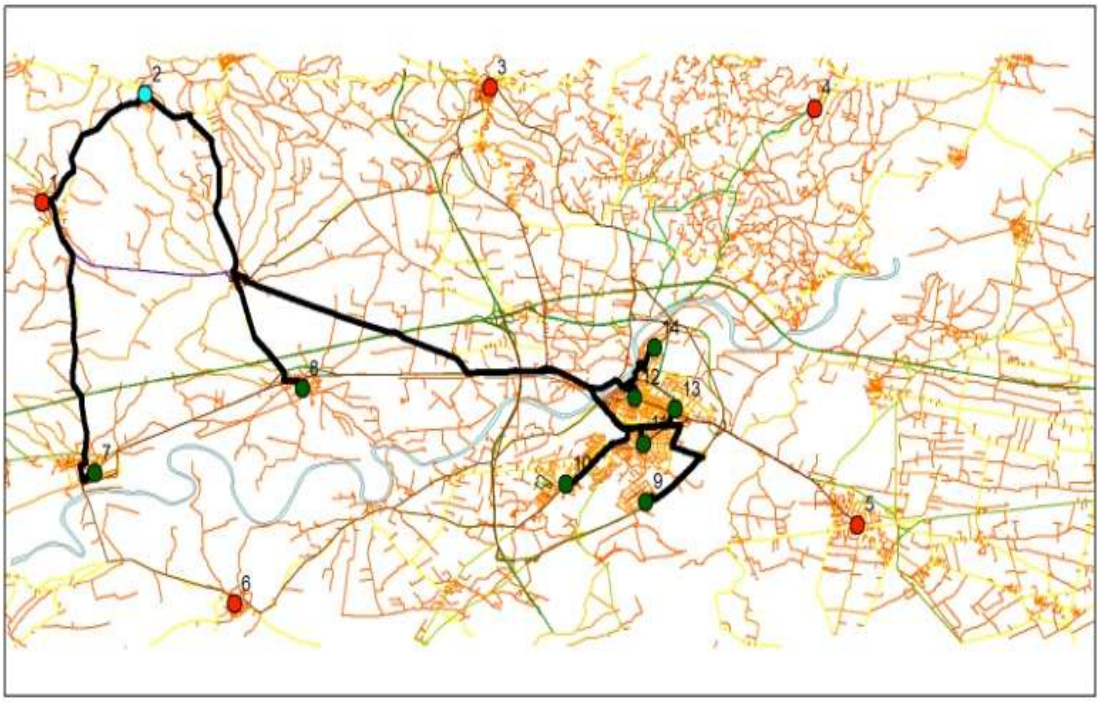


Figure 6-7 (b) Demonstration of all available paths from each population centre to terminal point No "2"

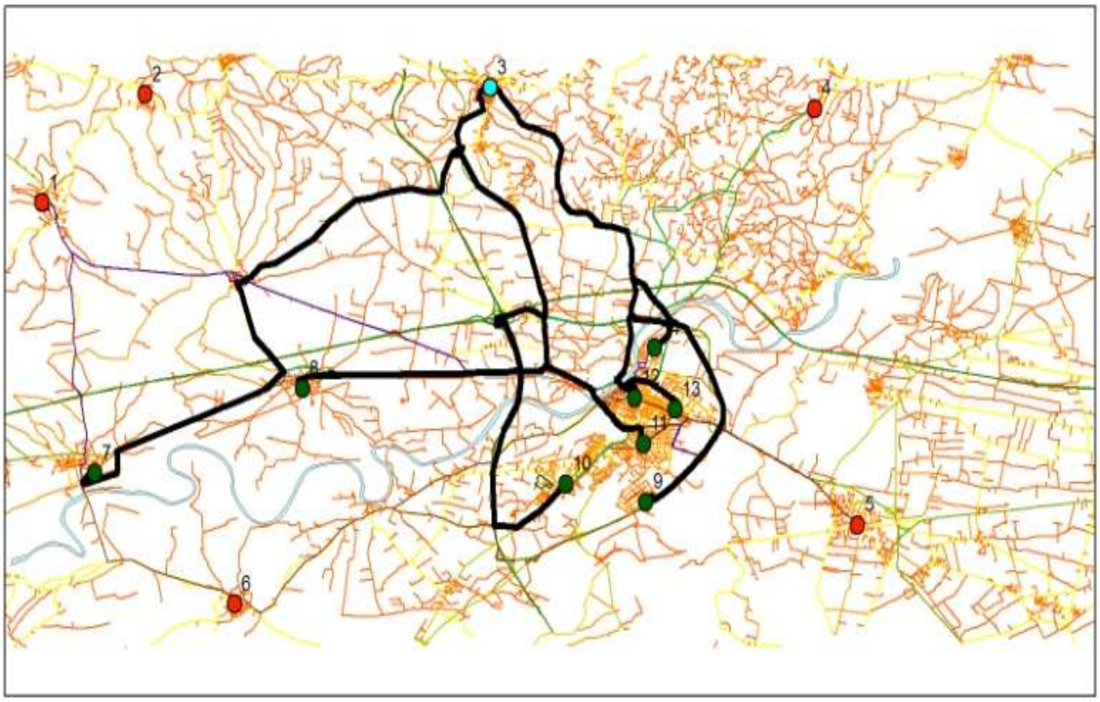


Figure 6-8 (c) Demonstration of all available paths from each population centre to terminal point No "3"

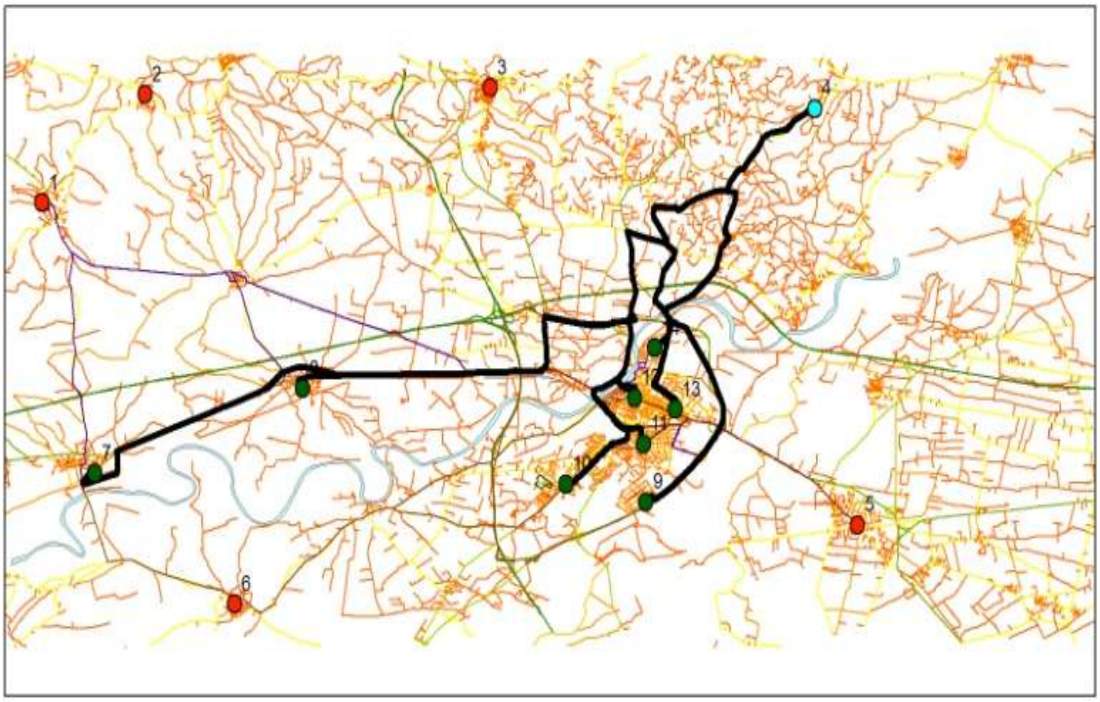


Figure 6-9 (d) Demonstration of all available paths from each population centre to terminal point No "4",

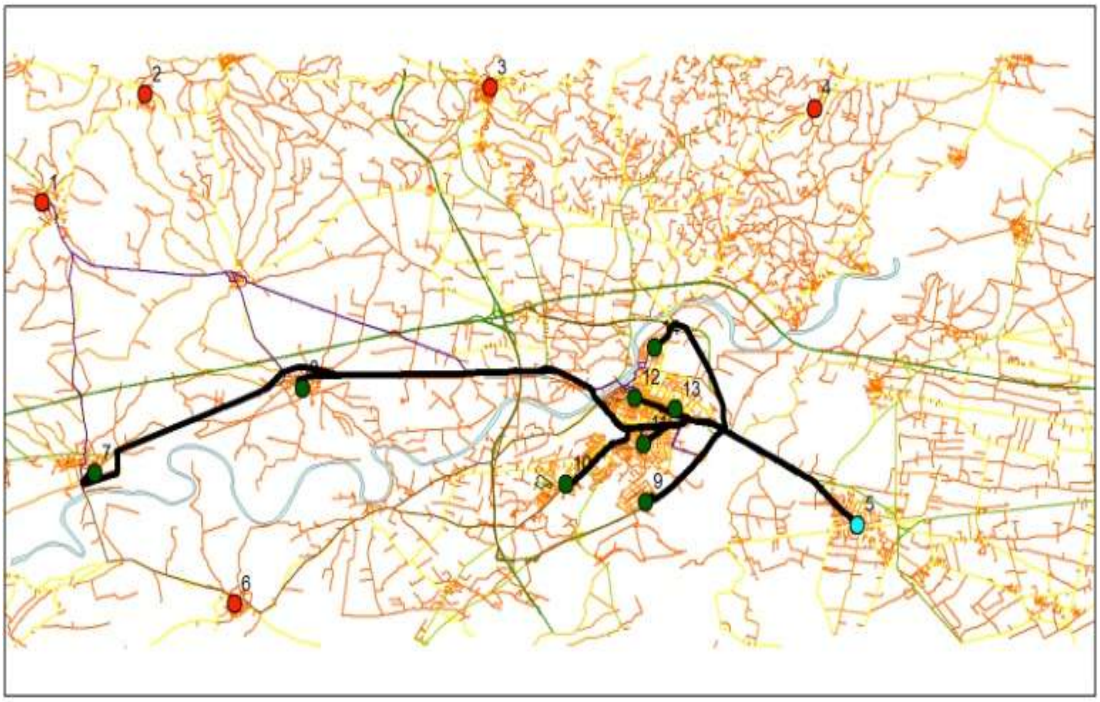


Figure 6-10 (e) Demonstration of all available paths from each population centre to terminal point No "5"

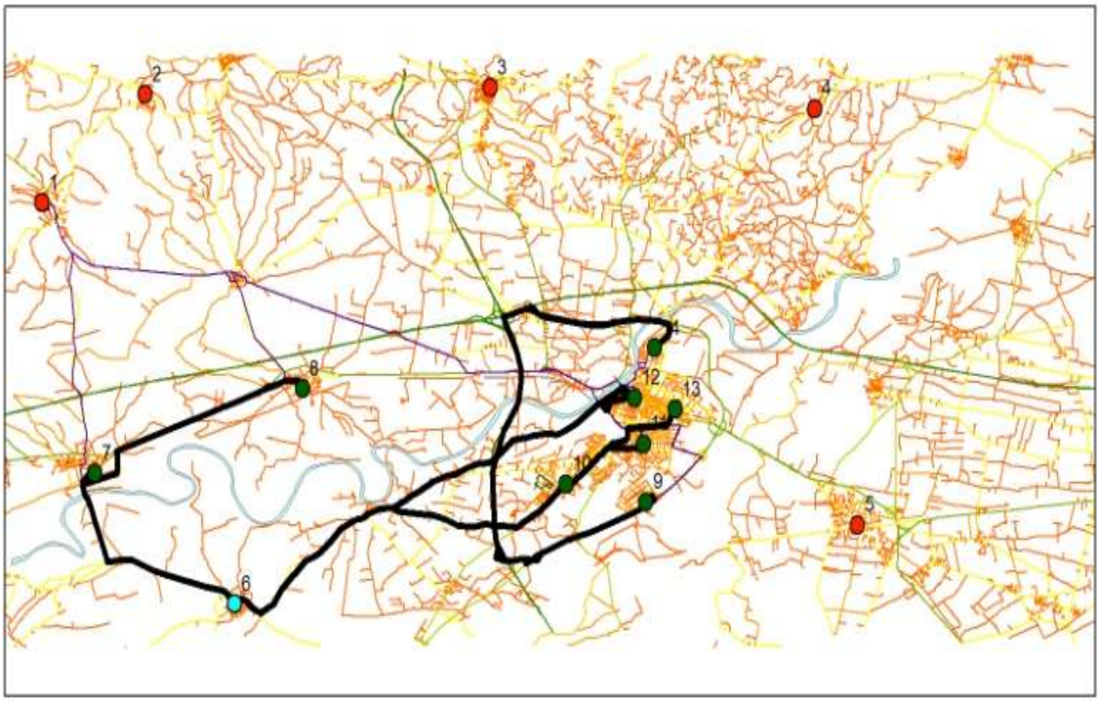


Figure 6-11 (f)) Demonstration of all available paths from each population centre to terminal point No "6".

Figure 6-12 Static pre flood evacuation emergency plan . There are not blocked streets due to the emergency because the alarm was announced on time before the evacuation (time local civil protection decides). (a) Demonstration of all available paths from each population centre to terminal point No "1", (b) Demonstration of all available paths from each population centre to terminal point No "2", (c) Demonstration of all available paths from each population centre to terminal point No "3", (d) Demonstration of all available paths from each population centre to terminal point No "4", (e) Demonstration of all available paths from each population centre to terminal point No "5", (f

We then calculate the hyperpath travel cost matrix from each population centre to one terminal point every time. Figure 6-13 shows such a result for the pre flood condition. We can understand that travel costs are more sustainable when vehicles can circulate through the network when all streets are available.

To avoid traffic congestion during the evacuation we assume that pedestrians are served by public transport (e.s. public buses) and the rest of the vehicles use all available paths already calculated. The evacuation travel time depends primarily on the relationship between traffic demand and road capacity (supply). When transport demand exceeds transport capacity over a particular time period, travel speed declines and traffic environment exhibits queuing. This is characteristic of congested conditions where the result is that traffic moves very slowly. These relationships (supply and demand) exceed the needs of this research. We assume that supply and demand are constant considering that people would use public transport to evacuate rather than personal vehicles. It is also assumed that public transport is well organized and follows the instructions of the local civil protection.

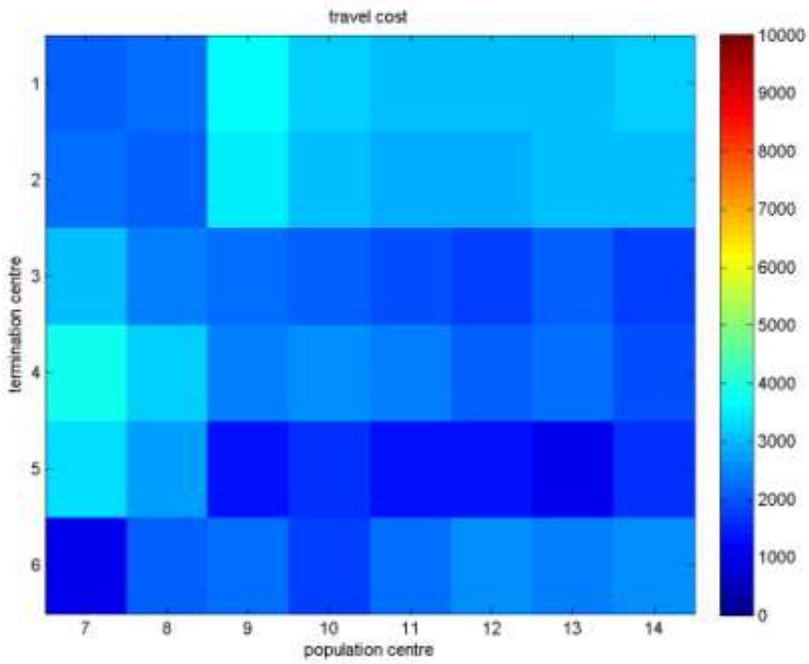


Figure 6-13 Hyperpath costs, evacuation before the "flood wave" - Static Version -Time in seconds

Having found the minimum hyperpath costs, we can now solve the rescue centre location problem. This is a form of the Set Covering Problem (SCP), since each terminal point covers a set of population centres and we are looking for the assignment of terminal points to minimise expected travel costs. This is a complex problem as the number of ways that *m* locations can be selected from *n* sites is $m!/n!(n-m)!$, although the maximum population coverage constraint imposed on each terminal point will reduce this number.

For the solution of the terminal point location problem we propose a greedy heuristic. Initially, both population and terminal points are considered terminal points. Every point is assigned to itself. There are as many terminal points as there are population centres plus terminal points and the expected travel cost *F* is zero. The algorithm repeatedly removes one terminal point. When a terminal point is removed, each population centre assigned to it is reassigned to the nearest remaining terminal point that has sufficient capacity. The extra expected travel time resulting from the reassignment of destinations is calculated and the terminal point that causes the least extra travel time is removed. *F* is then increased by the amount of extra travel time. Terminal points continue to be removed until all population centres are assigned to terminal points.

Figure 6-14 represents the result of the solution of the primary location problem where population centres are assigned to their related terminal points.

Figure 6-14 Assignment of population centres to their related terminal points.

Static post-flood evacuation

In this paragraph is described an emergency evacuation plan is described in which it is assumed that the state of emergency has been announced late and thus citizens have very few time to evacuate the city. At this particular stage there are a lot of closed streets and people have very few available possibilities to evacuate if not completely blocked by the flood.

As for the static pre-flood solution of the problem we calculate the hyperpath travel cost matrix from each population centre to one terminal point every time. In Figure 6-21 we illustrate the paths from all population centres to one terminal point respectively. Travel costs in this condition are not sustainable since vehicles have to avoid blocked links and reach their destinations after long journeys.

We set c_a value as the travel time of link a. We also set d_a value equal to infinity since we assume all links the flood wave reached are blocked.

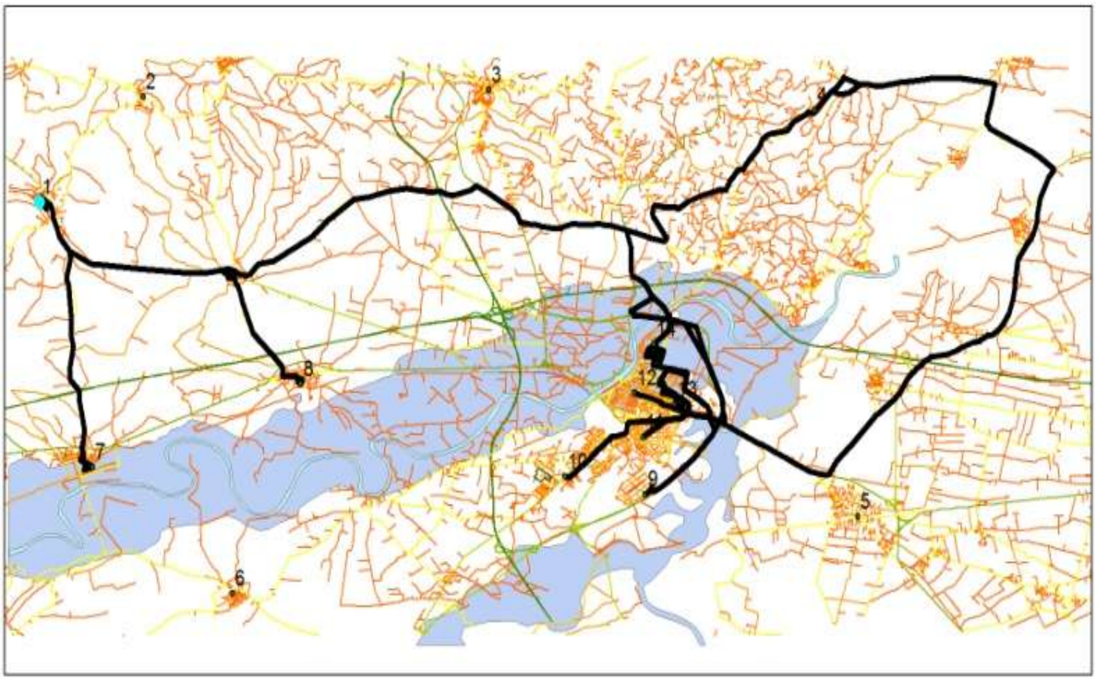


Figure 6-15 (a) Demonstration of all available paths from each population centre to terminal point No "1"

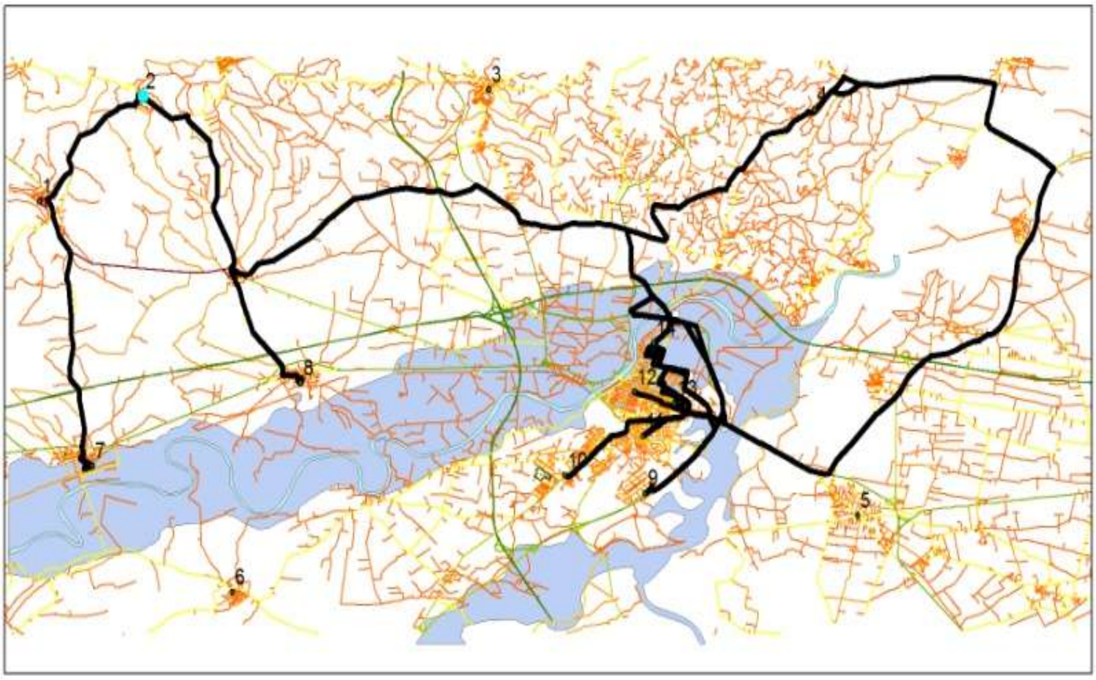


Figure 6-16 (b) Demonstration of all available paths from each population centre to terminal point No "2"

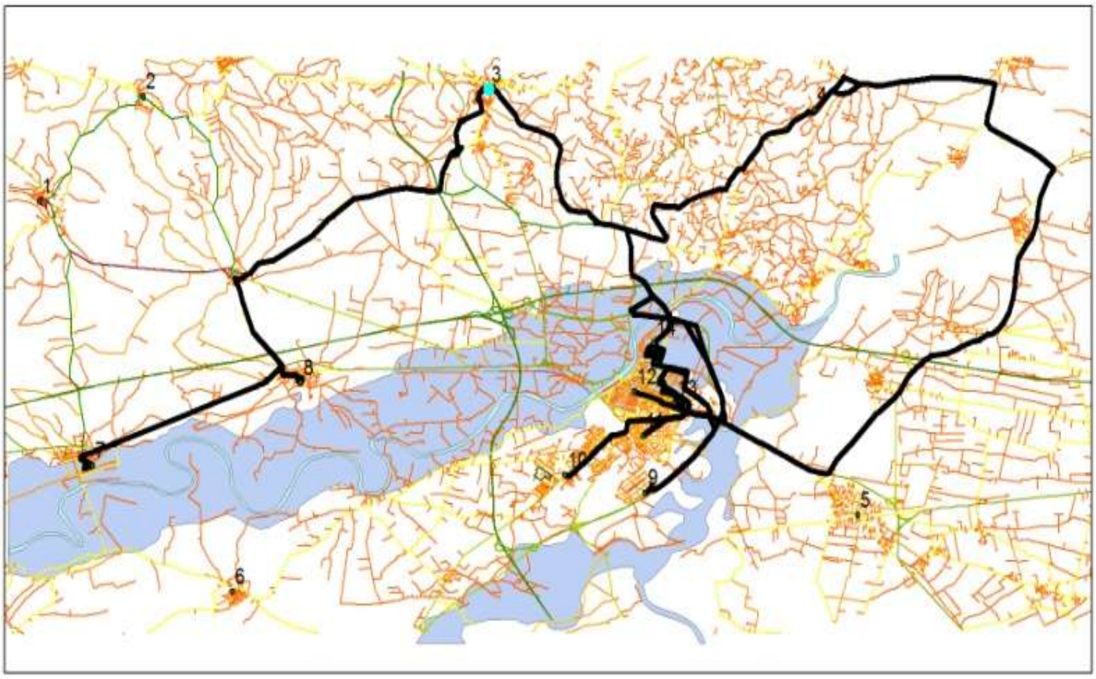


Figure 6-17 (c) Demonstration of all available paths from each population centre to terminal point No "3"

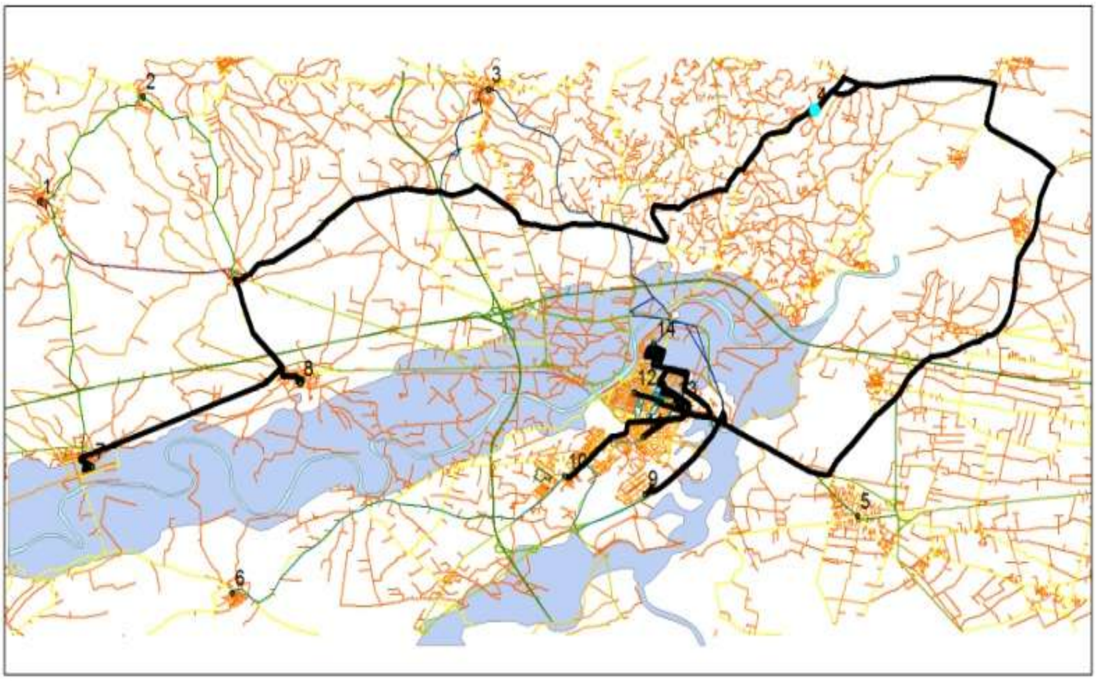


Figure 6-18 (d) Demonstration of all available paths from each population centre to terminal point No "4"

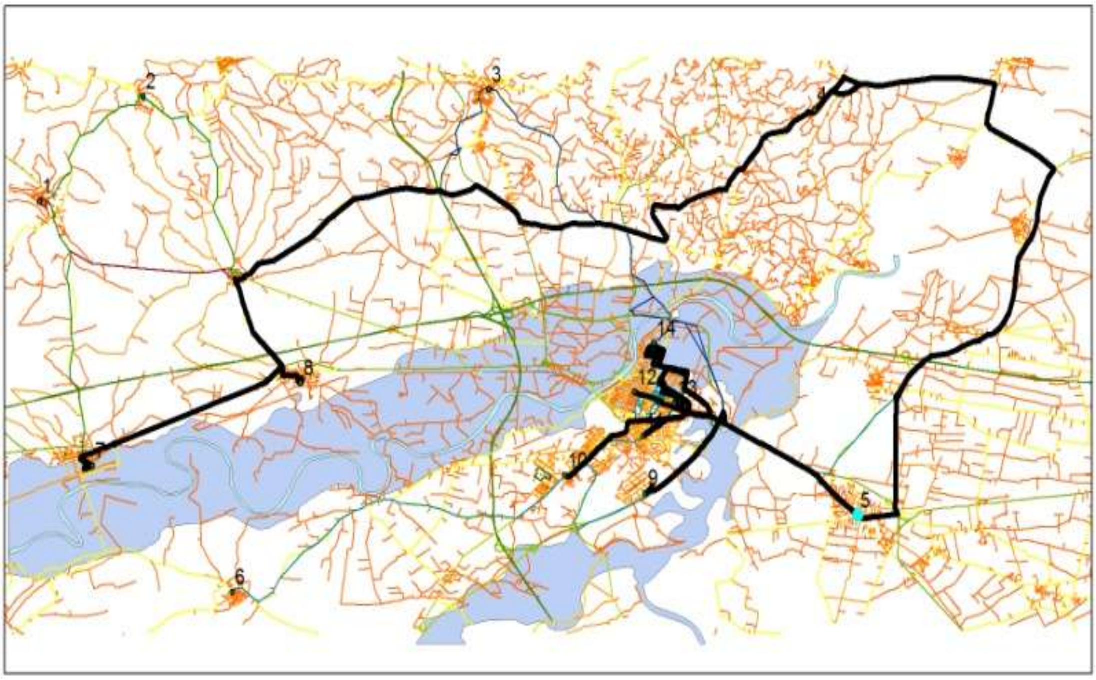


Figure 6-19 (e) Demonstration of all available paths from each population centre to terminal point No "5"

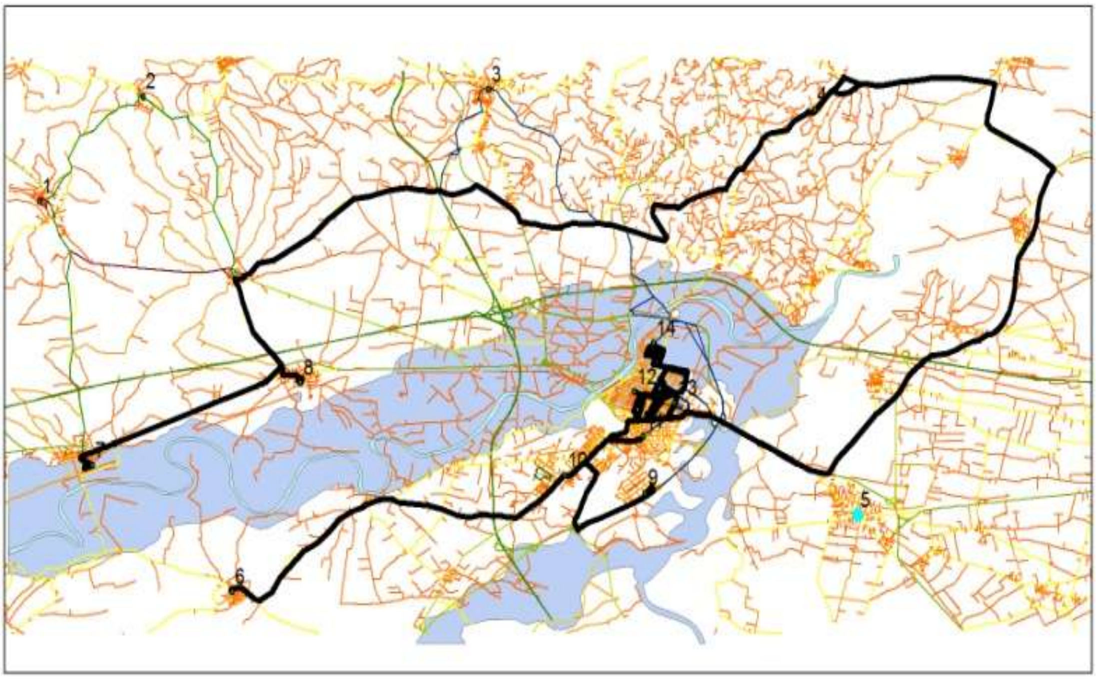


Figure 6-20 (f) Demonstration of all available paths from each population centre to terminal point No "6"

Figure 6-21 Static post flood emergency evacuation plan(a) Demonstration of all available paths from each population centre to terminal point No "1", (b) Demonstration of all available paths from each population centre to terminal point No "2", (c) Demonstration of all available paths from each population centre to terminal point No "3", (d) Demonstration of all available paths from each population centre to terminal point No "4", (e) Demonstration of all available paths from each population centre to terminal point No "5", (f)Demonstration of all available paths from each population centre to terminal point No "6".

Figure 6-22 illustrates the hyperpath matrix. This illustrates travel times calculated respectively from all population centers to each terminal point.

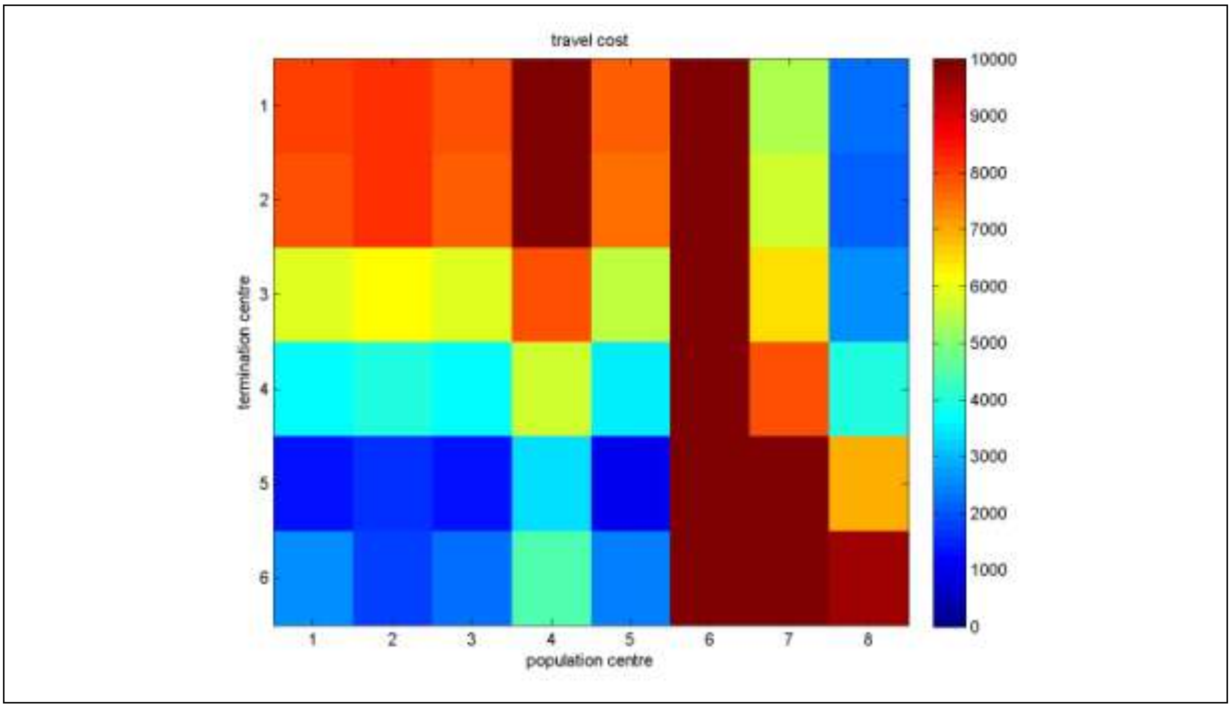


Figure 6-22 Evacuation after the "flood alarm"-Static Version -Time in seconds

Having found the minimum hyperpath costs, we can now solve the rescue centre location problem. Figure 6-23 illustrates the assignment of population centers to their terminal points.

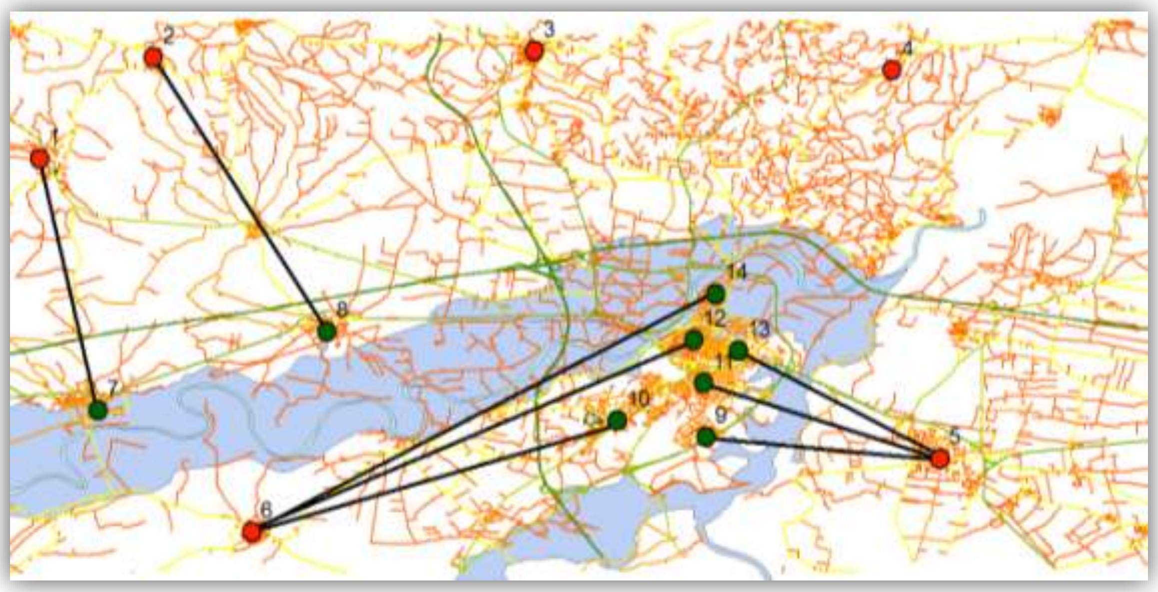


Figure 6-23 Assignment of population centres to the optimum terminal points after the "flood wave"-Static Version

Dynamic, In motion evacuation

For the dynamic solution of the problem we propose two methods that both depend on the decision of d_a value described previously. The areas that are more likely to manifest delays have a higher delay and alternative paths have to be found in order to avoid them. We have calculated these areas with the cellular automata CA2D flood model described before capturing the flood extension every five hours. Figure 6-28 illustrates the calculation in four consecutive stages for the catastrophic flood that took place in Alessandria, Piedmont Region in Italy, 2 - 6November 1994.

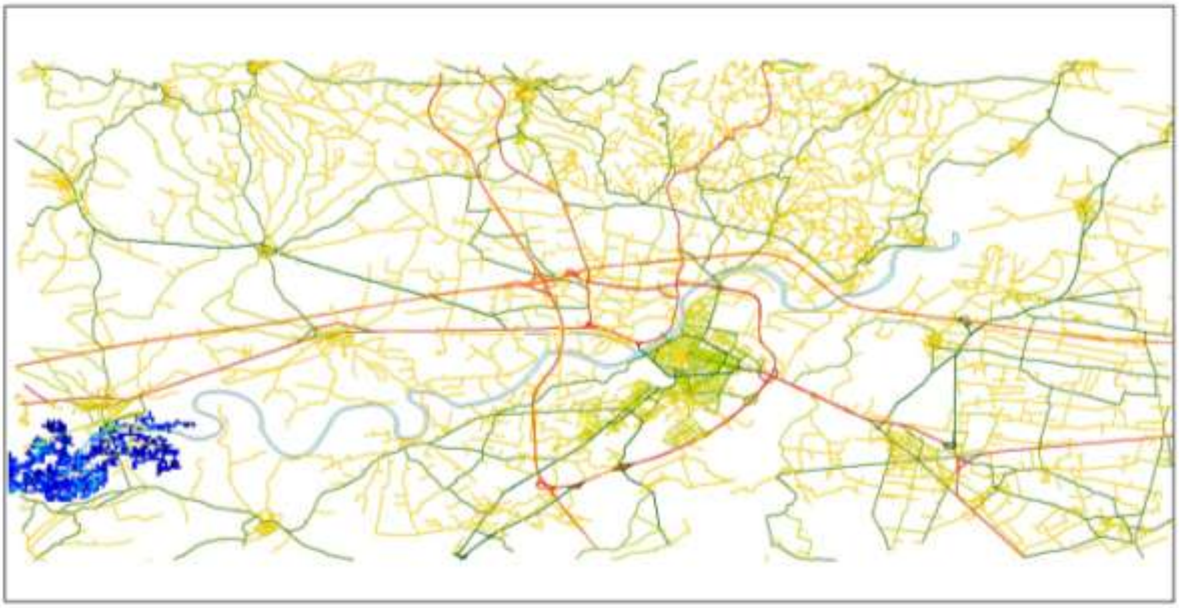


Figure 6-24 (a) two hours after the beginning of the flood

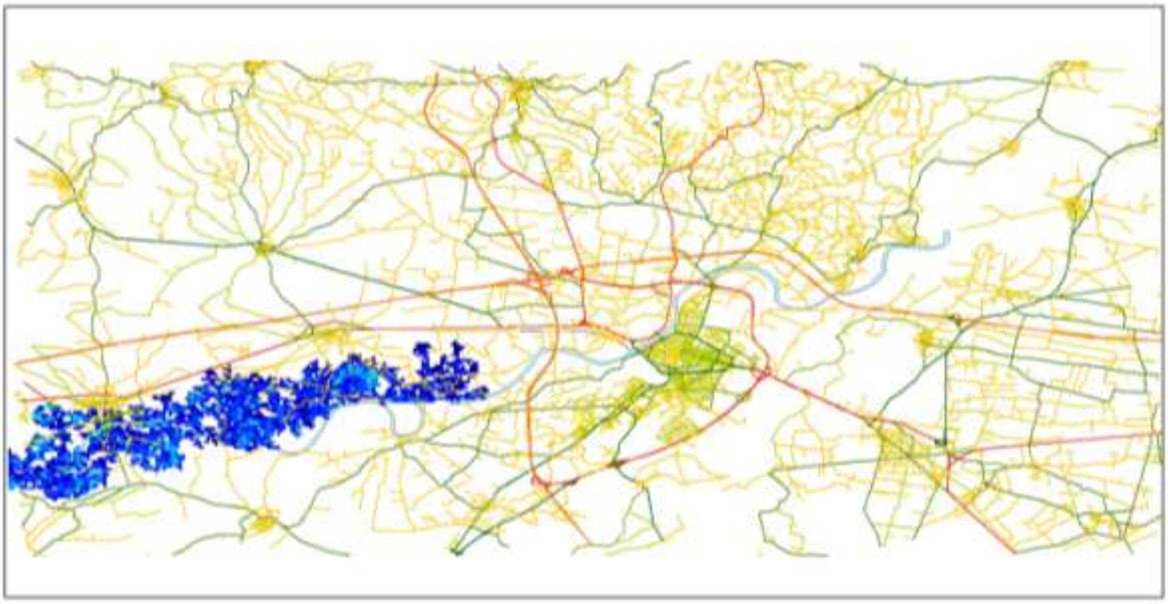


Figure 6-25 (b) four hours after the beginning of the flood

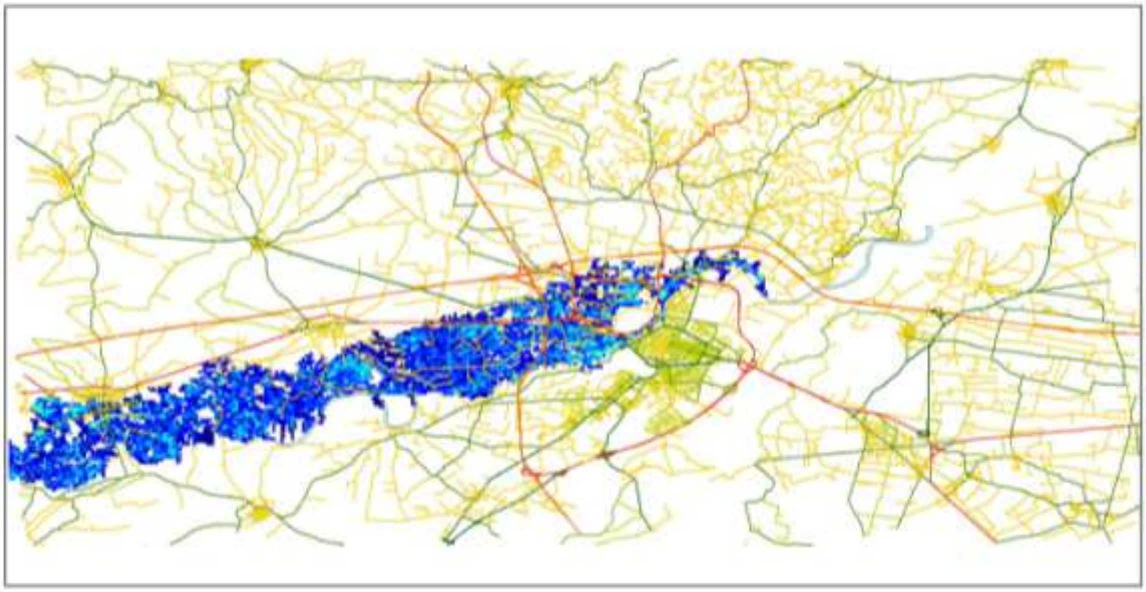


Figure 6-26 (c) six hours after the beginning of the flood

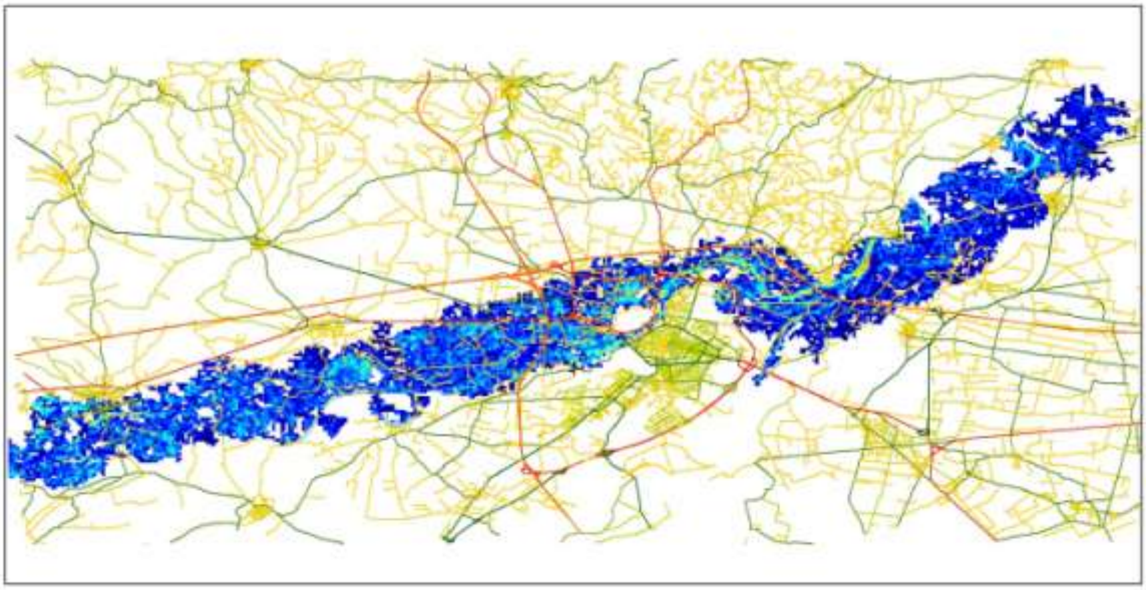


Figure 6-27 (d)eight hours after the begining of the flood

Figure 6-28 CA2D flood plain model: CA2D model interpretation two hours after the beginning of the flood (a), CA2D model interpretation four hours after the beginning of the flood (b), CA2D model interpretation six hours after the beginning of the flood (c), CA2D model interpretation eight hours after the beginning of the flood (d)

As mentioned before, we consider two different ways to calculate both the set of optimum paths from the population centers to the related terminal points and incidentally the assignment of the population centers in a second step.

The first solution we propose resembles the static version since we give fixed d_a values to four different areas as calculated by the cellular automata (CA2D model). At the moment d_a values are calculated in terms of the speed limit of a certain link a $d_a = c_a$/speed limit of link a. We add to the previous calculated d_a value a constant number that would increase d_a value 30 times in the area which is about to be affected by the flood wave after 5 hours. We make the same consideration for the areas that will be affected after 10, 15 and 20 hours , increasing 5, 3 and 1 times respectively to the zones already calculated by the catastrophic event Figure 6-29

We then calculate travel times (travel time matrix or hyperpath costs table) which we use to solve the terminal point location problem and assign the population centers to the best terminal point in terms of ease of reach. Hyperpath costs matrix for this solution is reported in Figure 6-30. The assignment of the population centers to the related terminal points is illustrated in Figure 6-31

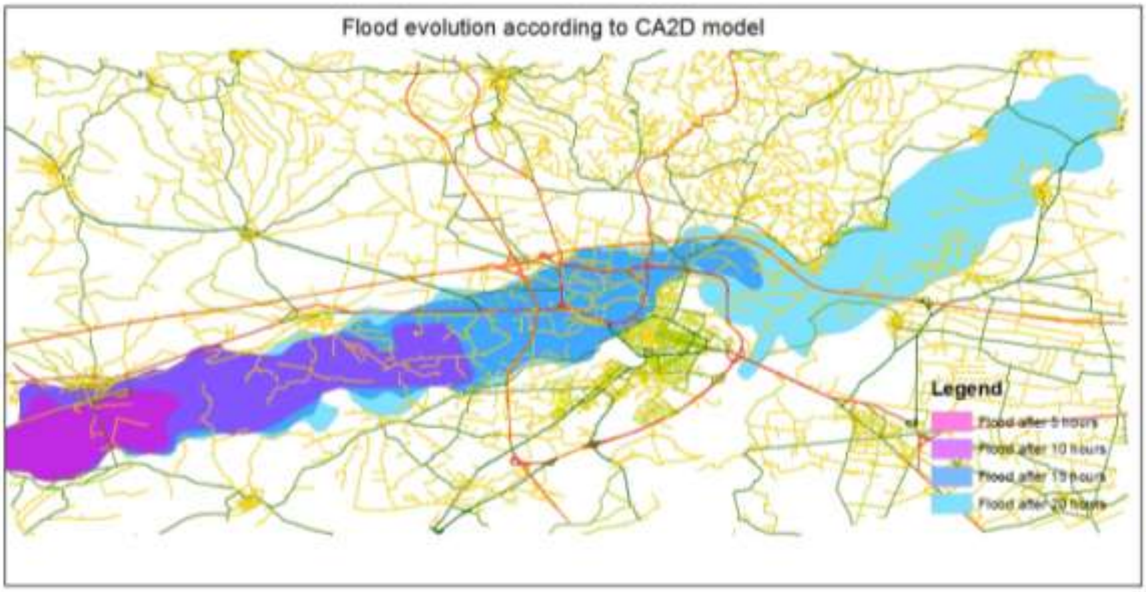


Figure 6-29 Flood evolution of the "Alessandria 1994" event according to CA2D flood propagation model

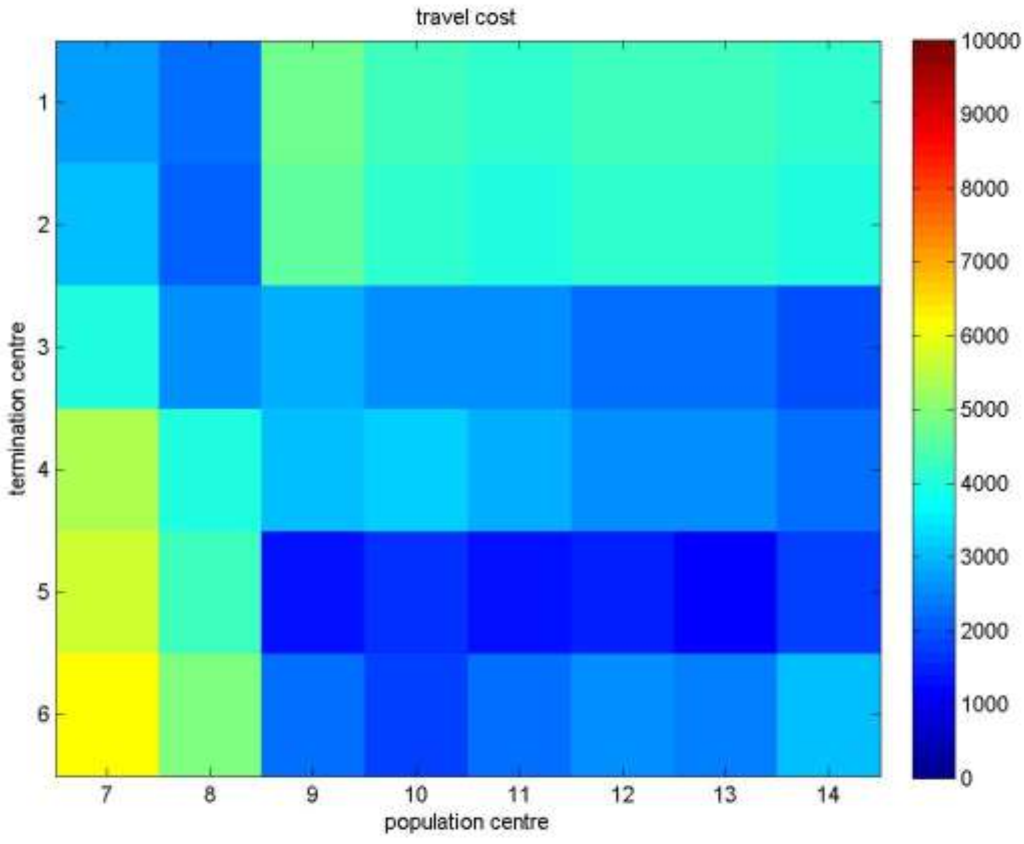


Figure 6-30 Travel times calculated from each population centre to each terminal point respectively.

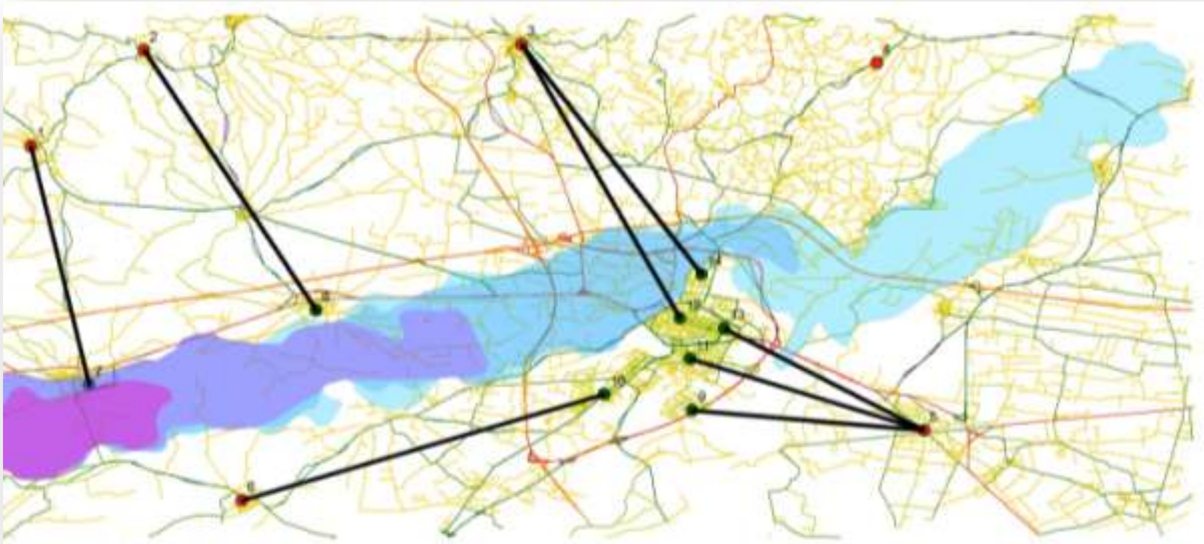


Figure 6-31 Assignment of population centres to the optimum terminal points according to the dynamic solution with fixed d_a values

For the second dynamic solution we propose, the assignment of population centers to their related terminal points changes according to the actual situation of the flood. To solve this formulation, we add to the previous calculated d_a value a constant number that would increase d_a value 100000 times. As a result, these links receive a very low probability to be selected. At the moment d_a values are calculated in terms of the speed limit of a certain link a $d_a = c_a$/speed limit of link a.

When the flood wave arrives, we consider a very high number of d_a values for each link that is within the flooded area calculated from the flood model the first five hours (we increase 100000 times the actual value of d_a). In termination of these five hours, we update the d_a costs with the same value with respect to the expanded flood after 10, 15 and 20 hours respectively as shown in Figure 6-29.

We calculate the different travel time matrixes for all four different solutions, every five, ten, fifteen and twenty hours from the arrival of the flood wave. Having found the minimum paths and their related travel times, we then use heuristics to find the optimum solution for the assignment of each population centre to the closest and less risky - in terms of alternative route finding - terminal point. These four different solutions are reported in Figure 6-36.

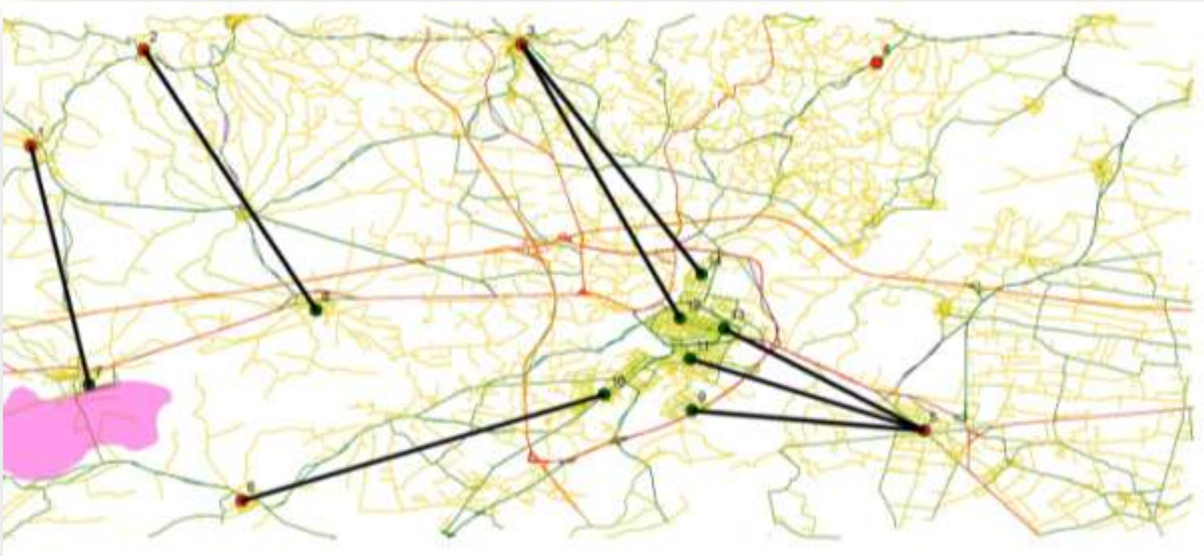


Figure 6-32 (a) , after four hours from the arrival of the flood wave

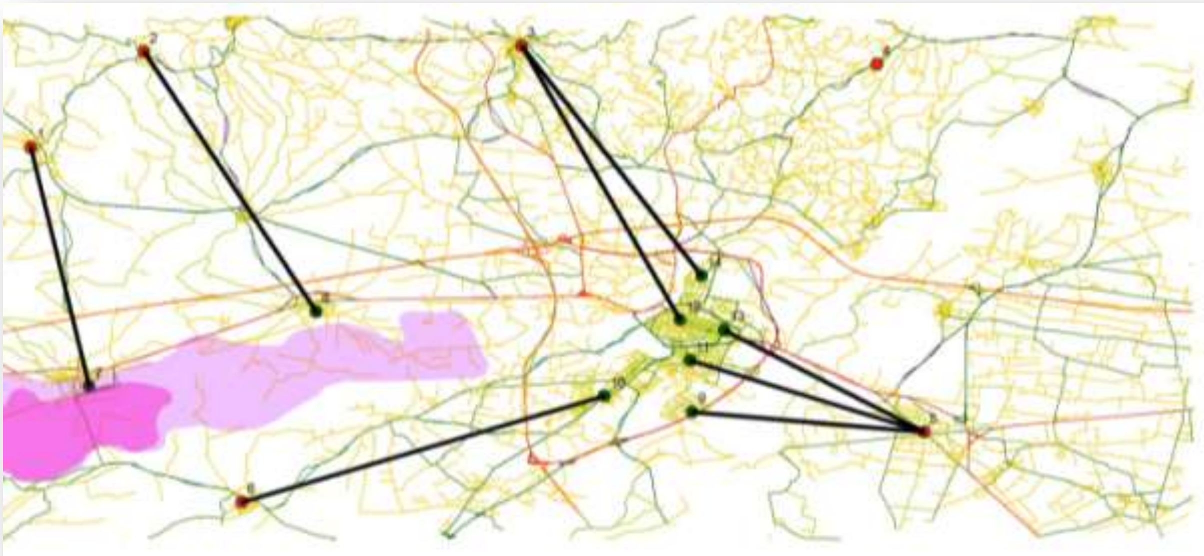


Figure 6-33 (b) , after four hours from the arrival of the flood wave

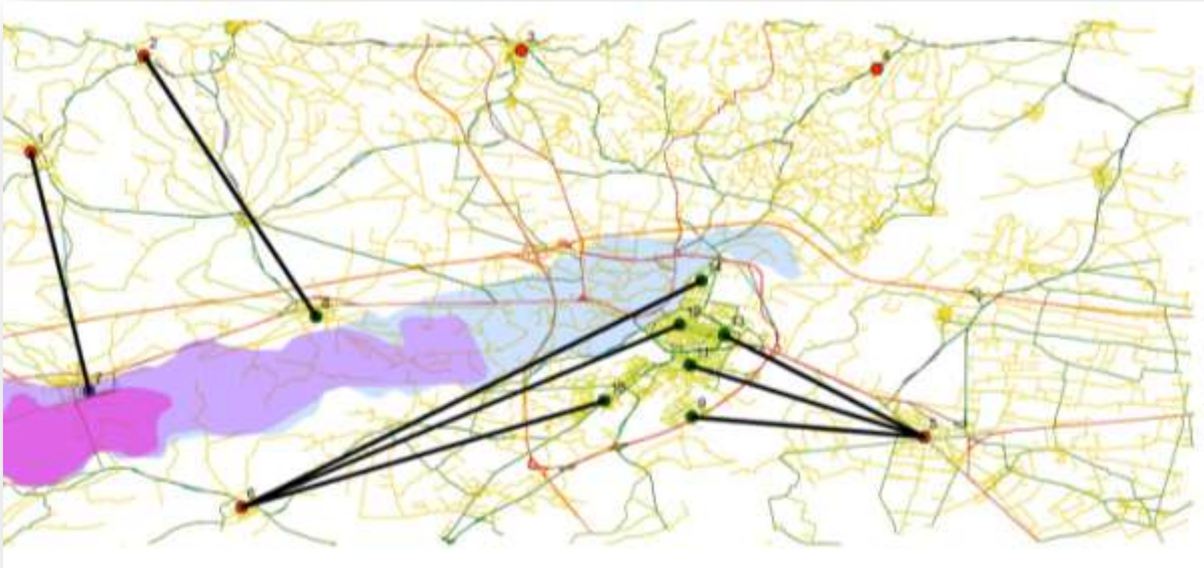


Figure 6-34 (c) , after four hours from the arrival of the flood wave

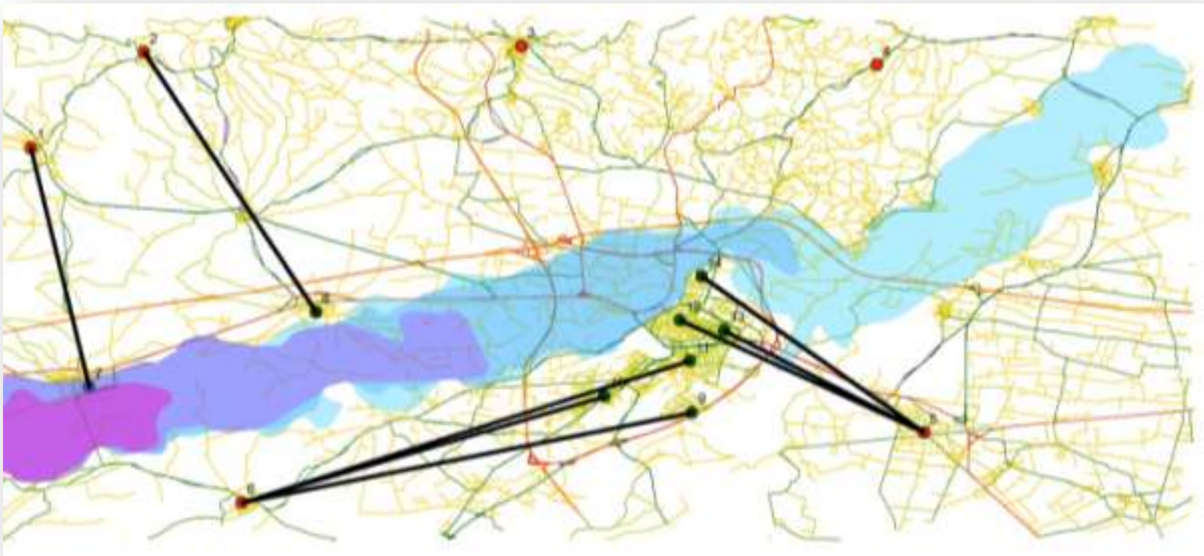


Figure 6-35 (d) , after four hours from the arrival of the flood wave

Figure 6-36 Assignment of terminal points to their related population centres the first two hours from the arrival of the flood wave (a), after four hours from the arrival of the flood wave (b), after six hours from the arrival of the flood wave, (c) after eight hours from the arrival of the flood wave

Case study Alessandria 2-6 November 1994

The Tanaro River entered a phase of extraordinary flooding from 4 to 7 of November 1994 with catastrophic consequences for the entire basin. As already stated, severe actual hydro geological conditions, together with exceptional rains enlarged the phenomenon. During the morning of the 6th November being aware of several flooded cities along Tanaro River(such as the city of Asti) the flood wave arrived in Alessandria; within a few minutes streets turned into torrents with drifting cars. By the end of the catastrophe there were also 14 victims.

Position and hydrologic conditions

The Tanaro (Tanaro drainage basin) is a 276 km long River, rising in the Ligurian Alps, adjacent to the French border. The Tanaro River is the most important right side tributary to the Po River in terms of drainage basin size 8293 km^2, discharge and length. Figure 6-37 and Figure 6-38 illustrate the position of the river and the extension of its drainage basin.

During the second half of October '94 the Tanaro basin was characterized by consecutive intensive episodes of rain precipitation. This caused a high degree of saturation in the Piedmont basin the first days of November , allowing low precipitations of rainfall to generate superficial flow capable of seriously restricting the entire hydrologic network. Figure 6-39 illustrates the hydrologic network and the stations of rain precipitation while Figure 6-40 reports the extreme precipitations captured by the existing network in November '94. In **Error! Reference source not found.** are reported flow alues of the day before the catastrophic day of the 4th of November 1994. It is observed that immediately before the event the hydrographic network, with a high degree of saturation, disposed flows of medium annual flows.

Table 6-1 Hydrological characteristics of some significant stations. Source EVENTI ALLUVIONALI IN PIEMONTE (Torino 1998)

Station	Basin surface (km^2)	Flow 3/11/94 (m^2/s)	Medium annual flow (m^2/s)
Carde	510	10	11
Carignano	3804	85	71
Torino	5210	90	95
S. Martino	581	9	15
Susa	628	19	11
Lanzo	582	30	20
Mazze	3837	58	96
Borgosesia	695	80	33
Gaiola	562	20	18
Alba	3415	80	71

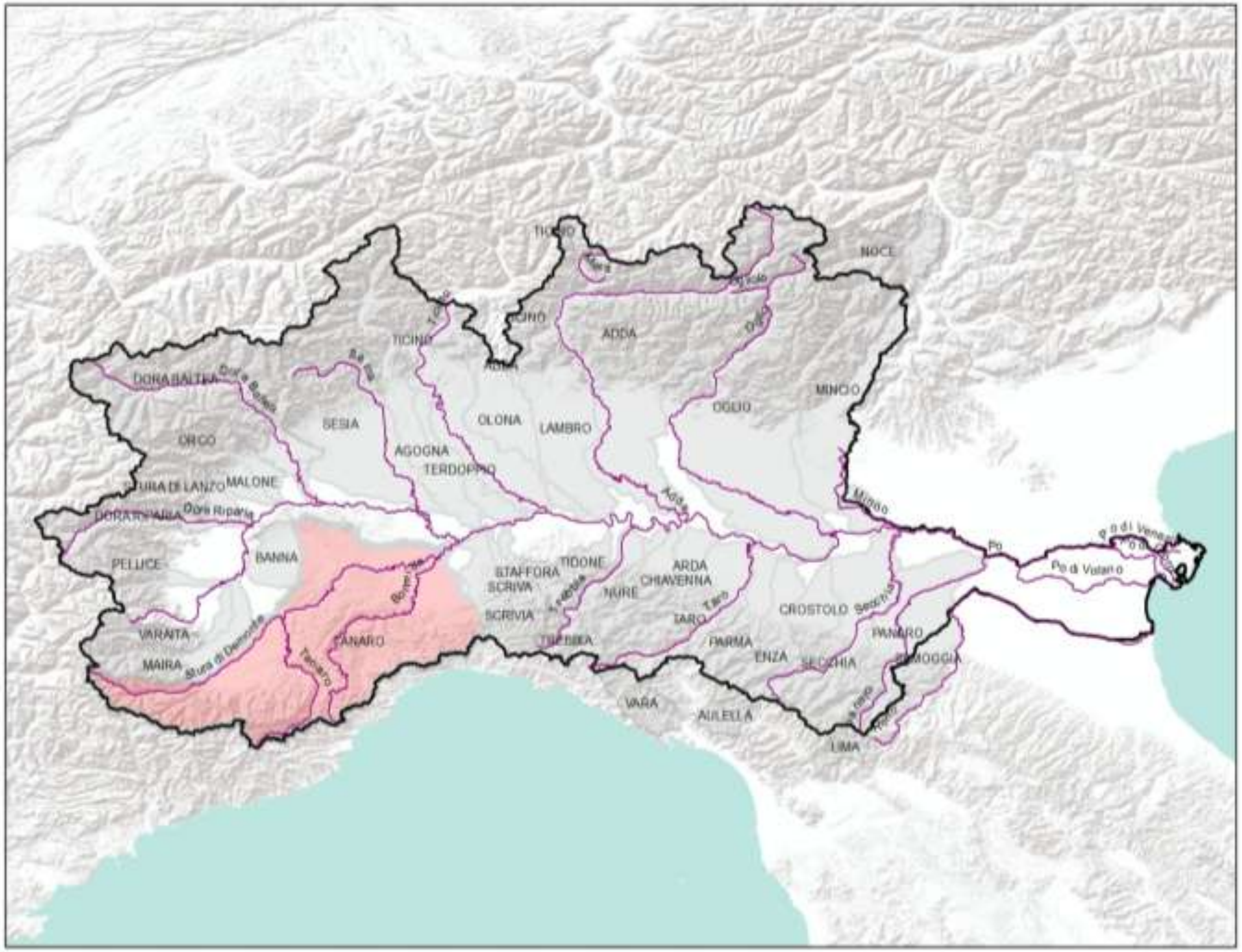


Figure 6-37 Position of Tanaro River basin

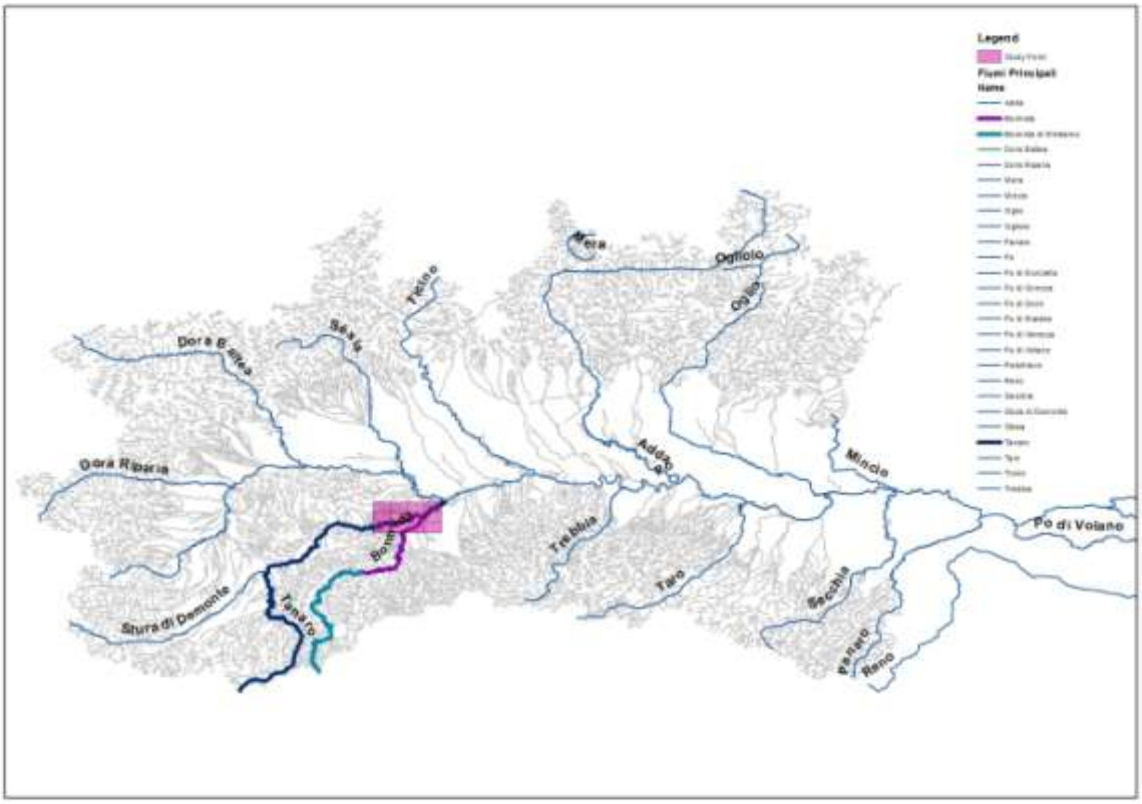


Figure 6-38 Position of case study

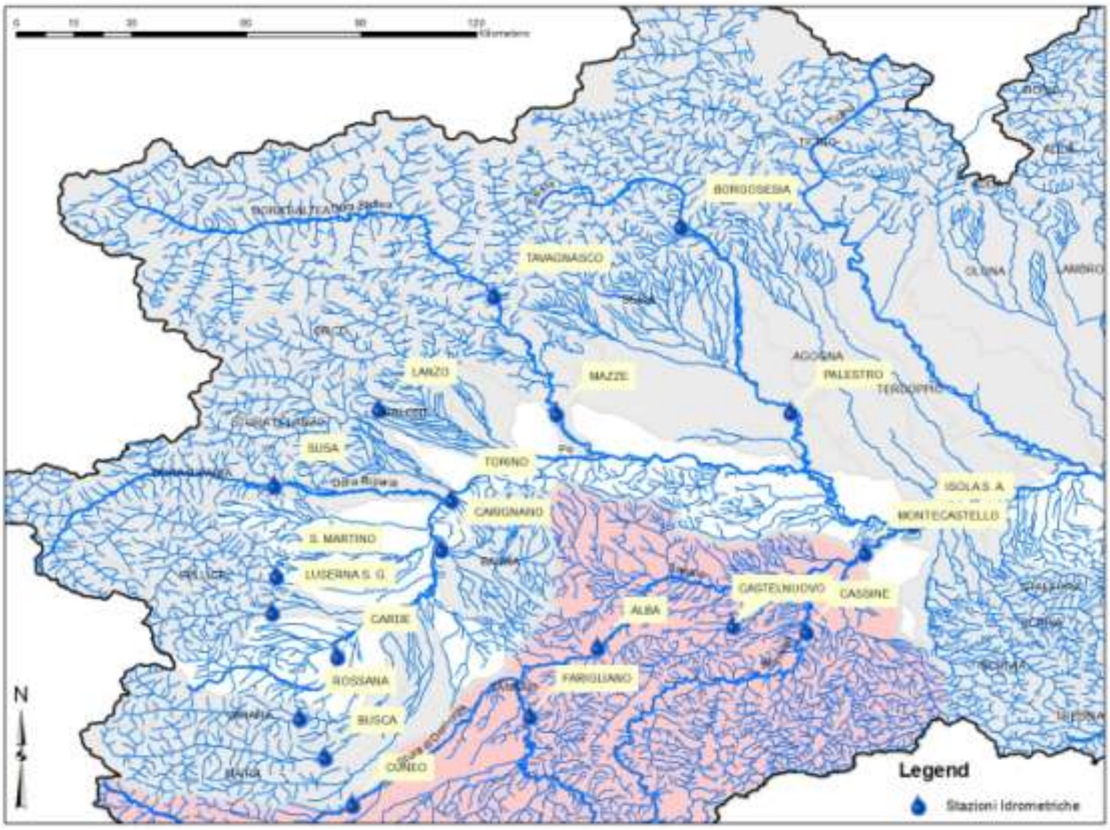
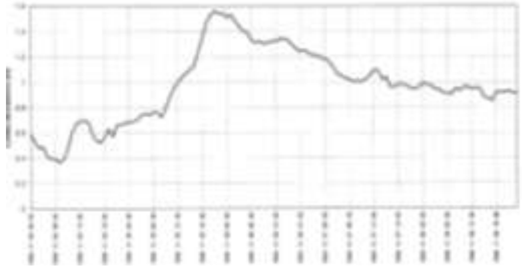
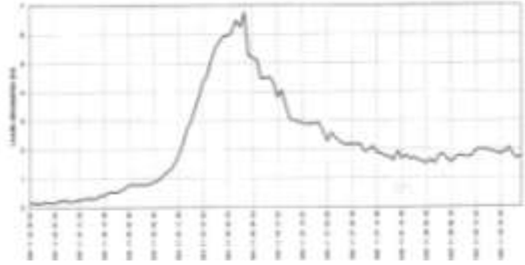


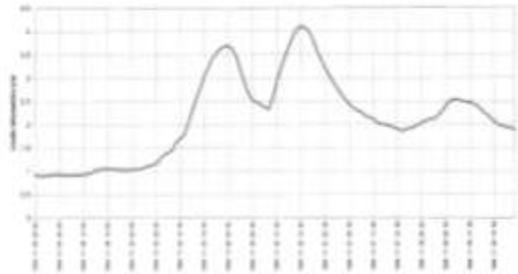
Figure 6-39 Position of hydrometric stations in 1994. Source EVENTI ALLUVIONALI IN PIEMONTE (Torino 1998)



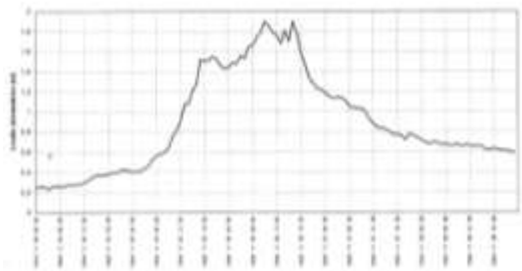
(a) Cuneo



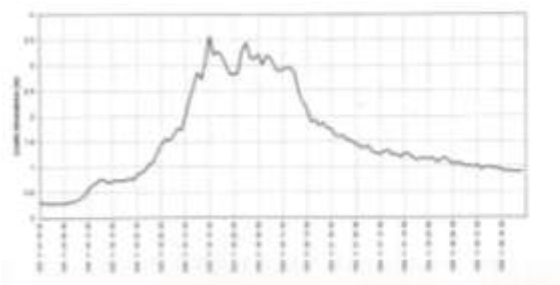
(b) Alba



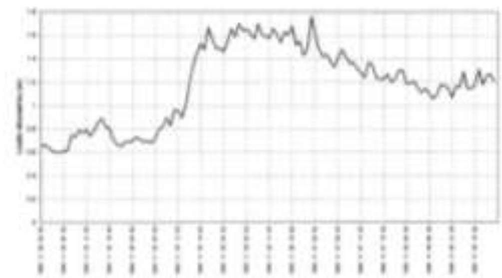
(c) Cardè



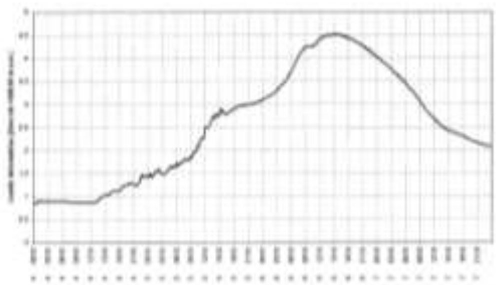
(d) Luserna S. Giovani



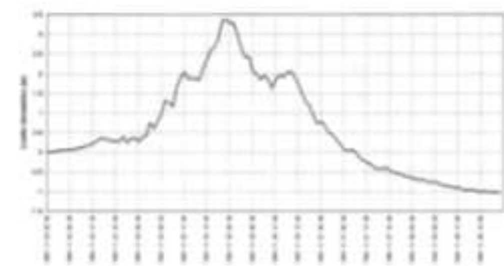
(e) Lanzo



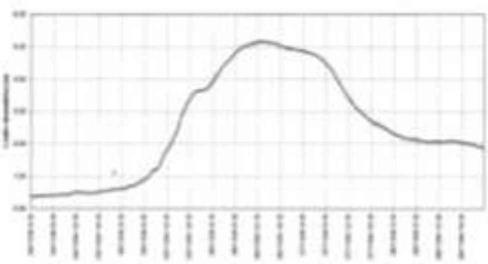
(f) Susa



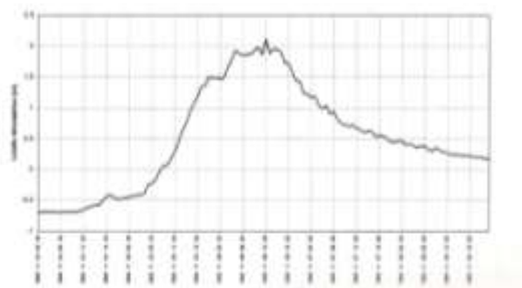
(g) Mazzè



(h) Borgosesia



(i) Torino



(g) S. Martino

Figure 6-40 Perceptions of hydrometric stations of Tanaro basin during 2-6 of November 1994. Source EVENTI ALLUVIONALI IN PIEMONTE (Torino 1998)

Flood dynamic

The city of Alessandria was hit by the flood wave on the 6^{th} of November after three days of continuous rain. We can distinguish three different phases of the event: the first phase 8:30-10:30 GTM + 1 time zone – preparedness phase, the second phase 10:30-13:0 GTM + 1 time zone - paroxysmal phase and the third phase 13:00-14:30 GTM + 1 time zone- catastrophic phase (source EVENTI ALLUVIONALI IN PIEMONTE 2 - 6 Novembre 1994, 8 Luglio 1996, 7 - 10 Ottobre 1996, REGIONE PIEMONTE).

The area affected by the flood event during the first phase of the flood (8:30-10:30 GTM + 1 time zone) is demonstrated in Figure 6-28 (a). Until the first hours of the morning of the 6th of November there were destroyed a couple of farms and cultivation areas were destroyed. A couple of minor infrastructure failures were captured.

During the second phase of the flood (10:30-13:0 GTM + 1 time zone - paroxysmal phase) "Orti" area plain (Figure 6-42 (d)) is gradually flooding in southwest direction. At this moment the entire cultivation are of "Orti" was hit by the event. Furthermore there have been captured several infrastructure failures along the river side, while water level at this stage is 4.0-5.0 meters higher than normality. "Cittdella" bridge, the older bridge of the city of Alessandria has been already subject to various damage. However, it didn't fail.

The third and most catastrophic phase of the event was yet to come. At 13:00 GTM + 1 time zone the junction between the railway and the highway failed and consequently caused almost three km of damage along the railway. Figure 6-41 illustrates the failure along the railway. During the first two phases of the event (8:30-13:00 GMT+1 time zone) the junction between the rail way and the highway A26 (Figure 6-41) maintained the character of "embankment" accumulating a great amount of water. Needless to say that after the failure of the railway junction the flood wave which occurred was devastating and destroyed almost everything along its passage.

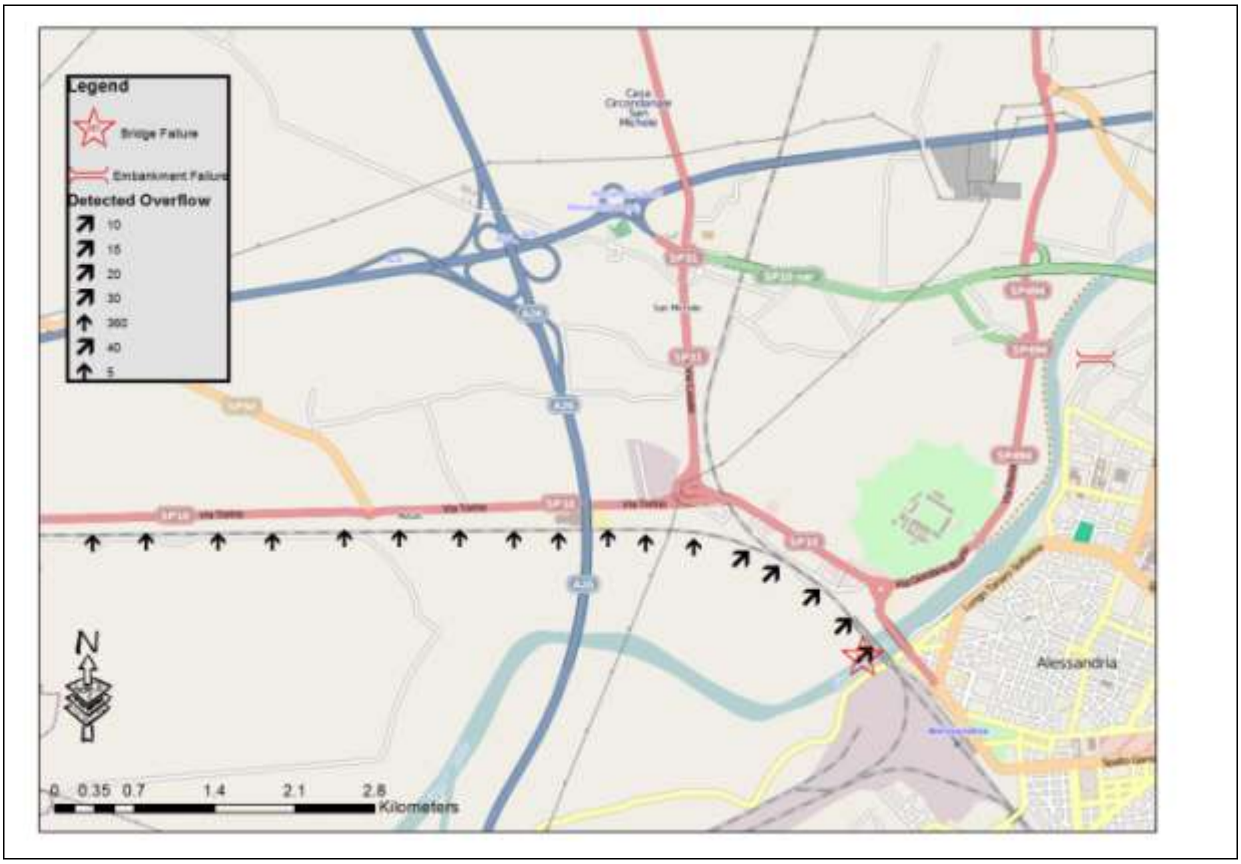


Figure 6-41 Infrastructure failure during the catastrophic phase of the flood (third phase 6th of November 1994 13:00-14:30 GMT+1)

Built-up area vulnerability

Urbanization is a long-term process of transformation from traditional to industrial economies over time. The process of urbanization in the city of Alessandria begins at the end of the 12th century with continuous growth until today. The city of Alessandria, situated at a strategic position at the confluence of Bormida and Tanaro Rivers Figure 6-38 has has grown over 12 km^2 during the last two centuries. Luino F., Arattano M. and Brunamonte F. (1994) explain the vulnerability of the city to flooding and in Figure 6-42 we report the expansion of the city from 1851 until 1991 (Luino et al., 1994). We also report from the same study, the urban development of the city of Alessandria over the last two centuries in **Error! Reference source not found.**.

The November 1994 event involving the Tanaro River was not the first catastrophic flood ever; there have been captured a long series of flood events on the Bormida and Tanaro Rivers. The most important goes back to 1879, when the entire plain from Asti to

Alessandria was flooded. However, damage was limited. In November 1994, the evident urbanization over the recent years (occupation of the entire river–side, floodplains and some parts of the river-bed itself, insufficient size of bridge arches, negative interference of road and railway embankments and lack of adequate maintenance and cleaning of the natural drainage network) led to devastating consequences.

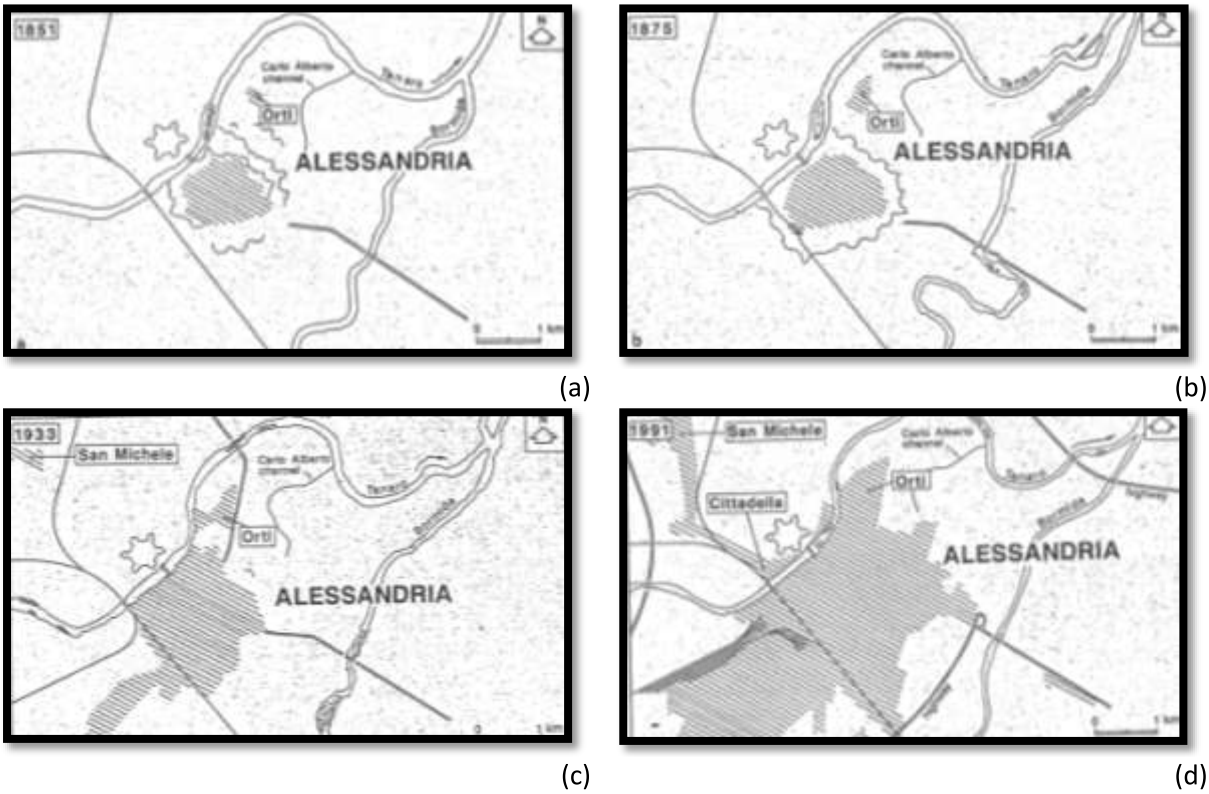


Figure 6-42 Urbanization of the city of Alessandria (a) 1851, (b) 1875, (c) 1933, (d) 1991, Luino. F. et al (1994)

Table 6-2 Development of the city of Alessandria over the last two centuries, Luino. F. et al (1994)

Year	Built up area in km^2	Inhabitants	Area (m^2)/inhabitants
1828	1.00	17,225	58.1
1851	1.20	27,057	44.4
1875	1.52	30,358	50.1
1933	2.73	53,619	50.9
1991	9.47	100,523	94.2

Simulation of the 2nd-6th November 1994 event into CA2D model

As described in the Cellular automata Flood Propagation Model paragraph the input data needed for the floodplain inundation model consist of an accurate Digital Elevation model (DEM) of the area of interest and hydrometric precipitation during the event.

We collected a 90x90 meter resolution digital elevation model from the SRTM (Shuttle Radar Topography Missions) mission. In the case of research, SRTM data is available for free. This international project was spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). During an eleven day mission in February 2000 the shuttle, consisted of a specially modified radar system , generated on a near-global scale the most complete high-resolution digital topographic database of Earth.

For research purposes there is also available another digital elevation model product with 30x30 meter resolution. This mission called Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model was sponsored by The Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA).

It has been shown (ANTONIOS MOURATIDIS, 2010) (ASTER GDEM Validation Team: METI/ERSDAC, NASA/LPDAAC, USGS/EROS, 2009, June) that for plain topography a SRTM 90x90 digital elevation model provides better results than the ASTER 30x30 meter DEM (Digital Elevation model) product. Thus we used SRTM even though it has a lower resolution.

As for flow information, we used the Alba hydro station reported in Figure 6-40 (b) using a value of 4200 m3/s since the rest of the precipitation tools were damaged by the violence of the event.

Chapter 7

Earthquake responses

We propose here a method for the positioning of rescue centres to face emergencies generated by earthquakes. Both the demand points (referred to as "population centers") and the candidate locations for rescue centres coincide with the nodes of a transport network which can be degraded by the disaster. There are methodologies that make possible to estimate for each link the maximum additional cost (or delay) caused by the damages generated by the disaster. The problem is formulated as a two stage optimization problem: The primary problem is a capacitated p-median problem in which the location of p rescue centres is sought which minimizes the overall weighted best-worst cost between rescue centers and population centers. In the secondary problem the *best-worst* cost between each pair of rescue center and population center is worked out as the payoff of the mixed strategy Nash equilibrium for a non-cooperative zero sum game between rescuers seeking to reach population centres and node-specific evil entities able to spoil a single link at each node.

Methodologies for seismic risk assessment

In the past there have been proposed methodologies for the seismic risk assessment. FEMA (Federal Emergency Management Agency of America) created Hazus (Hazard US) which is a GIS based software performing risk analyses. Kiremidjan et al., 2007 studied the degradation of a road network taking also into consideration effects such as ground motion, landslides, liquefaction etc. Caltrans (California Department of Transportation) created REDARS (Risks from Earthquake Damage to Roadway systems). In Werner et al., 2006 is described in detail this methodology. Such procedures measure global delays of the network and not the delay on a single road link, so as to get the system's risk curve.

The probability of damage to a given element due to an earthquake over a certain period of time is the standard definition of the Seismic Risk. The Seismic Risk of an exposed structure is the combination of the expected losses under different levels of hazard severity and its vulnerability to a discrete hazard degree. (Coburn et al. 1994). On the other hand, the socio-economic and human consequences, costs of repair, injuries or deaths is defined Loss. The difference between loss and Risk is not always clear and very often these terms are used to describe the same thing. The Risk is a probability (a number between zero and one) Risk=Hazard ×Vulnerability instead loss depends on the element, value or structure exposed at risk Loss =Hazard×Vulnerability×Exposure.

The emergency plan (rescue centre location in uncertain degraded road networks)

The rescue centre location problem is decomposed into two problems which may be solved separately. First the minimum hyperpath costs are found. Then these are used to solve the rescue centre location problem which has two sets of decision variables, namely **x,** which represents the decision to supply a given population centre from a given rescue centre, and **y**, which represents the decision to locate rescue centres at given nodes. The constraints ensure that each population centre is covered by one and only one rescue centre and that the maximum population that a rescue centre can cover is not exceeded.

The degradability of the network means that travel costs are not known with certainty. We assume that upon arrival at every node en route to a destination the preferred exit link from that node may be degraded or indeed blocked. For link a, d_a measures the cost of clearing or repairing the link if degraded. Where this is low, the incentive for finding an alternative route is correspondingly low. A very large value for d_a would correspond to the case where link a cannot be restored and an alternative must be used. P_2 delivers the set of paths from each origin to each destination that may be optimal if one and only one link exiting each node is degraded as well as the expected travel time corresponding to pessimistically estimated link failure probabilities.

The two parts of the rescue centre location problem are, as already mentioned, solvable separately. First we find the minimum cost hyperpaths and then using the hyperpath costs we find the optimum rescue centre locations.

Having found the minimum hyperpath costs, we can solve the rescue centre location problem. This is a form of the Set Covering Problem (SCP), since each rescue centre covers a set of population centres and we are looking for the assignment of population centres to rescue centres which minimises expected travel costs. This is a complex problem as the number of ways that *m* locations can be selected from *n* sites is $m!/n!(n-m)!$, although the maximum population coverage constraint imposed on each rescue centre will reduce this number.

For the solution of the location of the rescue centres we propose a greedy heuristic. Initially every population centre is assigned its own rescue centre so there are as many rescue centres as there are population centres and the expected travel cost *F* is zero. The algorithm repeatedly removes one rescue centre. When a rescue centre is removed, each population centre assigned to it is reassigned to the nearest remaining rescue centre that has sufficient capacity. The extra expected travel time resulting from the reassignment of destinations is calculated and the rescue centre that causes the least extra travel time is removed. *F* is then increased by the amount of the extra travel time. Rescue centres continue to be removed until only *m* remain.

Post earthquake uncertainties

We can define "earthquake prediction" the prediction that an earthquake of a specific magnitude will occur in a certain place, at a certain time or range of time. However it is impossible for seismologists to make a prediction for a specific day or month. For specific and well-studied seismic faults, there can be stated a probability that a segment may rupture for the next few decades.

There are varied phenomena that seismologists have investigated such as seismicity patterns, crustal movements etc. However, the catastrophic impact of an earthquake (of a certain magnitude) over a specific city, town or village depends a lot on its infrastructures, generally on its vulnerability. Damages can be also verified close to fault rupture itself due to crustal deformation . However, this has a strictly local character. Infrastructure damages depend a lot on their technical elastic parameters .

The functionality of the road network after an earthquake is not part of this research. However, we report briefly the components that may be damaged after an earthquake as well as complementary phenomena activated after an earthquake such as landslides or liquefactions. We do not consider the impact of destroyed buildings which may block a link. This, creates a reduced impact, with the adaption of the concept of the hyperpath.

Fault displacement

It is reasonable saying that Earth's crust deformation creates damages on the infrastructures located on such segments. Construction, generally, is not permitted along seismic faults (or generally seismogenic sources.

There exist comprehensive databases of Seismogenic sources:

1. New Zealand (Geological National Survey),
2. Japan (Institute of Advanced Industrial Science and Technology),
3. United States of America (Geological Survey),
4. Italy (Istituto Nazionale di Geofisica e Volcanologia).
5. Greece (GreDaSS (Greek Database of Seismogenic Sources*)*

We report here a note for the recently produced Greek Database of Seismogenic Sources. This is a unique product for Greece, devoted to provide of a complete and comprehensive tool for improving the SHA - Seismic Hazard Analysis of the country. It also represents an invaluable source of information for scientists who want to deal with earthquake scenarios and modelling, geodynamics, active deformation and much more.

GreDaSS consists of several layers, both graphical and metadata ones, based on the general structure of the Italian DISS. A brief idea about the DISS concept can be found in Basili et al. (2008).

A preliminary, simplified version of the database is soon to be released (http://diss.rm.ingv.it/SHARE), through the European project SHARE (Seismic Hazard Harmonization in Europe). An estimated date for the publication of a first full version of GreDaSS is March, 2012.

Earthquake Induced Landslides

Earthquake induced landslide morphologies and internal processes are not different from those generated under non-seismic conditions. However, they tend to be more widespread and sudden. The most abundant types of earthquake-induced landslides are rock falls and slides of rock fragments that form on steep slopes. However, almost every other type of landslide is possible, including highly disaggregated and fast-moving falls; more coherent and slower-moving slumps, block slides, and earth slides; and lateral spreads and flows that involve partly to completely liquefied material.

Liquefaction

Liquefaction is the transformation of saturated granular material from a solid state to a liquid state as a consequence of increased pore pressures that reduce the effective strength of the material *(*Youd, 1973*).* The liquefaction of a subsoil layer may induced surface disruption such as ground settlements, sand boils and lateral spreading and leads to structural damages at buildings, pipelines, bridges etc. Areas susceptible to liquefaction can be identified through detailed geologic, geomorphic and hydrologic mapping *(*Witter et al. 2006*)* while the liquefaction potential is evaluated based on data regarding the susceptibility to liquefaction of the soil layer and the expected value of ground motion triggered by the earthquake.

Vulnerable components

We refer to the Hazus (Hazard US) Methodology estimation of earthquake damage to a highway transportation system. Given knowledge of the system's components (bridges, roads or tunnels), the classification of each component for every category (e.g., for roads, motorway or local road), and the ground motion - shake maps (i.e. peak ground acceleration and/or permanent ground deformation).

Bridges

There are classified well 28 different types of bridges in Hazus. This classification scheme incorporates various parameters that affect damage into fragility analysis and provides a means to obtain better fragility curves when data become available.

Tunnels

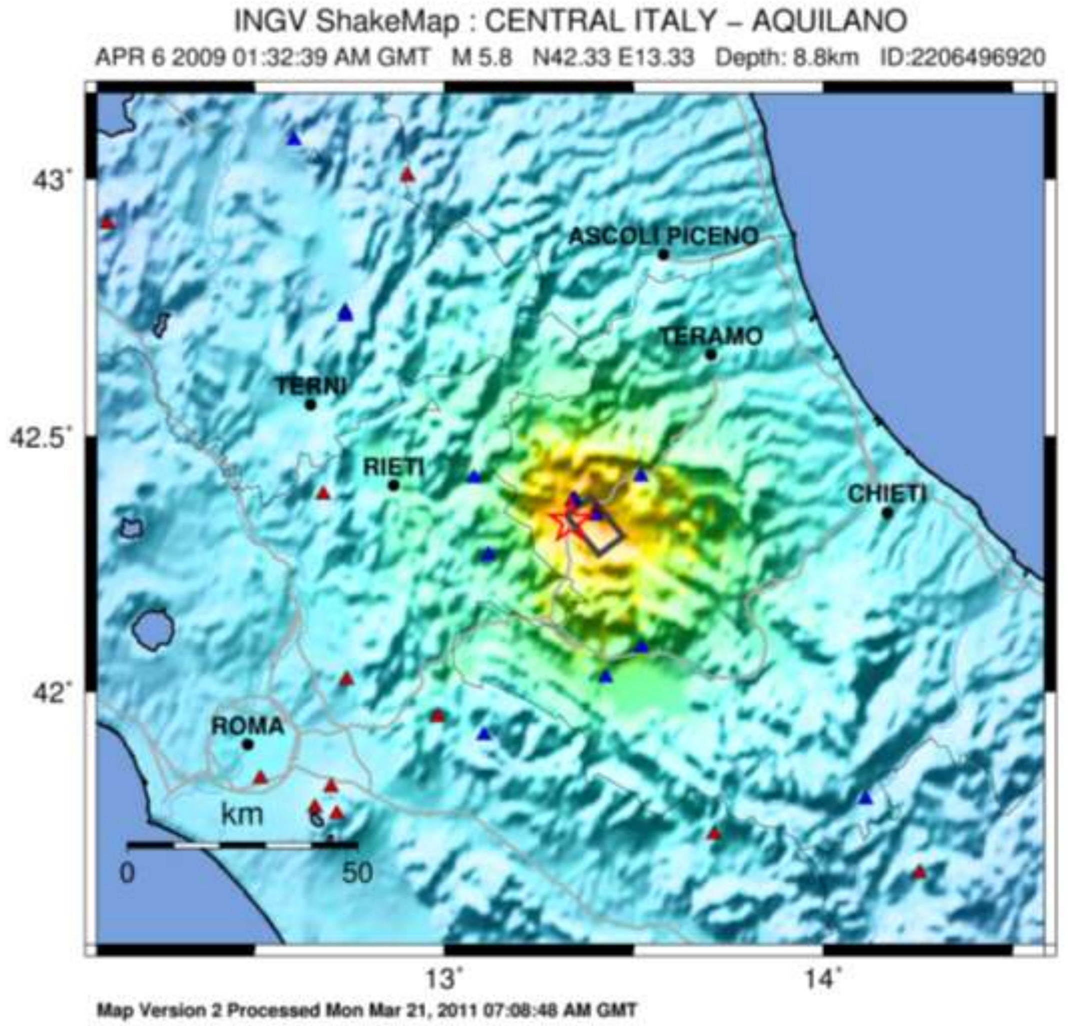
Tunnels in HAZUS are classified as bored/drilled or cut & cover.

Roads

In HAZUS, Roadways are classified as major roads and urban roads. Major roads include interstate and state highways and other roads with four lanes or more. Parkways are also classified as major roads. Urban roads include intercity roads and other roads with two lanes.

L'Aquila earthquake 2008

We applied the proposed model using as case study the earthquake occurred at the L'Aquila Region in Italy the sixth of April 2009. We did not use HAZUS methodology since such analysis is out of the field of this research. However we used reasonable macro seismic data available on the official website of the National Institute of Geophysics and Vulcanology (shakemaps INGV)



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.17	0.17–1.4	1.4–4.0	4.0–9	9–17	17–32	32–61	61–114	>114
PEAK VEL.(cm/s)	<0.12	0.12–1.1	1.1–3.4	3.4–8	8–16	16–31	31–59	59–115	>115
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

Figure 7-1 Macroseismic intensity of the earthquake occurred at the Aquila Region on the 6th of April 2009 - Official data INGV

In the following pages we report some maps showing the calculation of the hyperpaths. We assume that every rescue centre decided by the civil protection covers the population of the locality it refers to. We use rescue centres as population centres.

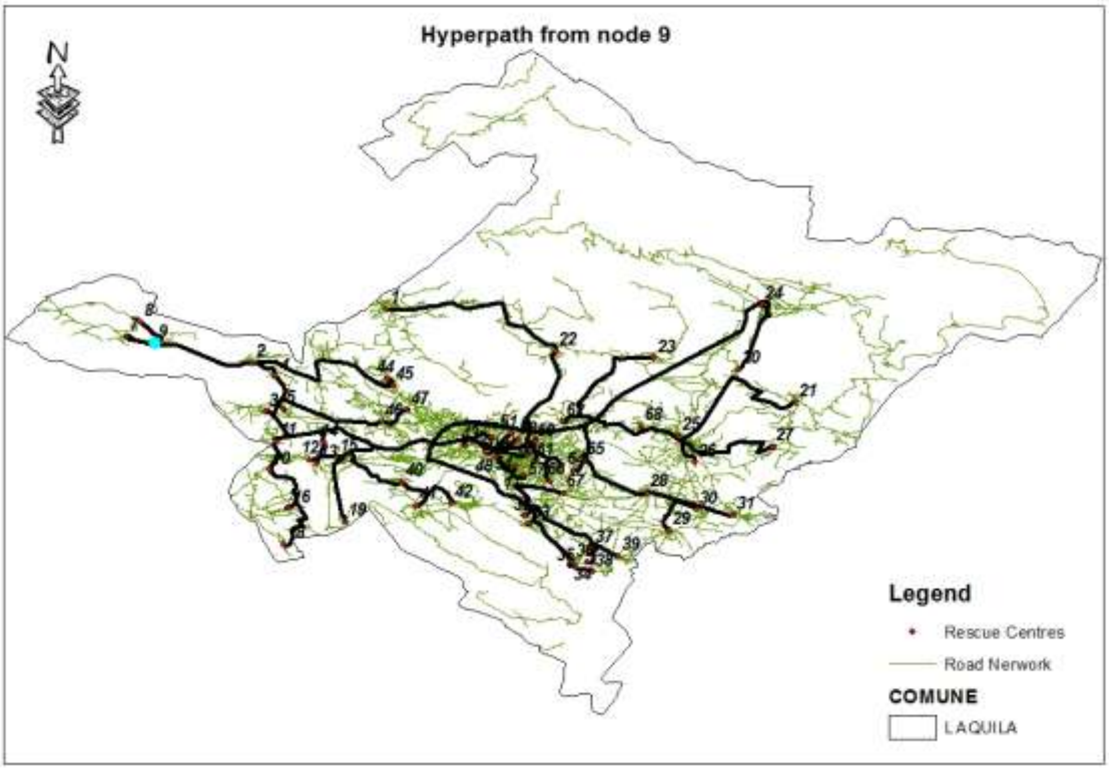


Figure 7-2 Hyperpath example from node 9

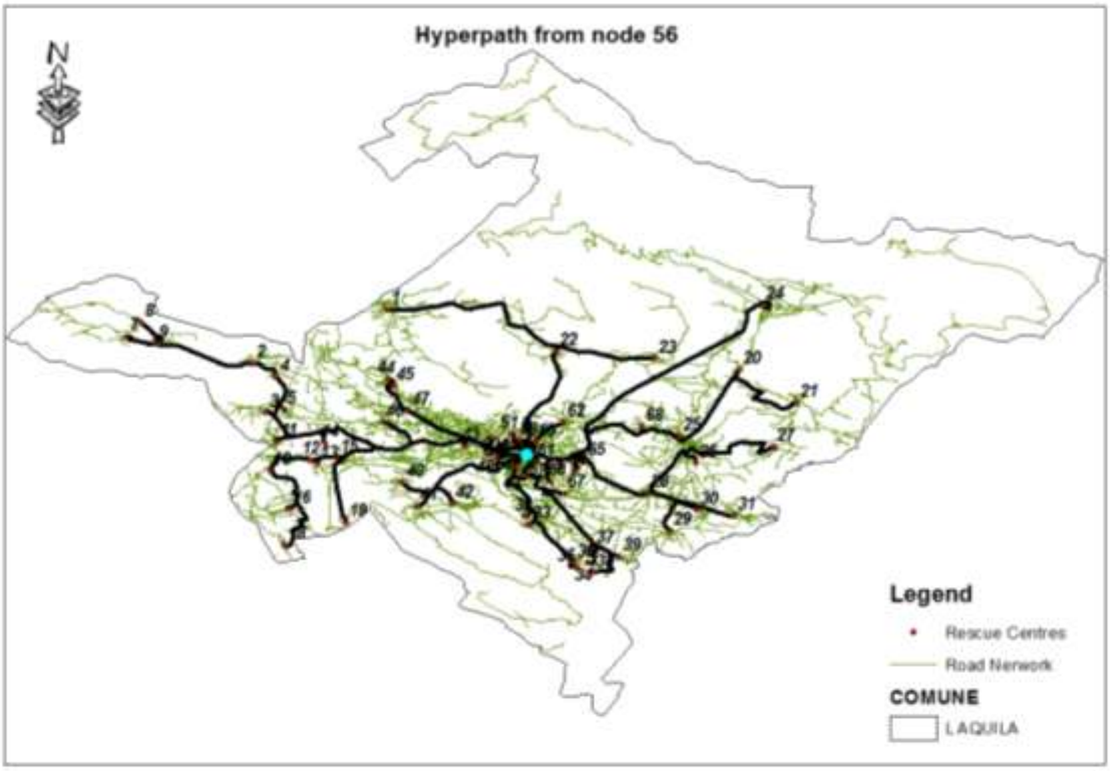


Figure 7-3 Hyperpath example from node 56

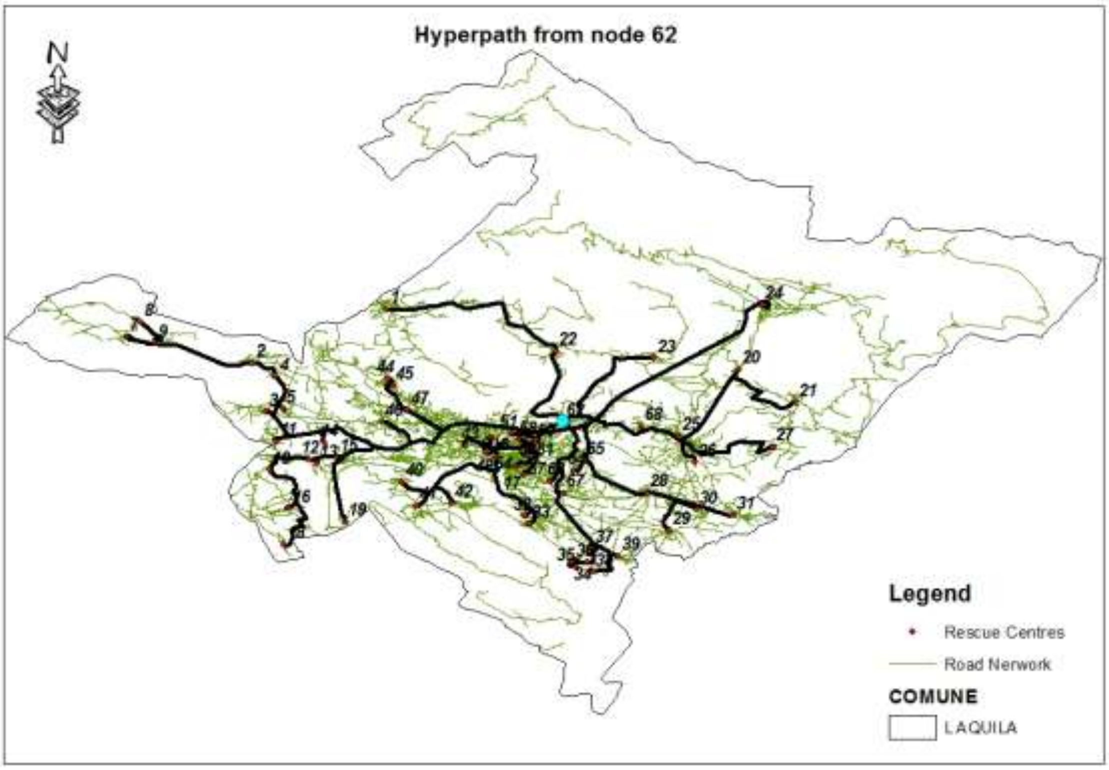


Figure 7-4 Hyperpath example from node 62

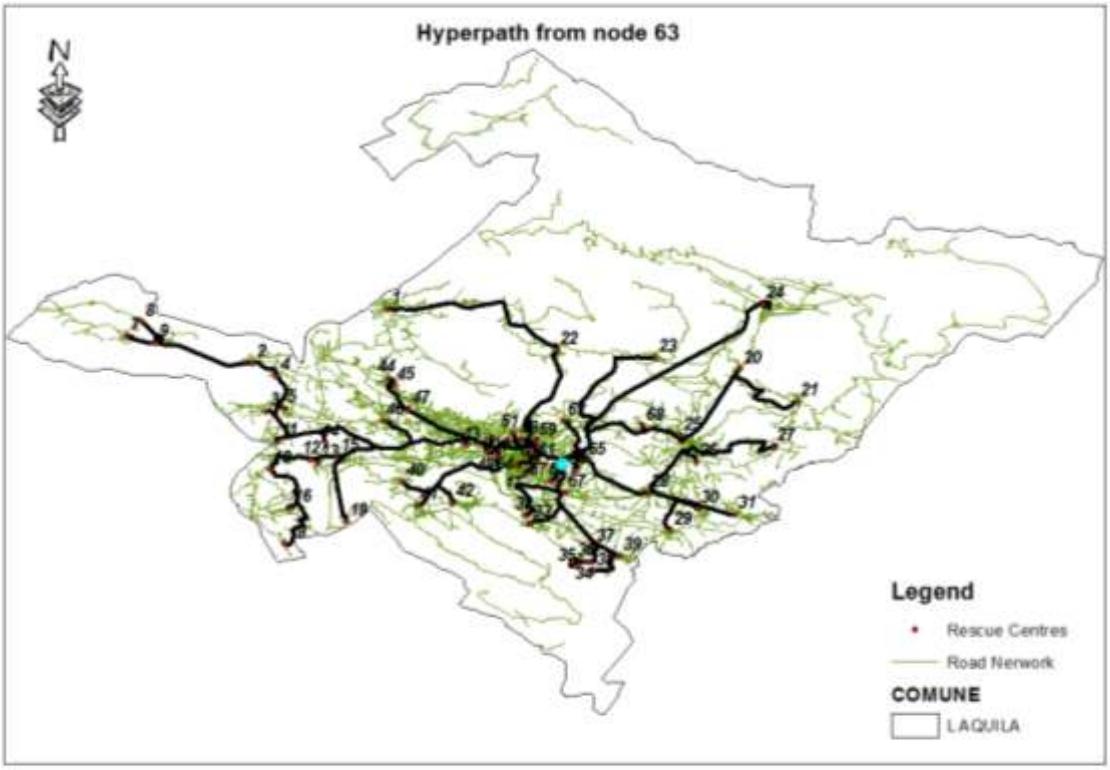


Figure 7-5 Hyperpath example from node 63

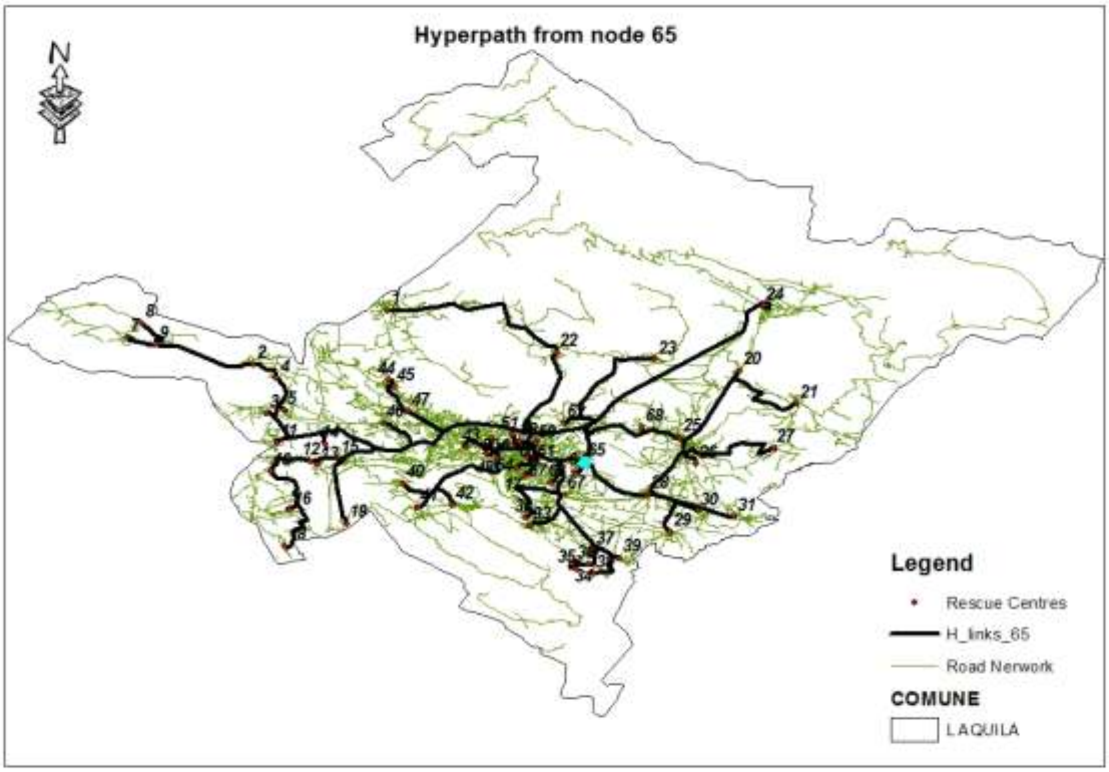


Figure 7-6 Hyperpath example from node 63

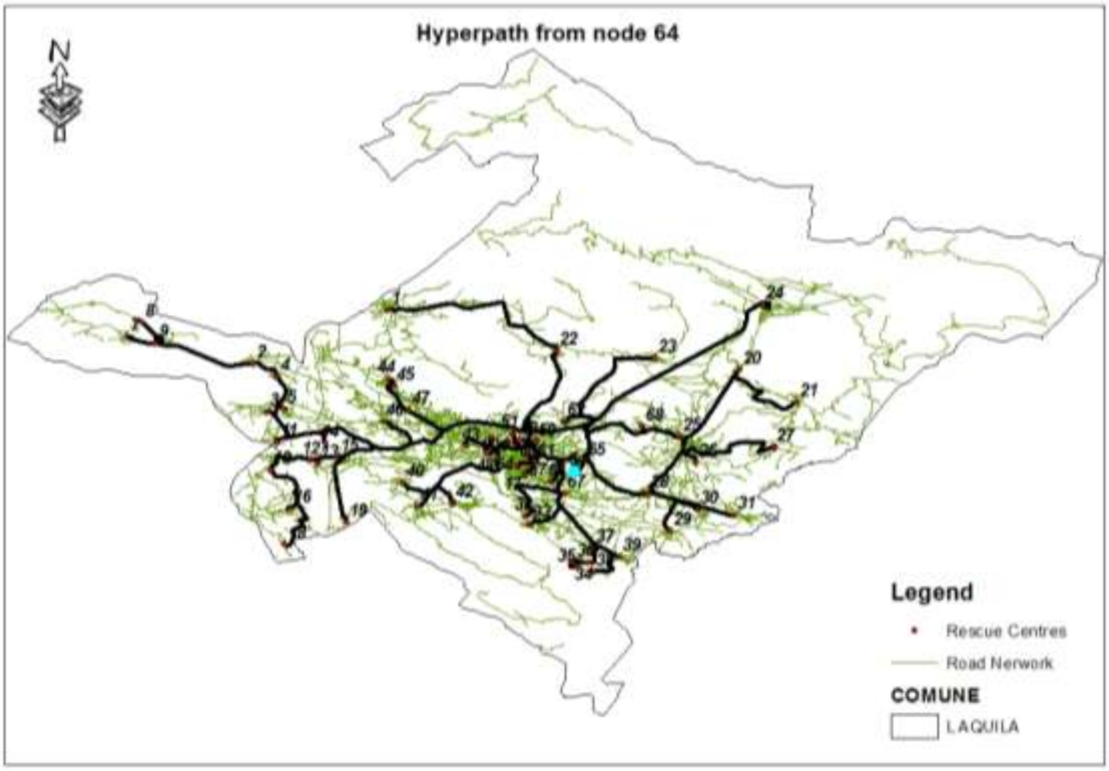


Figure 7-7 Hyperpath example from node 64

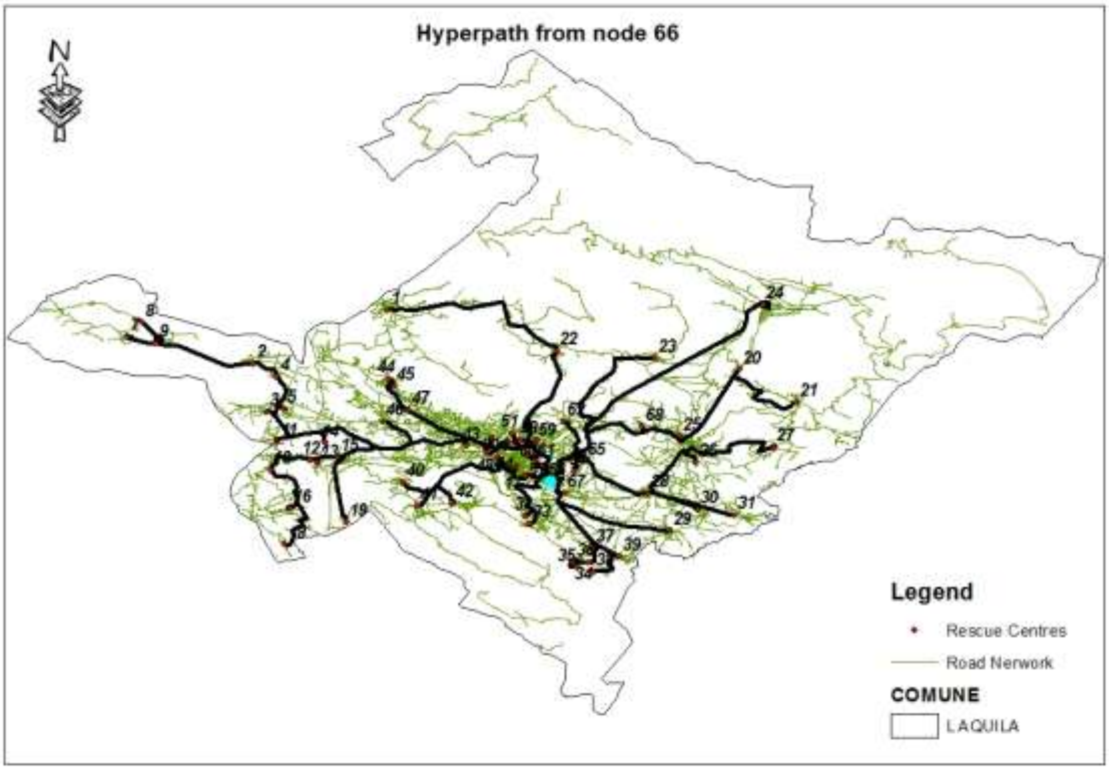


Figure 7-8 Hyperpath example from node 66

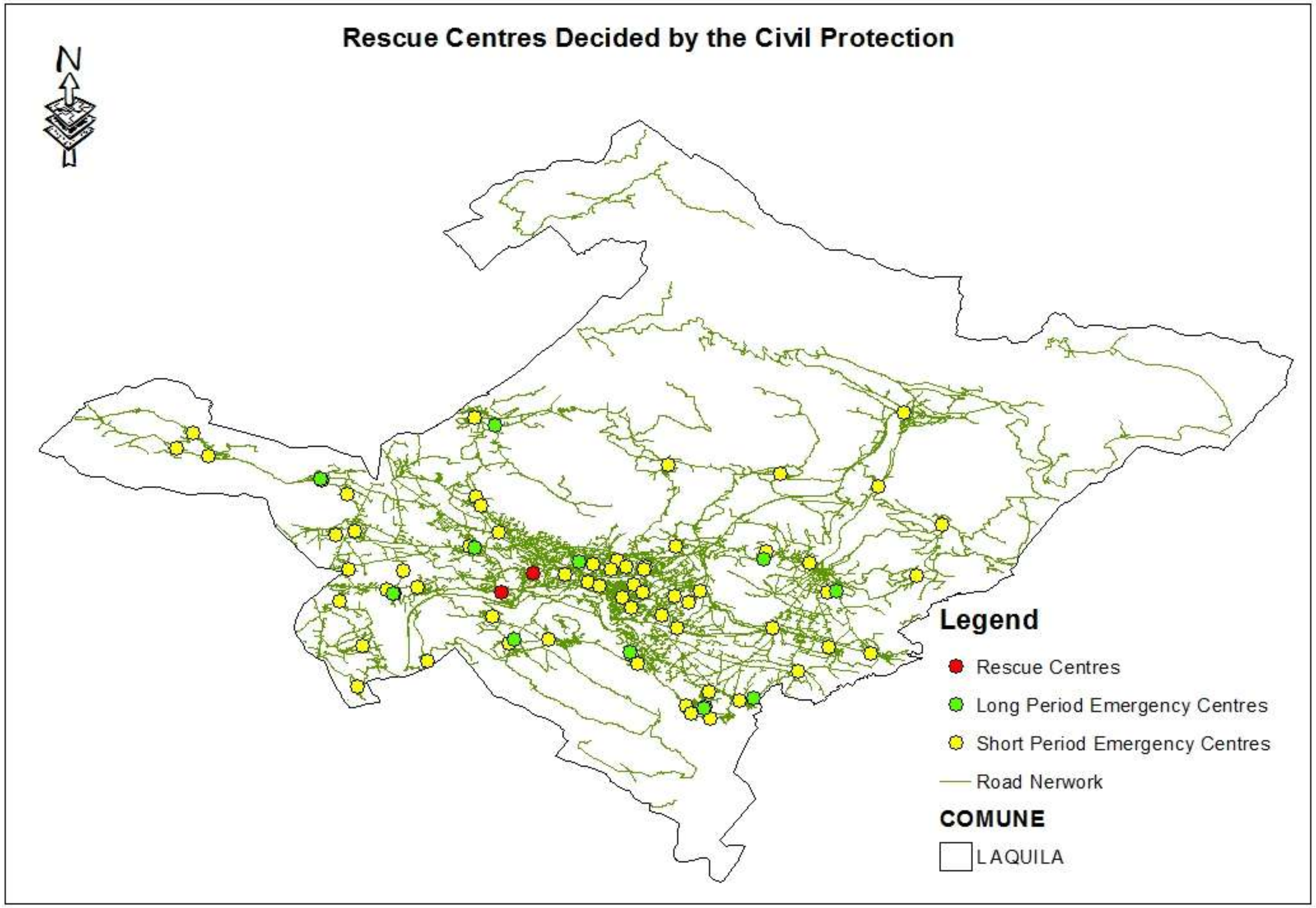


Figure 7-9 Rescue Centres Decided by the Civil Protection

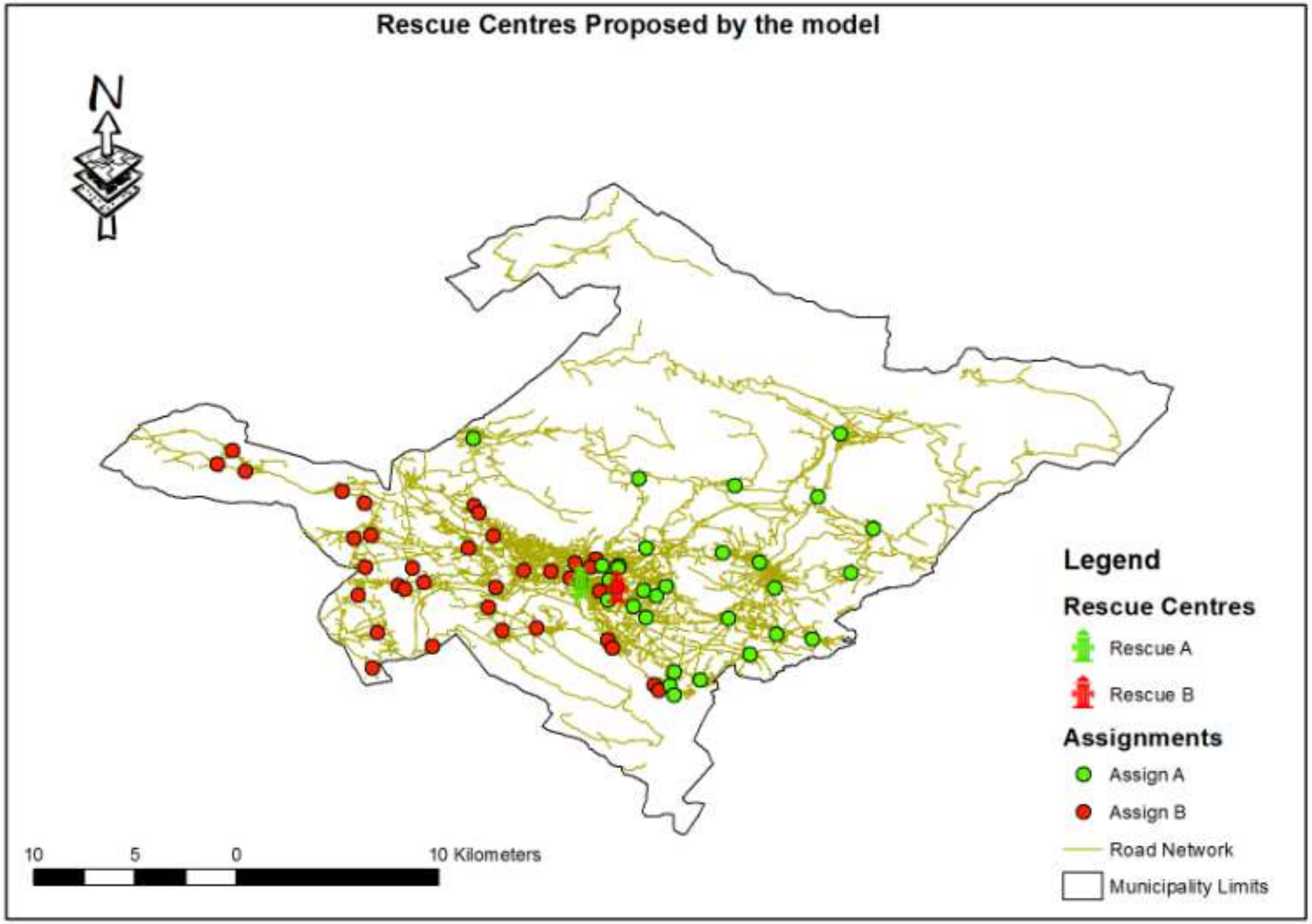


Figure 7-10 Rescue Centes Proposed by the model

Chapter 8

Discussion

We have presented a method for the evacuation of urban centres to avoid human loss in case of flooding and a method for locating rescue centres over a degraded transport network after an earthquake. These methods, both undoubtedly need improvements and corrections from many points of view. However, it is worth saying that this has been an attempt to involve different disciplines so as to propose a multidisciplinary method in which there may be the possibility of applying all competences involved. If we take advantage of all the disciplines proposed, we may be able to produce an excellent service - product (or on-line application) to be incorporated in comprehensive emergency management plans.

First and foremost, additional da travel costs due to the natural disaster itself have to be better determined. As described in the relevant chapters, floods are easier to treat than earthquakes since the phenomenon as a natural disaster is more predictable and there are more efficient methods to calculate Vulnerability, Risk and Costs.

An efficient flood model like the one we used (CA cellular automata plain flood inundation model) can accurately calculate the extension of a flood. If we also add all information acquired from past events it is possible to achieve results very close to reality. In case of floods, we calculated the higher possibility for road links to be blocked by the event itself using the CA model and this is codified as da cost. It is calculated as a delay meaning that according to the CA model, we assign very high travel costs to the road links that the model shows are covered by water after certain periods of time (after two hours, four hours etc) from the moment local civil protection decides to evacuate. In short terms da value is not a delay but a probability a road link is blocked after certain periods of time. After the flood event not all streets are available. There are still links blocked (by drifted cars, mud, collapsed infrastructures) which are not possible to know beforehand over the whole area of the flood. Thus, after the flood event, we can assign to da value, the cost of clearing or repairing a link during the recovery phase of emergency management division.

In the case of an earthquake, da value is the cost of clearing or repairing links. In both cases da value is measured in the same travel time units as link cost (time needed to cross a link without any delay). We understand that the earthquake, as a more complicated and unpredictable phenomenon, is more difficult to interpret and thus we are less certain about the outcome. However, the hyperpath technique as described gives great potential to solve earthquake problem it the future.

A deep transport study regarding the calculation of the evacuation time estimates respect to supply and demand values, time of mobilisation and maybe human reaction. We could consider using both pedestrian and vehicle modes to reach terminal points and maybe take advantage of public transport.

Apart from the discussion for the effectiveness of such a system either for the earthquake or for the flood response, we may also consider different natural disasters that may cause similar problems. Threats today do not include only floods and earthquakes, but also tsunamis, landslides, wildfires, tornadoes, hurricanes, pandemics, oil spills, and terrorism. Evacuation plans have taken on greater relevance, as disasters become more and prevalent.

Both the position of rescue centres as well as the one of population centres and/or terminal points in respect to location research presented in the third chapter can be further treated. We take into consideration only rescue centres or terminal points decided by local civil protection. However, it is important to state which nodes would represent better the concentration of the population and refer to them as population centres. It is also very important to consider their density and their 'capacity' at different hours of the day. Naturally, at peak hours we would have more dense population centres than evening hours or weekends. This should be also taken into consideration.

We can also consider population centres located in public transport stations (es bus stops- referred to as primary population centres). Either the hyperpath concept or a* algorithm can be selected as route choices from population centres to terminal points already decided by local civil protection away from the crisis zone (outside the flooded area).One must decide the capacity, period of stay and supplies for every terminal point proposed. For this solution, public transport can be determined as the main relief instrument for pedestrians while vehicles such as private cars may use the hyper path to arrive to a terminal point location. In such a case, every node of the network may be referred to as a secondary population centre and referred only to drivers located actually in the network seeking to leave the zone in crisis. No more people should be allowed to take the car at this point and they should only use public transport, in order to escape. Human reaction needs to be taken into consideration as well as estimations of mobilization time and evacuation response. The method proposed here can thus be used (rescue centre location) deploying either a* or hyper path costs to locate places in the upper floors of buildings that would be transformed into terminal point locations.

The proposed method to locate rescue centres can be used exactly as it is when it comes to deal with terminal point location inside the crisis zone. This is the case when people leave their cars and use only pedestrian mode in order to avoid any kind of congestion. Terminal points should be locations decided by municipalities together with local civil protection departments. These terminal points have to be in the upper floors of selected buildings, be independent and have supplies for a long period of time. This period depends on the time flood waters remain, keeping isolated every terminal point.

The hyperpath concept can be applied individuate to avoid incidents from landslides. After long periods of rain fall we could not be sure where a landslide may occur. There are indexes and plenty of techniques that generate the probability for a landslide to occur. We could use the hyper path to provide risk averse guidance when local civil protection alerts for a certain place or a certain periods are high. I understand this may vary due to meteorological conditions.

Tsunami terminal point location could also be an idea for further research. We could use the original rescue centre location problem and apply it to a tsunami preparedness emergency management method. Terminal points should be high enough so as to let the waves pass underneath their structure without being destroyed by the wave itself.

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APENDIX

Introduction

There was collected an amount of valuable data for the needs of this research. All dada was treated in a Geographic Information System (GIS). A Geographic Information system integrates hardware, software and data for capturing, managing, analyzing and displaying all forms of geographically referenced information.

ESRI support

For the needs of this research ESRI Italia, Italy's headquarters of the GIS software leader worldwide, offered an one year licence of the latest GIS product of ArcGIS 10. ESRI develops geographic Information Systems that function as an integral component in nearly every type of organization.

Data collection

All data collected for the research developed were treated with the World Geodetic System (WGS84) which is a standard for use in cartography, geodesy and navigation. The latest version of the World Geodetic System, WGS84, is used by the Global Positioning System. It is geocentric and globally consistent within one meter plus-minus.

A very valuable support for the needs of this research regarding the study of the event of November 1994 in Alessandria Region in Piedmont (Italy) and the collection of an amazing amount of data, was offered from Dr Fabio Luino of the Italian Research Centre, Italian Institute for hydrological Protection, Chair of Torino CNR-IRPI data collection for Alessandria flood. Among this important collection (see following pages) starting from the date of 1894 there were after event maps, with detailed explanations regarding, various levels of flood. More generally we can refer to aerial photos, maps, multimedia data such as videos, and other flood events happened at the Alessandria basin perfectly and very detailed described in a report produced by Piedmont Region namely "EVENTI ALLUVIONALI IN PIEMONTE 1994-1996".

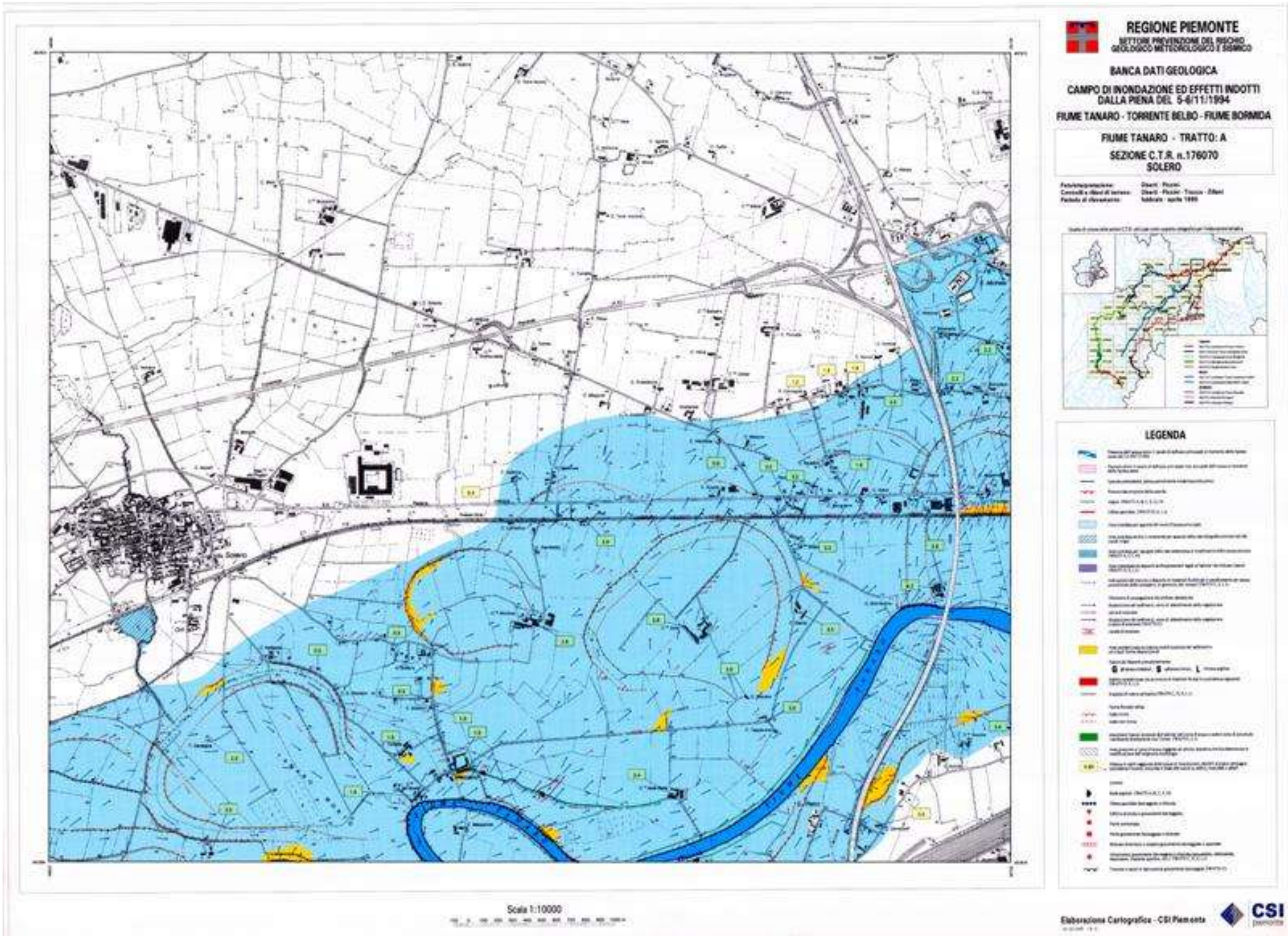


Figure 0-1 Base maps Provided by Dr Fabio Luino CNR di Torino

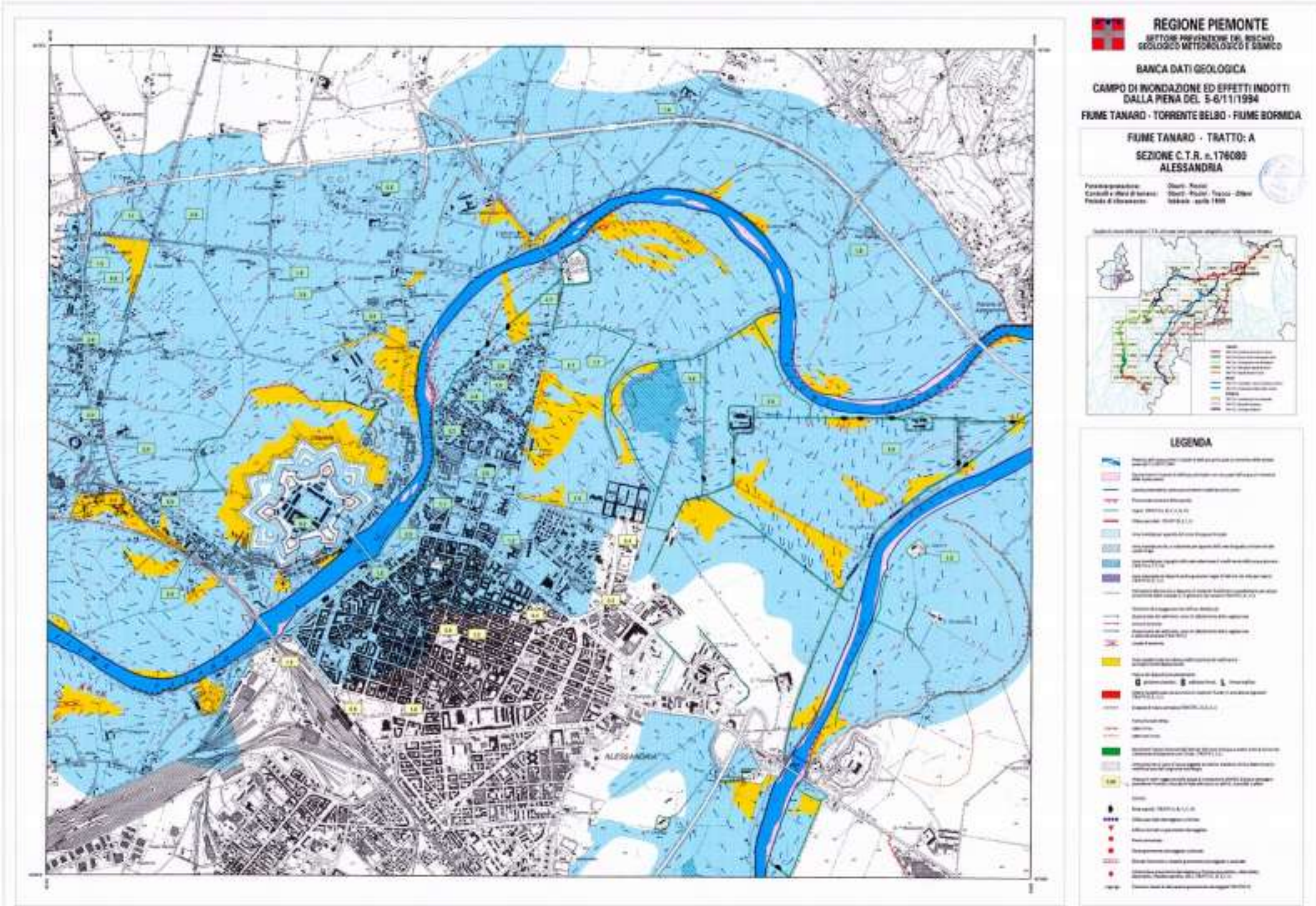


Figure 0-2 Base maps Provided by Dr Fabio Luino CNR di Torino

Figure 0-3 Orthophoto provided by the CNR of Torino (Dr Fabio Luino)

Figure 0-4 Orthophoto provided by thr CNR di Torino (Dr Fabio Luino)

We used the Tele Atlas® MultiNet® data collection kindly provided by ESRI Italia. ESRI Italia supports Italian Research by providing data, not for commercial scope. An amazing database of all sorts of spatial data, can also be found online and lately, it is also available in the last versions of ArcMap.

Tele Atlas MultiNet, is the most detailed and comprehensive street network database. It is the basis for demanding applications such as turn-by-turn route guidance, traffic information, and others Tele Atlas is committed to constantly providing high quality maps. All geographical data is continuously checked, upgraded and updated in the field. Furthermore, the digital map coverage is extended every day, for the availability of other regions, new product releases or all other information provided within the product. In the following pages we provide visible sample of the product.

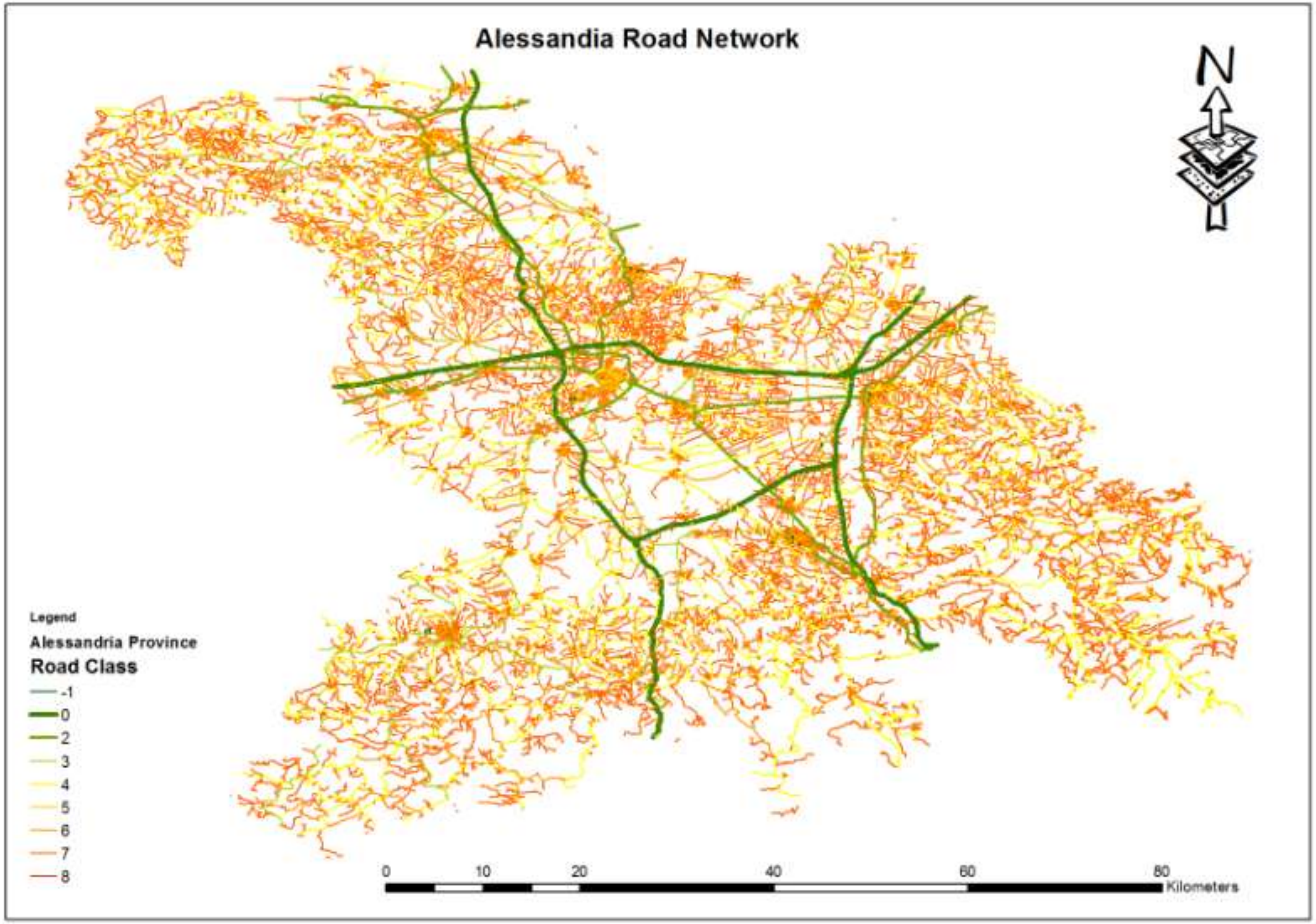


Figure 0-5 Alessandria Road Network - Multinet™ Data

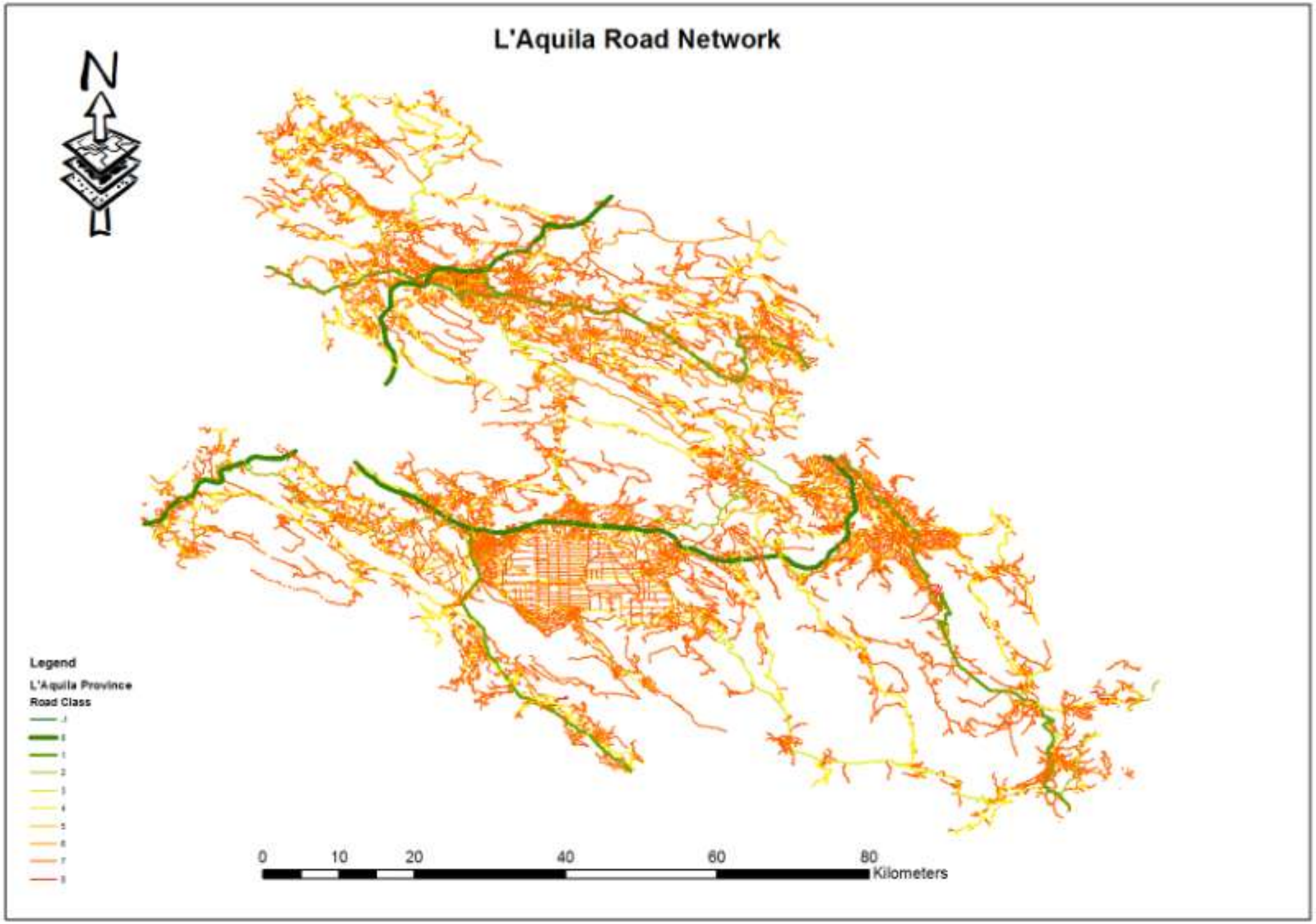


Figure 0-6 L'Aquila Network Multinet Data

Code implementation

Both algorithms, for the calculation of all possible routes from each population centre to all others, (hyperpaths) and for the facility location problem were implemented in MATLAB a coding language for technical computing. MATLAB product, created from MathWorks® is a programming environment for algorithm development, data analysis, visualization and numerical computation. With MATLAB it is possible to solve technical computing problems faster than with traditional programming languages such as C, C++ and Fortran. It is possible to use MATLAB in a wide range of applications, including signal and image processing, communications and others.

There exist several toolboxes for MATLAB. For the needs of this research we used the Mapping Toolbox for the generation of images and shapefiles. A "shapefile" is a popular vector data format for all Geographic Information Systems developed by ESRI. In shapefile we can store a range of non topographical geometries and attribute information for spatial features that can be found in a database.

Mapping Toolbox™ provides tools and utilities for analyzing geographic data and creating map displays. You can import vector and raster data from shapefile, GeoTIFF, SDTS DEM, or other file formats, as well as Web-based data from Web Map Service (WMS) servers. The toolbox lets you customize the imported data by sub setting, trimming, intersecting, adjusting spatial resolution, and applying other methods. Geographic data can be combined with base map layers from multiple sources in a single map display. With function-level access to all key features, it is automatically possible to create frequent tasks a geospatial workflow.

Flood and earthquake data implementation

For the simulation of the event occurred in Alessandria in 1994, both Aster (90 meter resolution) and SRTM (30 meter resolution) Digital Elevation Models (DEM) were collected. The inundation model Cellular Automata of Francesco Dottori was used as described in the sixth chapter. Francesco Dottori is part of the research group of Prof Ezio Todini, who supervised this work.

Small part of the research described, (Database of Individual Seismogenic Sources, Instituto Nazionale di Geofisica e Vulcanologia, 2012) (Shake Map Archive, Instituto Nazionale di Geofisica e Vulcanologia, 2012) was dedicated in seismic risk assessment. For this purpose we used information provided by the Italian, National Institute of Volcanology and Geophysics, available online for research purposes. INGV provides a wide range of information to researchers through their web page http://www.ingv.it/banche-dati/. We were only referred to shakemaps and the database of Individual seismogenic sources. Apart from that, Dr Stefano Salvi from the group of remote sensing of the National Institute of Geophysics and Vulanology in Rome, kindly provided interferometric data. Interferometric synthetic aperture radar, also abbreviated InSAR is a radar technique very common in remote sensing and geodesy.

Rescue Centres - L'Aquila earthquake 6th May 2009

We report here the spaces that Civil Protection individuated to function as rescue centres or allocation places for populations hit by an earthquake.

These are the places, where population who has been recently hit by a natural disaster such as earthquake, or flood can find a shelter during response and recovery phases of emergency management.

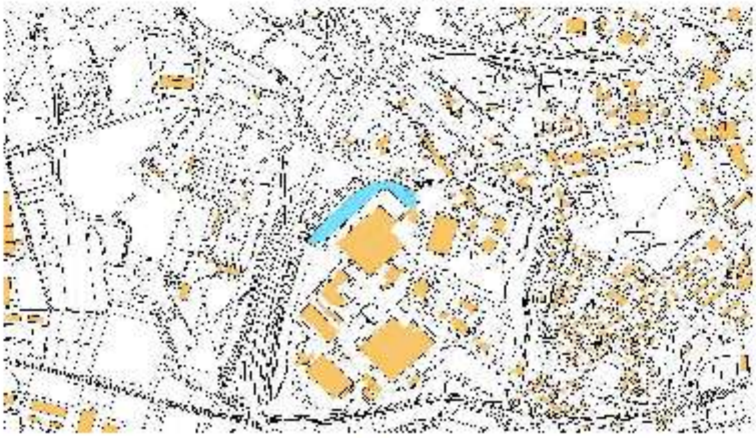
There have been individuated three types of emergency management shelters:

- Short period emergency centre or attend areas (aree di attesa)
- Long period emergency centre (aree di accoglienza)
- Rescue centres (aree di ammassamento) where rescue vehicles are located

In the following pages we report some index cards for the places described above.

AMM_01-: PARCHEGGI EX FINMEK				
Individuazione	Zona Industriale Loc. Pile con accesso dalla SS 17 Coordinate X =2385326,737 Y = 4690845,882 (Gauss-Boaga)			
Superficie totale	Mq 12.000	**Area parcheggio**	Mq. 3.000 in zona limitrofa	
Tipologia del suolo	Asfalto	**Pendenza**		In piano
Infrastrutture presenti	illuminazione ed in parte canalizzazioni di acqua fogna energia elettrica, magazzini.	**Proprietà**		Privata
Note	L'area risulta a moderato rischio alluvionale - Già utilizzato come Area di Accoglienza			

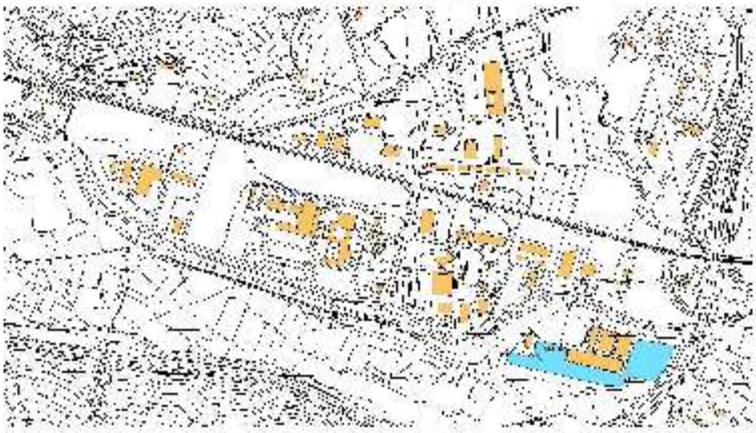
Vista aerea dell'area



In azzurro l'area di accoglienza identificata anche dal simbolo: ⊕

AMM_02 PARCHEGGI CENTRO COMMERCIALE IL GLOBO				
Individuazione	Via Saragat Loc. Campo di Pile Coordinate X = 2384434,058 Y = 4689920,277 (Gauss-Boaga)			
Superficie totale	Mq 32.000	**Area parcheggio**	Mq.	
Tipologia del suolo	Asfalto	**Pendenza**		In piano
Infrastrutture presenti	illuminazione ed in parte canalizzazioni di acqua fogna energia elettrica	**Proprietà**		Privata
Note	Area alternativa - Già utilizzato come Area di Accoglienza			

Vista aerea dell'area



In azzurro l'area di accoglienza identificata anche dal simbolo: ⊕

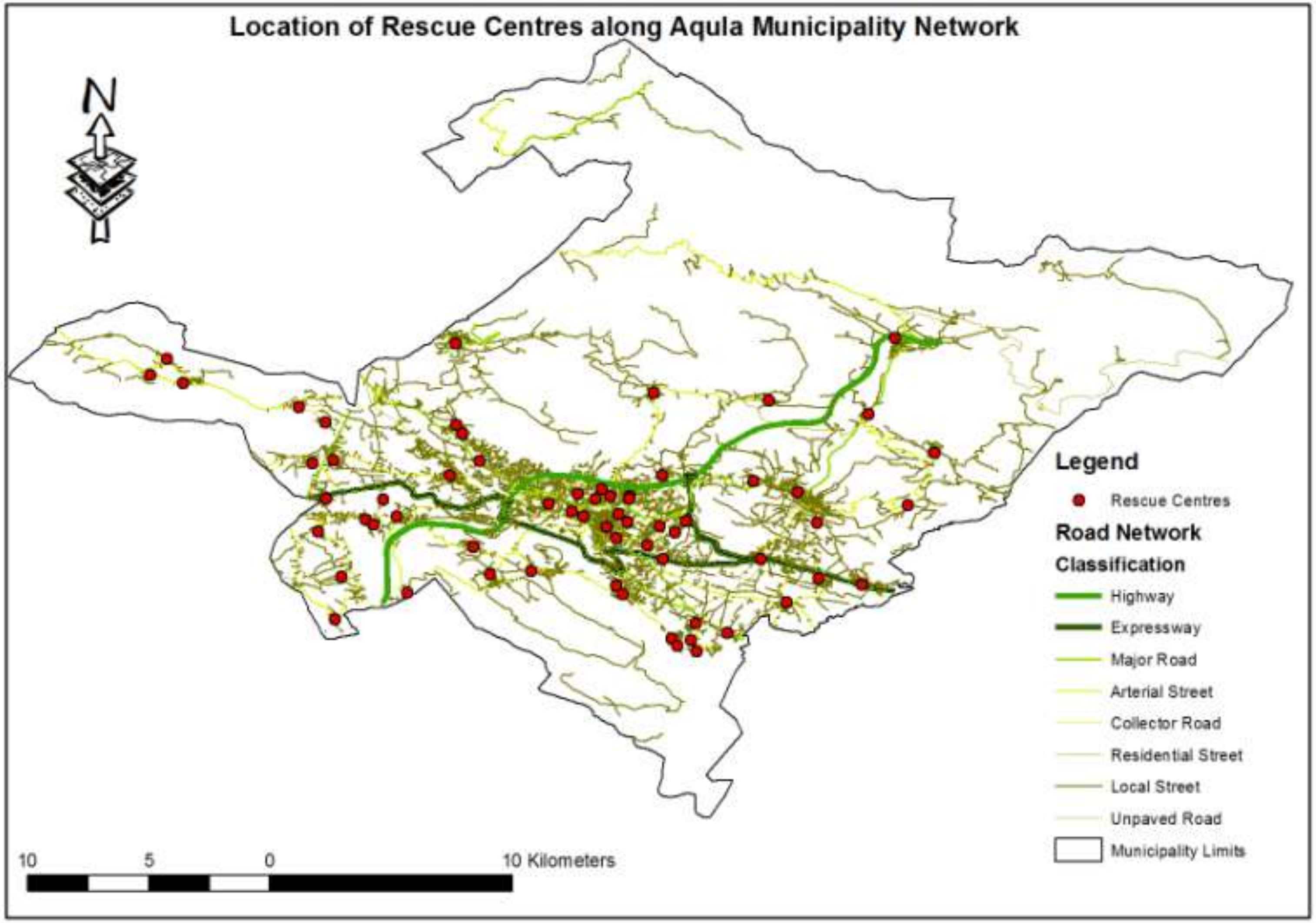


Figure 0-7 Rescue Centres along L'Aquila Municipality Network