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ROAD NETWORK VULNERABILITY ASSESSMENT:

A CASE STUDY OF ROUTING ANALYSIS IN CIVIL PROTECTION RESCUE SERVICE IN TEHRAN

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... in the specific case of the road network, a definition of vulnerability that is of a more general nature is suggested. Vulnerability in the road transportation system is a susceptibility to incident that can result in considerable reduction in road network serviceability ... (Berdica, 2002)

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Abstract

The reliability and vulnerability of road transportation network as a critical infrastructure is gaining lots of attention these days. The concept of the vulnerability requires discussing lots of relevant definitions and neighboring terms, especially reliability as a complement of vulnerability and its concept as feasible theoretical approach. Vulnerability assessment problem is to find how to describe road network vulnerability and how to model and assess the consequences of a degradable network, where the impact is studied for different views. The study reveals who care about reliability and vulnerability analysis of road transportation network and in which point of view each stakeholder approach to the problem.

In addition, road transportation network of Tehran is considered for routing process during an emergency for civil protections. Thereby, in order to find important factors some questioners are designed. Regarding analytic hierarchy process main criterion and alternatives leads to develop finalize factors and via TransCad software and Dijkstra algorithm routing process has been done.

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1 Introduction

Today societies are changed to modern one, which stays over the various systems and establishment known as infrastructure in order to approach to comfort and security for the people. All these systems are characterized in supply side and have different important respect to others; some of them are more fundamental and have more complexity than others. These systems can mention as water supply, power supply, telecommunication and – the goal of this study – the most important one which is known as transportation network.

Clearly, the welfare and quiet of society has a direct relation in which these systems are developed and maintained. An unpleasant side happens while a sudden failure or degradation occurs and intense strains impose on the system. The magnitude of these failures will be different, the system (or in our study the member link(s) or node(s)) which the degradation cause the largest negative effect would be more critical and requires more consideration.

The term *vulnerability* is used in order to assess potential degradation of components and their impacts on society or different stakeholders who relates to this issue. As there is no superseded for transport network which has a significant rule on people`s everyday lives, and it shows the importance of this network. Vulnerability assessment is thus the extend to recognize by degraded component what will be happen on functioning of the network and in following on welfare of the society or in a simple word define risk of each element in case of disruption or relevant identified factors. Road network vulnerability assessment consider as a special case of infrastructure networks, where different factors can have a rule on these analysis. Different attitudes, goals, perspective and approaches leads to methodologies to show how can approach to the problem.

This study is divided in two main parts, the first is the way of approaching to term vulnerability, and the second is about routing process for civil protection during an emergency in Tehran.

There are many ways for studying vulnerability, thus there is no unique definition to describe the term. In the first part regarding probable different perspective the issue is studied, where it is represented how to define and approach the term of vulnerability. To reach the goal all required neighboring terms are studied with respect to the study such as *resilience, redundancy, level of performance, serviceability* and the main which is known as *reliability* with its own classification. Risk cannot be eliminated from this kind of study which embraces the term of vulnerability, and combination of probabilities and consequences are surveyed on the topic.

Same as other infrastructures, road transportation network involves with different stakeholders with their own goals. Here for vulnerability analysis and reliability study each stakeholder for approaching this goal see the issue from different perspective. In this thesis we see each stakeholder identify the problem in their own point of view and see why the vulnerability is studying. To solve the problem different methodology with recognized cost factors and important factors will be developed base on the type of vulnerability assessment.

Base on the state of the art and the problem of routing in Tehran, a methodology is developed and applied on Tehran transportation network. As reliability can be considered as a complement of vulnerability, the routing process carried out base of identification important effective factors on the issue. Because here regarding reliability the new definition of vulnerability is discussed as an appropriate serviceability under the functioning condition faced during a given time period.

A mathematical methodology is applied on the Tehran network, considering recognized significant factors and its weighting process. At the end with TransCad which is GIS base software and its routing option the best possible route from rescue centers to damaged point will be calculated for civil protection rescue services.

2   State of the art on Road Network Vulnerability

Vulnerability is the issue which has been attractive topic for all networks researchers, and presented in all systems. Where series of research and analysis are carried out in different majors and fields to avoid any reduction in performance, system`s convenience and recognize capabilities also limitations to withstand in a specific situation. Computer networks, telecommunication and power supply, information security field, Industrial system and electrical power delivery system are such a fields where vulnerability assessment was a substantial task to analyze weaknesses. Apparently in the recent years, vulnerability and reliability analysis became one of the most controversial issues in multifarious infrastructures. Especially in Road networks modernization where it contains a complexity the necessity of vulnerability analysis makes more sense. Road network Vulnerability assessment leads the organizations, traffic planner, rescue teams, civil protection, environmental and government agencies to recognize critical links, measure total cost of interruptions and so on.

Sustainable transport refers to the broad subject of transport that is or approaches being sustainable. Which all trades, users, and industries are trades for sustainable economic growth and transport functioning in long term. To gain the goal it`s not only physical link existence but also capability to host and open to traffic is the matter. However, various incidents and conditions may lead the network impassible or reduce the capacity of traffic system. The inconveniences and congestion effects lead to reduction in level of the service, and in worse cases impossibility of using the link(s), the results cause serious losses in terms of different costs in travel. The cost could be different in different aspects where we are going in detail in following; the point is vulnerability analyzes which can be addressed, as finding out the possibilities and problems of link(s) in different point of view. In this way suitable policies, for each characterization will be done, to avoid malfunctions. The point of interest for analyzing vulnerability of roads network is to find possible consequences of reduced system performance. The most vulnerable link(s) is the one which by disrupting impose the most travel cost to the network or to the specific two nodes as origin-destination.

Basically there is no uniformity for the concept of road network vulnerability it is currently under debate for different scholar and stakeholders. However the key point in the matter is how to describe the vulnerability, and how analyze the consequences of road disruption or any probable inconvenience. In order to develop Vulnerability definition perspective it is necessary to know each stakeholders and scholar in which point of view studying vulnerability, by distinguishing cost factor for each problem and the approach to solve the problem, then distinct definition of vulnerability for each case will be caught it can be seen with different aspects. Generally the entire former researcher agreed that road network vulnerability is accentuate in losses as well as in the matter of searching the relevant results after an abnormal events.

2.1 How to define Vulnerability

Vulnerability in a descriptive point of view is varying depending on the context which is used. Apart general definition to describe vulnerability, it defines in different aspect according to disparate beacons. (Berdica, 2002) was the first one who defined vulnerability in road transportation network as a *susceptibility to incidents that can result in considerable reduction in road network serviceability.* From the very beginning it requires definition to see how the vulnerability is defined.

In fact the term vulnerability related to losses and the results after an abnormal *incident*, to get in the way for defining the vulnerability (Berdica, 2002) explains some terms which has been affected by abnormal situation. These terms could have an effect on function of the system and in final in level of the service of the mentioned system.

2.1.1 Accessibility

It is growing concern on the topic of lifeline systems (like sewage system, energy supply, water supply, communication and transportation systems). Vulnerability is assessed for all the mentioned lifelines separately in case of failure and disruption because of variant hazards like earthquakes, floods and etc. The interesting point was when the networks are analyzed all together and the effects of them decomposed their interdependency. Hopkins. (1991) notes transportation network has key rules between the others and characterized by the most important one, where the amendment of all other lifelines system virtually depends on stakeholders (ie, users or rescue teams and etc) be able to reach and have the *Accessibility* to the site where the damage is occurred, by failure or damage in transport network itself other lifelines are effected indirectly.

In transportation generally, accessibility assigns to the ease of reaching destination. The term "ease" has been discussed by academic and planners to indicate how show the term and measure it.

The measure that usually use for accessibility is;

$$Accessibility_i = \sum_j Opportunities * f(C_{ij})$$ Equation 2-1

Where;

- *i* = index of origin zones
- *j* = index of destination zones
- *f (C_{ij})* = function of generalized travel cost

Accessibility is defined in several ways depending on the context. These include such well known definitions as "the potential of opportunities for interaction" (Hansen, 1959), "the ease with which any land-use activity can be reached from a location using a particular transport system" (Dalvi & Martin, 1976), "the freedom of individuals to decide whether or not to participate in different activities" (Burns, 1979) and "the benefits provided by a transportation/land-use system" (Ben-Akiva & Lerman, 1978).

Alternatively in a regional scale with given typical sparseness of road network and the dispersed population in rural area, it makes more sense and it is more useful to describe antonym term of accessibility which means *remoteness*. It is "measured by the difficulty in accessing services and facilities while using the road network".

The term accessibility also has been seen from two different views, demand and supply side. Where the degree of function of the system represents approaching to the issue from demand side. On the other hand the availability of the link for functioning between two nodes represents approaching to the issue from supply side. The performance of the road network makes more sense to describe as *serviceability*.

It is defined as: The Serviceability of a link/route/road network describes the possibility to use that link/route/road network during a given time period. Vulnerability of the road transportation network is considered not from safety point of view; however it is about problems in reduction of accessibility according to mentioned reasons. By going in detail another approach is represented where in compare with serviceability approach indicates the accessibility more precisely. (Goodwin, 1992) developed the idea of quality margin and discussed that is meeting as a significant part of transport policy, he believe in networks should deliberately preserve a degree of reserve or space capacity in the systems, as a principle condition to improve quality of movement. He notes "the basic ability of a system to deliver you from where you are, to where you want to be, at the time you want to travel, at a cost that makes the journey worthwhile".

2.1.2   Incident

There are some events where in the case of vulnerability in the road transportation networks make the disturbances in traffic flows; it can be some sudden or unpredictable incidents and also everyday minor one. It is interesting to recognize and classify these events, where by identifying the significant potential cause of closure studies will be held more precise.

The characterization for road network systems can be dividing in structure-related, nature-related and traffic related;

- ➢ **Structure related;** it depends on the construction of the path, and the road network characteristic itself, not only in terms of connectivity and topological aspect but also in terms of the physical body of the path. (Like Geometry, curvature, width, bridges, tunnels, etc.)
- ➢ **Nature related;** it depends on characteristics of the natural environment, topography and terrain that the road passes over there, and also nature given incidents like flash floods, rockfall, snow and ice, earthquakes, landslides, tsunami, climate changes.
- ➢ **Traffic related;** it depend on characteristics of flow decrements and the generic flow of traffic, like daily rush hour, maintaining procedure, accident clear-up, sport events and ongoing construction works.

But also sabotage and acts of war and terrorist can be added to this classification. Vulnerability assessment should take in to account each characteristic separately and, at the same time as a whole.

Incident is an event, which directly or indirectly may result in considerable reduction or interruption in the serviceability of a given link/route/road/network. The task here is also possible to see in terms of demand and supply side, the incident leads to reduction in capacity and increment in demand.

2.1.3 Risk potential lead to loss

Generally risk is defined as a potential that a chosen action or activity (including the choice of inaction) will lead to a loss (as an unpleasant outcome). Risk definition is also need attention from an expert on the subject; however it is mostly in common in two terms of probability and consequences. (1) a probability or threat of damage, loss or any other negative incident, (2) how the incident is extended and the consequences of the it. Perception of risk can be different for different views in various ways, risk analysis in some ways to aim improving methods for eliciting opinions about risk, providing a basis for understanding and anticipating public responses to hazards. There is no consensus on the way of measurements the affect component of risk, but regardless of the model the result should be in common.

(Nicholson & Dalziell, 2003)notes that Risk and Vulnerability unified which the consequence of negative event can be considered commonly with the impact of the event. Actually it notes that vulnerability analysis apply a scheme for following analysis of risk assessment in the transportation network. In view of (Einarsson & Rausand, 1998) consequences is explained as costs, the Risk related to the negative event *X*, is represented by *R(X)* and it is the combination of probability of the negative event *Pr(X),* and the consequences which is defined as a Cost *C(X).*

$$R(X) = Pr(X).C(X)$$

Equation 2-2

Statistically, the level of the risk can be calculated as a product of the probability that harm occurs multiplied by the severity of the harm. Probability can be from very rare event with low probability like bridge collapsing to every day probable incidents which may lead to reduction in traffic flow like car accidents and the severity can be presented as consequence of the incident.

Figure -2-2, illustrates a Risk matrix as a combination of probability of incident to occur and the effect of consequences. Risk matrixes usually are used for risk assessment to indicate various level of risk, it is more useful for managing decision making.

As it can be seen from the risk matrix, an everyday minor accident (means high probability) is stand in the lower right hand corner, while a low probable incident like bridge collapsing that lead serious resulting (means high severity in consequences) stands on the top left hand side. It is interesting to know the study area of the matrix is the right side of diagonal from top left to bottom right the area with high probability and high consequences.

Figure 2-2-Risk Matrix

The estimation of risk for each hazard contains both probability and the consequence of it occurrence. In the consequence contains the cost of any remedial work (like bridge repair or replacement) and the cost relates to users will be affected respectively. Estimation of probability and consequence is related to the range of hazard which means for each hazard there is a range of possible incident magnitudes. However in some case there is limited availability of historical data in some low probable with significant consequence events (like bridge collapse) to assist the probability of disruption, and also uncertainty in such a case like closure duration by maintenance staff make the probability estimation uncertain. Although the particular characteristic of the hazard event affect it. The task of vulnerability analyzes in case of risk assessment have series of factors which can be consider as a whole separate topic while we pass it up here and we do not go in detail on it. Although in general after identifying the hazard risk

assessment will carry on to find if the risk is acceptable or not. If the risk levels are concerned too high the process for reduction and mitigation will be considered. It would be different in each case and relates to vulnerability analyzes; it could be retrofitting process or Installing a road weather information system and etc.

2.2 Vulnerability and it`s relevant terms

In this section, the different definitions and relative terms for approaching to vulnerability are analyzed. Thereby, analyses are carried out on the field of transport as a significant infrastructure but also regarding transport and social science.

As usually vulnerability analyzes are studying with respect to infrastructure management and risk engineering; therefore a framework and terminology is developing regarding to compatibility with these fields.

2.2.1 Terminology in the field of disaster management

Regarding to previous studies the concept of vulnerability in this point of view concluded of the social science and defined conceptually in replication to the hazard-oriented perception of disaster risk management in the 1970s (Schneiderbauer & Ehrlich, 2004). The comprehensive review of (Birkmann, 2006)reveals that no common definition of the term vulnerability has emerged so far, but different concepts are widespread. The disaster risk terminology (Davidson, 1997)views hazard, exposure, vulnerability, coping capacity and measures \as separate features. Naturally, the field of disaster management needs to follow universal approaches when defining hazards, risk and vulnerability as the range of application is broad and involves (Earth, 2011).

2.2.2 Terminology in transport state

Regarding to transport perspective, the term vulnerability similar to disaster management terminology, is used in various ways. (jenelius, 2010) differentiates between the technological and societal side of an infrastructures system. For the first one, the impact of failure of a given infrastructure component is defined as the component`s *importance,* where by combining with probability, *criticality* defines as the result. For the second side, the equivalent of importance is called *exposure*, with considering the failure impact to an individual user. However by combing with probability of failure it derives vulnerability definition.

In (Taylor & D`Este, 2003), (Taylor & Somenahalli, Application of Accessibility Based Methods for Vulnerability Analysis of Strategic Road Network, 2006), (Taylor, 2000)and Taylor (2008) the probability of failure occurrence is not considered when indicating vulnerability. It is discussed that the measurement of happening probability and the resulting consequences is obscure for many types of accident. Therefore, regardless of failure probability, the term vulnerability is used to describe the accessibility drop for individual communities caused by a link failure

In literature it is possible to find several definitions for vulnerability that derives from Latin word *vulnus*, injury. One among them defines vulnerability as "how prone is a system to be damaged in a given stress". In a part of studies it has been seen the complementary concept of the vulnerability is *resilience,*

(Gunderson & S.Holling, 2002)defined resilience as "the capacity of a system to experience disturbance and still maintain its ongoing function and controls".

2.2.3 Vulnerability

In general vulnerability refers to the inability to withstand the effects of an adversary environment, by considering interaction among the units and aware of external influences; however it includes large variety of definitions, depending on the topic of focus. The term has been defined as different measures which derive from the aspect that is under study; it can be accessibility between different nodes in the network, travel time as a cost factor or other factors that we are going in detail in following characterizations. The study of vulnerability which represents as a significant task in lifeline engineering indicates discussions and analyzes to identify weaknesses of a system. The weaker link means by disruption on that, with the same level of attack the most critical loss will be faced on the network. It is clear by knowledge of inabilities in a logical way strengthening of the system will be done, with recovery ability consideration of the network. Vulnerability analyzes is one of the main task in road transportation networks, where it is considered as a principal for construction, planning and management.

There are many ways to describe the term vulnerability and it has been defined for different cases with its own perspective. (Laurentius, 1994)describes vulnerability as "susceptibility for rare, though big, risks, while the victims can hardly change the course of events and contribute little or nothing to recovery". As it derives from this definition, concentration is just focused on the catastrophic event. In vulnerability analyzes for road networks this definition is quite narrow, it means in this case deviation from the normal situation after abnormal or sudden occurrence without previous alert and predictable probability will be concern. In previous definition "rare and though big risk" represents low probability with high consequence which in road transportation, bridge collapsing can be consider as its example. It is mentioned this is narrow definition because the event should not be downright big, tough and unpredictable; in road transport even planned event like maintaining procedure may lead to drastic disturbances. According to discussed terms and with the base of vulnerability definition, (Berdica, 2002)defined Vulnerability in road transportation system as "*susceptibility to incidents that can result in considerable reductions in road network serviceability".* As it is clear emphasize here is not on catastrophic incident it could be predictable or unpredictable incident which has been caused voluntarily or involuntarily, by man or nature. (Berdica, 1998) presented vulnerability analyzes and sensitivity of road links for the Stockholm region, different scenarios in different groups applied on the network to analyze the effects in terms of changes in average travel time, trip length etc. The studies conclude with a methodology discussion around possible reasons for the sometimes lower than expected resulting effects. Comparisons and analyzes of studied scenarios indicated even predictable or planned inconvenience may lead to significant disturbance and base to (Laurentius, 1994)definition for vulnerability, the task was modified.

(Berdica, Analysing vulnerability in the Road Transportation system, 2000) notes by reducing vulnerability can thus be looked up as reduction in the involved risks, by making the mentioned terms in above; it can be seen as successive definition which is presented by the wheel of concept.

Figure 2-3-sequential definition of vulnerability in the road transportation network

It reveals that the first response is critical because failure to effectively service the network may lead to even more serious deterioration. The concept comes from (Abrahamsson, 1997) which notes small incident in a critical place, time and situation may lead a significant failure even in the whole network.

(Berdica K. , 2002)) is not the only person, who describes vulnerability in the road transportation networks; (D`Este & Taylor, 2003) relate vulnerability to the degree of accessibility of a given node in the network, where the accessibility is expressed as the travel cost needed to access the particular node, comparing optimal and alternative routes or detours. They define vulnerability to be likelihood of severe adverse consequences if a small number of links (or probably even one link) is degraded. Compare to previous definition which has been defined by (Berdica K. , 2002)accessibility is specified as a cost factor and they distinguished between *connectivity vulnerability* and *access vulnerability.*

Connectivity vulnerability is considered for a pair of nodes and the distributed travel cost which has been defined between them. Vulnerability between chosen nodes is defined when abnormal event, loss, disruption or degradation of a link(s) may lead a significant loss that affect on travel cost; in this case the link between them is introduced as a vulnerable one. However focus in access vulnerability is limited to a node, means all quality of access from the mentioned node to other nodes of the network. Substantial degradation due to any incident that lead to significant reduction in the accessibility of the node defines vulnerable node; vulnerability can be measured here as an index of accessibility. To derive the differences between two recent vulnerability definition, it is clear that the former has more focus on the consequences of degradation however (Berdica K. , 2002) considered mostly probability of the incident.

2.2.4   Robustness
In general there are so many other terms which are impressible or parallel to the term vulnerability, however specifically in the task of vulnerability in road networks may not be relevant. *Reliability* is the first and the most important term which is in common to approach to the problem, it debates in matter later.

The second term as a neighboring tasks around vulnerability is *Robustness,* it is derived from the word "strength" and in the case of systems analyzes it is defined as the ability of a [system] to resist change without adapting its initial stable configuration. It can refer to different topics; however robustness is studied more in computer science as the ability of a computer system to cope with errors during execution, and is a consideration in failure assessment analysis. From the definitions in case of road transportation networks; vulnerability analysis are carrying on to reach to the *robust* network. As it is clear robustness is stand on opposite of vulnerability, the objective of these analysis is to indicate the importance to improve the robustness of the road network. The methods and approaches derived from studies answer question, what is the importance of robustness for the road network? Researches and comparison between road transportation networks and other networks represent which elements are likely to make a network robust. Apparently robustness and vulnerability have a strong relation, but they are actually each other`s opposites. In a simple word vulnerability describes weaknesses of the network vice versa robustness represents a strength of the network. According to these consideration about the general definition for robust network, with a attention on performance of a whole network with the whole probable disturbance on link(s), node(s), and routes that may lead to sectional degradation of the link(s, node(s) or even loss of the whole network operation; *Robustness is the extent to which, under pre-specified circumstances, a network is able maintain the function for which it was originally designed.* (Snelder, van Zuylen, & Immers, 2012). It is clear from the "function" in road network it expects enable to have a trips from origin to destination. The level of this functioning is usually specified by a government organization and relates to standards parameters.

In the case to measure robustness the issue is same as vulnerability and we need to define some indicators; it is important to consider the indicator should describe all elements robustness, it is clear it should be considered if the indicator can be estimated inside a computer model within an acceptable computation time. It can be static indicator, graph theoretical measurement or other direct and indirect dynamic indicators.

2.2.5   Resilience

Resilience in dictionary is defined as an ability to become strong or successful again after a difficult situation or event. Specifically it is a controversial issue in ecology and is defined as a capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering quickly. It is also generalized in the field of road transportation and it is considered as ability for going back to normality after any disruption. Studies are carried out to determine the level of resilience of roads and key influence that impact on it, loss of access for emergency services and need for lifeline restoration. But also the task to find level of resilience has a key role in risk management, and by achieving a level of performance it would enable the response and recovery after the events. (Buckle, 2005)represents resilience as a function of vulnerability and rate of recovery.

$$\textit{Resilience = f (Vulnerability, rate of recovery)}$$

<div align="right">Equation 2-3</div>

To illustrate the issue in a conceptual way, below illustration reveals the relation of resilience and vulnerability with respect to performance of the network. Where performance of the network is critical issue and relates to loss of quality of access (service) and outage (period of loss of quality of access).

Figure 2-4-Resilience definition

The illustration shows resilience for a link as a combination of its low vulnerability to disruption or degradation in an incident and the short time within which can the network back to normality after the hazard. (Brabhaharan, Wiles, & Frietag, 2006)

The term performance or expected level of service is related to many factors of using the road links, as performance state (resilience state) is an important issue in this part. Here some considering points to determine the level of performance is mentioned;

- Users safety and others
- Accessibility for emergency services
- Restoration of other lifelines dependent on access
- Alternative paths in the case of closure
- Accessibility to reinstate after the event
- Recovery and restoration of mobility to back to normality in case of socio-economic aspect

The interesting point in our consideration is the relation of resilience with vulnerability as our main goal, it can be noticed as an analyzing issue to enhance the resilience of network; where by reduction in vulnerability, performance enhancement will be achieved.

2.2.6   Redundancy

Another neighbouring term which is regarded as related to the general topic of vulnerability and can be generalized in our specific case vulnerability is called *redundancy*. In dictionary it defines when something is not use because something or the same already exists, however it has not been seen like

this way in science fields; it is considered as an alternative way to survive and continue functioning of a system even when part of it fails.

In engineering, *redundancy is the duplication of critical components of function of a system with the intention of increasing reliability of the system, usually in the case of a backup or fail-safe.* The concept distributed to the field of transport while it content to the road network as alternative route that can continue functioning of the system and provide service in a supply side even if degradation or disruption occur in a link or part of the network. In particular it means the transport network should supply and render service by facilitating evacuation, emergency services, and acceptable traffic flow even in the incident of extreme condition. In the simple word it is considered the importance of road links as backup alternative in the case of failure in other links of the network.

The studies on redundancy aspect require a consideration on alternative route; while the disruption happened, the new route would be superseded. The replaced road can be noticed as an important alternative rout when many users are able to use the link as a part of an alternative route when the main usual link is closed due to any disturbance. In this way the mentioned link contains important redundancy to the transport system, and it is regarded as *redundancy importance.* The interesting point is the link importance of alternative route is considered as a typical route with small flow under normal circumstance, however on the other hand it can be used for heavy flow and should host extraordinary situation when the link is selected as an alternative; while the link importance should analyze in former situation as well.

To measure and also introducing concept of importance redundancy in this case, from former studies and parallel with traditional flow-based and impact-based; (Jenelius, 2010)notes two corresponding measures of redundancy importance. "Flow-based redundancy importance is defined as the net flow that is redirected to the considered link when some other link is closed, using a weighted sum across all other links as a summarized over all other links".

Apparently redundancy studies can be considered as a main factor in the field of vulnerability assessment in a road network, while when propagation of traffic is routinely divided among all possible routes in everyday use and normal circumstances, the redundancy is active. Ferry service activation after a bridge collapse and disability of using the bridge is an example of passive redundancy (ie, potential to activate another service after the failure).

To indicate the task more clear (Jenelius, 2010)considered a small road network as an example; it is assumed all links host travel with the same speed and the way that user chose the link between origin to destination is the fastest route. It is clear traveler between A-B normally chose the (a, d) route; the firs assumption is when link *a* is closed. As for there is no effect of congestion on other links after the closure (as simplicity) it is logical the alternative route would be (c, f, e) while it is the shortest path and most users will switch (after some equilibrium perhaps) to the alternative route. It has been seen the flow between two nodes A and B is redirected to the links c, f and e, which host the traffic as an alternative for the link a. The situation would be equivalent when the link d is closed; therefore the route c, f and e are considered as an alternative route for both cases. Therefore these three alternative

links are flow-base redundancy importance with respect to both *a* and *d*. Apparently there is no other pair of nodes as Origin/Destination that may affect by closure of these two links *a* and *d*.

Figure 2-5-representing redundancy

The worst case with a significant impact would be happened when link *c* is closed along with *a*, in this case there is no other available route as it has been shown in this part of the network. On the other hand along closure of link *a*, while link *f* or e is closed there is another alternative route which has sever less impact than former case; for the discussed Origin/Destination the alternative route is rerouted to *c*, *b* and *d*.

2.2.7   Reliability

Reliability is not a new concept, however not in engineering aspect, however it is considered as goal of interest because of demand increment for robust network until to host emergency services but also just in time services. It is defined in general and in a systemic definition; means while a system able to keep functioning and performing in routine or even unexpected circumstances. In system engineering (Bell & Iida, 1997)reliability as the degree of stability of the quality of service which a system normally offers, specifically in transportation systems the degree of stability is strongly related to ability of the network to provide normal functioning of the system (expected service) under a degradation or any other failure(i.e. fluctuation of a network could be physical or traffic).

There is one common definition where it is acceptable for all engineering fields generally; (Ebeling, 1997)notes reliability as "the probability that a component or system will perform a required function for a given period of time when used under stated operation condition. It is the probability of a non-failure over time." In the road transportation network it refers to successful travelling from origin to destination. Although the concept has been developed with respect to different approaches and related aspects; where it can be divided in different categories.

In road transportation system vulnerability has not been measured directly mostly, and reliability analyzes leads to approach to the vulnerability assessment. Although reliability analysis are more focused on probabilities, however in the vulnerability assessment consequences are also are considered as a goal as well. Literature on reliability is a vast issue, as it has been studied upon statistics and

probability theory, the statement probability and therefore reliability is enough to explain that measured from deductive reasoning based on statistic.

The definition of road network vulnerability has not been commonly accepted yet (J, 2004) (Husdal, 2005) notes that it is not easy to consider vulnerability issue as the opposite notion of reliability i.e. how the network reliability is bigger the vulnerability of that means less. However reliability is the complement to vulnerability and describes adequate serviceability under the operating conditions encountered at a given time.

(Wakabayashi & Iida, 1992) note the most accepted definition for the network reliability; reliability is probability of a road network performing its proposed service level adequately for the period of time intended under the operating encountered. The point is in former studies consequences in reliability analysis was not totally exclude from the field, however consequences is considered as a level of performance here. The probability of functioning of transport network in a predefined level of serviceability leads to the term reliability. As it is defined different serviceability indicates to approach to the task in different perspective; where different reliability measures derive from these distinct indicators. One of the measures which has been seen as one of the earliest as well is reliability of connectivity or terminal reliability, where is defined as a probability to reach to a given destination at all; it means the network nodes remain connected. (Wakabayashi & Iida, 1992), (Bell & Iida, 1997)indicated connectivity reliability as the probability of the presence (or the lack) of connection between a given two nodes as an Origin-Destination pair. Afterward studies emended by (Yang & Tang, 2000)and (Chen, Transport Research Board 79th Annual Meeting)and travel time reliability introduced. The new measure notes the probability of a trip which can be finished within a determined time interval given daily random travel time variation, the index contains coefficient of variation of travel time (Asakura & Kashiwadani, 1991). On the supply point of view the third measure introduced by (Chen, Yang, & Tang, Capacity related reliability for transportation networks, 1999)where is concerned with the probability that a network can accommodate a certain level demand at a given level of service, it is called capacity reliability. The former studies on the topic of reliability mostly related to the urban network reliability which leading to connectivity reliability, travel time reliability and finally capacity reliability, and as mentioned before there was a lack of consideration on consequence assessment of network failure. In the case of road network degradation as a result of the negative consequences in rural area road networks, vulnerability consideration should apply to compensate the deficiency.

2.2.7.1   Travel time reliability
The quality of transportation network depends on different factors which are various in terms of the importance of transport for other stakeholders or users. One of these valued aspects is reliability of the network for business point of view; however it would come by safety and regularity all together. The other aspects which are in common for all participants are time and cost, which can be as a main factors in transportation development. Besides terms of maintaining, contingency planning and such a traffic management issues, prioritization is carried out respect to *Vulnerability Index* attached to links and nodes.

It is well known that large number of people trying to reach their destination at the same time, even during peak hours. It is an important issue that travelers want travel time reliability in order to do all daily activities on time; like going to work, doctor appointment, picking up the kids and so on. Generally users are more tolerant with everyday congestion rather than unexpected delays where it has larger consequences than the former.

Figure 2-6-Travel time reliability representation

Travelers remember bad congested days during a year where the annual average travel time does not indicate this matter. The graph above at the left side reveals how traffic conditions have been communicated where the right one illustrates what travelers experience; while the specified picks are represents what travelers remember during a year as a congested and big delay days. The first step to enhance travel time reliability is the way to measure it, where simple average is not a good idea and commuter`s experience would be the better choice.

From the definition of reliability where was probability of a non-failure and functioning system over time, (Ebeling, 1997) further clarifies the definition specifically by preparing unequivocal and with evident explanation of failure, but also with unit of time where each failure evaluated. It became an acceptable definition in the field of transportation, although several other definitions have been developed by it. The concept was developed by (Asakura & Kashiwadani, 1991) which notes in travel time reliability the fact of travel needs of the road network and traveler behavior should be considered as a main issue.

(Booz & Hamilton, 1998)defined reliability as the level of variability between the expected travel time and the actual travel time experience, while expected travel time derives from scheduled or average travel time and actual travel time includes as a part of the effects of non-recurrent congestion. The level of mentioned variability is not well defined; it means the level which the variability will be considered as a reliable one is not clear, no definition for the failure. However for the facilities which have been stock and congested for a long period of time, the expected travel time would be a high time; in this case the difference between expected travel time and the actual travel time would be small and the facility will be considered as a "reliable", when it is surely congested.

(Tuner, 1962)in study of reliability measure in transportation system performance defined travel time reliability as the range of travel times and, similarly to the previous definition, does not define when "failure" has occurred.

(Immers, 2004)represents the reliability of travel time as a certainty of travel time which has been estimated by traveler. The degree of uncertainty is related to variation in traffic demand and supply; the variation may contain series of expected or unexpected situation. Where as an everyday occurrences it can mention rush hour or bad weather in expected situation category or as an unexpected situation like minor accidents. On the other hand some exceptional conditions may lead to inconvenience in traffic demand and supply, like public event (expected) and calamities (unexpected).

The point is the realization of travel time may be changeable for different travelers, it means it is a characterization between objective and subjective in travel time. In a simple word, the knowledge of travelers or users has a significant role in the consequences of a system failure. A main task in reliability analysis is how to measure it. (Hilbers & Snellen, 2004)characterized three main groups of indices for this measurement. The first group contains measures respect to conversion in experienced travel time, the second group considers delays in travel time at the first beginning of the departure and the last one probable delay should not be more than acceptable delay it means this measure is about the probability to reach the destination on time.

Below flow chart schematically reveals the important factors influencing on the reliability of travel time, it is derived from (Immers, 2004)studies on robustness and resilience of road network structures;

Figure 2-7-Travel time Reliability

In this case there are different approaches with different points of view, where (Florida, 2000)developed the method as the Florida reliability method that studies were on a highway segment as the percent of travel that takes no longer than the expected travel time plus a certain acceptable additional time, components are defined as it defines below;

Table 2-1-Florida reliability method components

Component	Description
Travel time	time takes by traveler from origin to the end of corridor
Expected travel time	average travel time across corridor during the time period being analyzed
acceptable additional time	the amount of additional time, beyond the expected travel time, that traveler would find acceptable during a travel

The discussed acceptable travel time can be represented mathematically as it reveals below;

Acceptable TT = x̄ + Δ

Where;

x̄: The median travel time

Δ: Acceptable additional time, expressed as a percentage of median travel time

Reliability an variability are the issues where authors focused on them from different point of view, but commonly reliability noted as the level of consistency in transportation service and vice versa variability is considered as amount of inconsistency on operating condition.

Table 2-2- Reliability and Variability in travel time reliability issue

Travel time Reliability		
Concept	Characteristic	Requirement
Reliability	Probability of non failure over time	quantitative definition of the failure
Variability	Based on traveler perspective	measure of central tendency and dispersion

The first type of definition from the above table represents approach for tracking the performance of a facility over time, and it is dependent to congestion of the road. The way to describe the failure is based on fixed value and therefore agencies can use the outcomes to derive performance monitoring.

In the second definition the reliability is defined as an unpredictability of travel time, this type would be more useful for travelers , as help them to indicate expected travel time and it`s variability. The definition is based on mode of travel time, which may be changeable over time; so there it would not useful for performance monitoring of agencies.

The topic of travel time reliability is an interesting field of study, while there is developing issue in case of knowledge of the importance of travel time reliability, specifically for industries and travelers where the delivery date for their goods needs definite travel time; so it can be considered as a measure of service quality for users. The concept was developed by (Bell & Schmocker, Estimating the terminal reliability of degradable transport networks, 2001)to the travel cost reliability, containing travel time, travel distance, vehicle charges, and public transport costs; if the whole cost for a trip is less than a defined threshold value, the related path will be considered to be reliable.

2.2.7.2   Connectivity (terminal) Reliability

Series of incidents could be cause of disruption in link(s) in road network, from regular accidents, weather conditions or maintenance process to hazardous events like earthquake, floods, landslides or etc may be cause of the disruption. These series of researches are focused on the way that the geographical disparities depend on the road network structure and travel pattern.

According to relation between network structure and vulnerability/reliability has been studied long time ago, Baran(1964) studies represents which distributed, mesh like networks which have more robustness in compare to centralized, hub and spoke networks in case of random failures in link(s) or node(s). The below illustration reveals the scheme of these types of network;

Figure 2-8- Distributed, centralized, hub and spoke Network

Terminal reliability study the probability that if the transport system can host a very basic function, between each nodes pair there is a functional path and it considers successful in case of connectivity, i.e. to provide a path between two nodes as an origin to destination, where the cost of travel is not considered. It is the basement of reliability of transportation. To specify this measure, the functioning probability is dedicated for each link, which shows how often the link will function at any time. The probability will be 1 if the link always functions and 0 otherwise; however the definition can be limited by considering the level of service for functioning; which will be mentioned in following.

Generally, reliability in transport networks represents the network which is able to continue functioning for a given transport operation notwithstanding effects of network malfunctions in a specified time an environment. Increment in complexity of recent transport networks made it difficult to simulate and analyze the network with the former methods. Reliability theory based on time domain has been applied to analyze and solve the problem. However in some cases reliability analyzes based on time-

domain is not efficient to assess reliability functions in case of degradation or any failure. Developed methodology contains analyzes like frequency domain reliability which has ability to capture higher order moments of system characteristic. (Mine & Kawai, 1982)were the first one who proposed connectivity, which reveals probability to maintain connectivity between nodes in transport networks.

Apparently a high reliable road network would be the interesting point in both normal and abnormal periods; studies are carried out to identify the most crucial and important link in the network in order to improve the link and subsequently improve the network reliability. In addition to calculate the connectivity reliability of road network is derived by combination of path sets and cut sets, as an example while a path set includes several links therefore the reliability of the path is a combination of link reliability. So that the connectivity reliability improvement needs to identify the key link in the path or network. Thus, the second step would be defining and proposing some indices such as reliability importance and criticality importance. However it does not mean the mentioned indices are completely sufficient to find the key link, but also they have some shortages. In addition, cost benefit analysis also can represent as a significant task where it spends to repair the traffic system in order to improve the network reliability. (Iida & Wakabayashi, 1989) defined terminal reliability of a highway network as the probability that two given nodes over the network are connected with a certain service level of traffic for a given time period. In a same way it can be defined for link reliability as the probability that the traffic has a certain level of service for a given time period. In the following terminal reliability R, is defined as the below equation by using minimal path sets:

$$R(r) = E[1 - \prod_{S=1}^{p}(1 - \prod_{a \in P_s} X_a)]$$

2

Where;

$P_s = S_{th}$ minimal-path set

p = total number of minima-path sets

The method is called as the Boolean absorption method by (Wakabayashi & Iida, 1992). Here, X_a represents binary indicator variable for link a as it reveals below;

$X_a =$ { **1, if link a provides certain LoS of traffic system,**

0, otherwise

Then the link reliability is;

$$R_a = E[X_a]$$

2

The network structure and the link reliabilities are two factor that the terminal reliability of a traffic network relates to them. They are two fundamental approaches that are using to improve network reliability. The study is on the key link which should be identified and should be improved in order to maximize the reliability improvement of the network.

The link reliability determination relates to performance indicator which has been used; basically, link reliability is the probability of link condition (represented by any performance indicator) that better than a defined level in a given period of time. In order to determine connectivity reliability, it is necessary to know the minimum number of links needed to disconnect and/or minimum number of links needed to connect a pair of nodes (i.e. minimal cut set and minimal path respectively).

However domestic researches are focused on the topic of travel time reliability and connectivity reliability from different perspectives. As an example the definition of urban road network connectivity reliability in complex network is derived as the ability for urban road network to maintain connectivity state, after being attacked in different ways and the network suffering from certain level of destruction.

To sum up it can be seen, what it is in common and could not be eliminated from the definition is the necessity of relating ability to reach from origin to destination.

2.2.7.3   Capacity reliability

Most of the reliability studies are related to travel time reliability and connectivity reliability which has been mentioned before, however it may not be adequate and plenary for mentioned measurement of road network performance. Where (Chen, Yang, & Tang, Capacity related reliability for transportation networks, 1999) introduced capacity reliability as a new network index. It defines the probability of network which can host the definite traffic demand on the desired level of the service, however it contains the mentioned connectivity reliability and travel time reliability. It was like a transform from studies with physical and structural perspective to the loading traffic flow. Where common influence between capacity of the road network and travel demand are considered as well. In the beginning this new performance index represented by (Chen, Yang, & Tang, Capacity related reliability for transportation networks, 1999) as a probability that the network can host a definite traffic demand at a defined level of service, while accounting for drivers` route choice behavior. Previous reliability indexes are considered in capacity reliability as a main and special case and also side product, where connectivity is the special one and travel time reliability as a side product.

Capacity reliability studies are carried out to enhance reliability of a road network from different perspective like; efficient flow control, capacity expansion, and other relevant works. The studies have potential to create a tool for designing road network with respect to avoid disturbances in traffic flow. To analyze capacity reliability of a road network, authors will be faced such a problems; the one that can be considered, is the maximum attainable flow that a network can carry. It is like a main core for capacity reliability determination. From the graph theory consider $G\ (N, A)$, where N is set of nodes and A is set of links. W is subset of links i.e. roadways which determines pair of nodes from origin to destination. For each link (roadway) a certain capacity is introduced (C_a) and the maximum capacity of the network is determined by µ as the value of output. It derives from capacity of all the links;

$$\mu = g(c_1, c_2, \dots , c_a)$$

The function g is directly related to the scheme of the network, where the links between OD pairs were series of parallel the function would be closed and the maximum capacity will be derived; however by complexity in network the function would not be exist analytically anymore and needs optimization procedure. On the other hand others factors make the measurement of capacity reliability dependent as (Yang & Bell, Models and algorithm for road network design: a review and some new developments, 1998)) notes capacity of road network depends not only on the links capacity, but also on demand level, congestion effect, and route choice. Although in analyses simplification for capacity measurement, by omission the driver distinction of choosing paths; the mentioned factors is not considered. After the studies on capacity reliability a new approach presented by (Webster & Cobbe, 1966)to analyze a simple, isolated signal-controlled intersection, and called it reserve capacity. Furthermore the concept generalized based on request and field of study, like capacity of priority junctions and roundabouts, or for complex system and also developed approach for a general signal-controlled road network under route choice model and etc. It is in common as the largest multiplier applied to a given existing (or basic) OD demand matrix that can be allocated to a network without violating the link capacity.

In engineering problems the fact of uncertainties are unavoidable. It may derives from physical phenomena that are inherently random or with predictions and estimation of reality based on (Ang & Tang, 1990)study. The former is associated with the inherent variability of the random process that cannot be determined exactly, while the latter is due to the imperfection of the model used to replicate the real world. In transportation network analyses it could occur from the following origins:

1. Variation in link capacities; particularly relevance to maximum network capacity estimation.
2. Variation in travel demands; usually not considered while determining the maximum reserve capacity of the road network.
3. Imperfection of the route choice models.
4. Uncertainties in the parameters of the link travel time function.

Another problem in the field of capacity reliability analyses in road networks is dependency of component states. In most of system reliability analyses, all component states are often considered to be statistically independent, however in a road network, this assumption does not normally obtain. Road way capacities are random in nature with continuous degree of degradation and possible correlation among the components.

Therefore, in a road network, capacity reliability is defined as the probability that the maximum network capacity is greater than or equal to a required demand level when link capacity is subjected to random variation. This definition identifies the probabilistic variation in determining the network capacity but pertains to needed demand as a fixed quantity, as shown below. In this case, as the shaded area in the graph reveals the expectancy that the system is inadequate. To evaluate capacity reliability, the determinate demand level h is incrementally increased to indicate the maximum network capacity, so it implicitly incorporates the maximum attainable demand that can be accommodated into the calculation.

Figure 2-9-Probabilistic capacity and deterministic demand

Let μ_r indicates required demand level. The capacity reliability which can satisfy the mentioned required demand is:

$$R(\mu_r) = P(\mu \geq \mu_r) \qquad\qquad 2$$

It reveals the study network is how reliable with distrusted links can host and accommodate a given level of required demand. It is obvious the system is completely reliable when there is no demand and it would be unreliable when the demand is infinite.

2.2.7.4   Reliability discussion

To sum up, it reveals capacity reliability analyzes is irrelevant for extreme condition analysis such as earthquake compare to daily operation analysis. While in extreme condition connectivity analysis would be the interesting point where it shows if there is at least one route between Origin/Destination pair. However inefficiency of connectivity analyses in defining real time traffic flow authors derives that reliability analyses should not be limited to disaster situation and it needs to extent with perspective of daily operation analysis. Nicholson and Du were from first scholars who proposed from system point of view and travel point of view travel time reliability and capacity reliability. The controversial issue is that many indexes can describe the same reliability. As buffer time, statistical indexes, probabilistic indexes can describe the travel time reliability.

Table 2-3-Travel time reliability indexes

Travel time reliability indexes	
Index	**Characteristic**
Buffer time	time reserved to assure punctuality
Statistical index	suit for information provision rather than theoretical analyses
Probabilistic indexes	probability that travel time satisfy specific condition

Assume C and C_0 indicate network functionality in normal situation and degradable condition, $u(C)$ and $u(C_0)$ represents travel time respectively and ϑ level of service, then travel time reliability could be represented as:

$$\zeta\,(\theta) = P(\frac{u(C)}{u(C0)} {\leq} \theta\,) \qquad\qquad \text{Equation 2-4}$$

The above equation represents the route travel time reliability; although in similar way there is OD travel time reliability and network travel time reliability. As an example the OD travel time can be defined as a mean value of all route travel time, and for network travel time reliability as it mentioned before in definition we have:

$$R\,(\mu_1) = P\,(\mu{\geq}\mu_r) \qquad\qquad \text{Equation 2-5}$$

Where μ_r shows defined level of service.

The below flowchart reveals the relationship of reliability indexes, where based on a basic reliability indexes some high level indexes are presented by Chen. While proposed unblocked reliability indicates possibility for traveler that can travel under specific level of service at road or intersection. The probability that a traveler between defined origin destination pair departing at a certain time interval arrives at destination on time or within time threshold early or late, it represents schedule reliability base on Li and Zhu definition.

The extension of three basic reliability indexes shows advance studies but with the same principle compared with travel time reliability and capacity reliability.

Figure 2-10-Reliability index system

The flowchart below illustrates the interaction between traffic supply and demand before and after incident where analyzed by Nicholson and Du, which leads to below reliability equilibrium analysis framework.

Assume $h(D)$ and $g(C)$ are distribution of traffic demand and supply, the common area which is derived from overlapped of these two graph indicates the congestion result. Because of some difficulty to obtain real data, demand, supply and etc some consideration are carried out to hear some specific distribution. Some distribution functions are fitted using real data. Brilon defined road capacity through traffic demand: traffic is uncongested when supply exceeds demand; otherwise the congestion occurs, which implies the capacity stochastic.

Figure 2-11-Reliability framework

(Nicholson & Du, 1994) distinguished various ways to improve the reliability of network, which there are mentioned as following;

1. Amplifying component reliability (like replacing or reinforcing bridges).
2. Improving the figure of the network (by constructing new links).
3. Preparing alternative and stand-by components to activate after disruption (like bailey bridges).
4. Monitor critical links which to find out the disruption and degradation (to inform for the alternative paths).
5. Regular Maintaining process.
6. Figure out priorities for maintaining critical links which are more susceptible.

2.3   Vulnerability Discussion

Road vulnerability analysis could thereby be regarded as a hub for the whole battery of transport studies needed to gain the insights necessary to describe how well our transport systems work in different respects, what steps to take and what policies to implement in order to reach desired goals. (Berdica K. , 2002)

The most significant problem in vulnerability assessment is to find "How to describe road network vulnerability?" and "How to model and assess the consequences of a disturbance event in a network?" what it is clear from the studies and as it has been discussed in previous part are approaches to reach to the vulnerability assessment, where it can be seen in many aspects. In order to achieve to a comprehensive work it needs to characterize the vulnerability types. In this part we will see how vulnerability is classified in general and it has been developed for the case of road networks. For each type with its own perspective different approaches are presented, by investigating the problem and identifying which approach would be appropriate with the case of study analyzes are developing. In the

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next chapter we will see stakeholders responsibility and who cares about studying vulnerability, then in which point of view they approach to the problem.

Generally vulnerability in scholars is divided as a below types:

- **Physical Vulnerability**

Investigates how much items like population, residential buildings, critical facilities, industries, and lifelines are prone to a dangerous phenomenon. In literatures there are many methods used to assess damages. For direct tangible damages they are explicit, i.e. damages are evaluated directly from physical evidence and the value is given as a loss to individual unit (e.g. buildings, factories, etc.) however, within this category, we can distinguish between:

- Detailed surveys: consists of a field investigation ex-post aimed at quantifying real damages.
- Other assessments ("damage function"): are grounded on historical, pre-existing data, they can be used either in ex-ante or ex-post appraisals.

- **Systemic Vulnerability**

Systemic vulnerability concerns mainly lines facility like power, water, sewerage and communications. They are characterized by three aspects:

1. Interdependency: dependence between two systems
2. Transferability: the possibility to transfer some functions to another system
3. Redundancy: how many options you have to be served by lifelines in a given area.

Considering critical facilities accessibility, a critical point is that the roads to the facilities have to be redundant. The lack of redundancy may result in the complete disutility of critical facilities and so critical facilities may become vulnerable items instead of resources during emergency phase.

- **Organizational and social vulnerability**

How society copes with hazard. Analyzing both population and agencies, vulnerability the assessment looks for:

- Individual vulnerability
- Population preparedness
- Organizations knowledge/preparedness
- Inter-agency vulnerability

After general look on the concept of vulnerability and its characteristic, we are going more in to detail for the specific case of road networks, where different perspectives for distinct goals of studies made

separate types and definitions for vulnerability; while the difference derives for different tasks. The following categories are deduced base on above characteristic of vulnerability but also has a direct dependency to the task of study and introduced cost factors depends on each study case with specific situation.

In road transportation system on the one hand regarding to reliability analyses and its categories which has been described in former parts, and on the other hand based on general studies of vulnerability and also specific case of road networks; the below classification is developed:

Topological Vulnerability

Physical Vulnerability

Functional Vulnerability

Systemic Vulnerability

Although various types of vulnerability according to approaches are exists but they are not completely separate, actually they influence each other.

2.3.1   Topological Vulnerability

The testing analysis to recognize the most vulnerable edge (usually also called arcs or links) may be accomplished regarding to the network theory significantly from topological point of view. The perspective of this aspect of vulnerability analysis will be focused on the term of accessibility in the case of degradable system. This type of vulnerability measure indicates consequences of one or more links failure (it could be base on generalize travel cost).

In a degradable network when a link or series of links are disrupted and they were unavailable anymore (because of any probable incident), the connectivity of the network between different nodes would be expunged. As the topological structure of the network is the fact that represents by the connectivity of the network, therefore studies on vulnerability of the road network topology structure becomes an issue as a type of vulnerability assessment. Same as other types there are different approaches to solve the problem and investigate the vulnerability perspective, where introducing indexes such as vector-formed and also base on graph theory the issue is quantified. The vector-formed index is an useful index to compare different networks so it can be beneficial for planner in road transportation system. The cardinality of vectors represents the number of link sets, that if there is not available it may lead to destroy connectivity between the nodes. Vulnerability has a direct relation with the number, i.e. a greater number indicates more vulnerability in this case. Base on the case of study other indexes can be presented beside the topology vulnerability index, such as applying criticality index. In the same way larger criticality index for a link indicates more critical link, and this identification would be helpful for planners.

Topological properties of a network can be divided in three below definition:

- Geodesic distance: it shows distance between two nodes that with the minimum number of links that have to pass from them between one node as a origin to another node as a destination. (The average geodesic distance between every pair of nodes presented by *I*)
- Clustering coefficient (*C*): to measure to what extend the nodes are forming small, tightly connected groups, which is common.

The clustering coefficient of a node *i* is defined as:

$$C_i = \begin{cases} \frac{Li}{ki^{(ki-1)/2}} & \textit{If ki>1,} \\ \\ 0 & \textit{otherwise,} \end{cases}$$

Equation 2-6

Where *ki* represents the degree (number of neighbours of *i*)

L$_i$ represents number of links between the neighbours of *i*

- Distribution degree P (k): the fraction of nodes with degree k for k=0, 1, 2 …

It has been found to follow power laws, *P(k) α k$^{-γ}$* , for some positive parameter γ usually ranging between 2 and 3.

The term connectivity which is mentioned can presented as an issue of accessibility while we are going in detail for this case in the part of stakeholders attribute in case of vulnerability approaches.

2.3.2 Physical vulnerability

The physical road system parts include of road, bridges, tunnels and etc; the potential for physical impact on the build environment introduce it. However different definition for the concept of physical vulnerability in road networks can limit or enhance the volume of study. While in the context of Lalitpur it is limited just in road system and bridges. It is considered in a structural direct damage where induce because of incident.

An analysis for physical vulnerability assessment requires studies on different effective factors on the elements. It can be from the age of a structure (when the bridge has been build?), material of road surface and its quality, degree of importance (it is also defined as importance index), maintenance attribute and so on. The factors information can be gained from the condition of roads and structure it is based on field observation or sample tests. In addition different approaches can be applied for the assessment as an RADIUS or HAZUS and etc. where the method developed by RADIUS indicates percentage of damage bridges per total bridges and studies are based on the damage curve. It does not consider the characteristic of the structure, and the location of the damage is not identified. However in

HAZUS method the material, design code, shape and other characteristic of structure is identified. On the other hand for physical vulnerability assessment there should be an attempt in case to use the develop assessment tools for different types of structure and different hazards. Where useful parameters are in doubt, unless for specific structures, physical vulnerability approaches can be deduced on the base of statistical processing of damage observation. The most significant issue is to certify the type of physical stress that will be tolerated by the structure (i.e. the stress imposed by flooding is different from soil settlement or landslide). Therefore this type of vulnerability strongly related to the characteristic of the threat.

While studies on road vulnerability assessment is not confined to physical vulnerability while physical destruction as a bridge collapse, will impose on multiple transport system components. As it is expected physical vulnerability can lead to increase injury severity, while the studies on the topic and enhance the weaknesses will reach to prevent road safety problems.

2.3.3   Functional vulnerability

There is wide range of scenarios that can make disturbances in the road transport network. It can affect functioning of the system by traffic itself or other external incident. It measures tendency of a component to suffer loss in functioning. In this perspective of vulnerability assessment the point of interest refers to ability to fulfill its purpose of function. The studies are intended to provide, ranging from a high degree of travel mobility to land access functions. Although it contains less critical consequences, includes inability to get to work on time, usual activities like shopping, pick up and drop off children, and so on. For companies inconveniences relates to delivery time, increase in freight cost, meeting cancelation. The expectation from a reliable road network is to satisfy defined demand; to reach to the goal, reliability analyses of supply side should be considered as well.

The studies are concentrated on any inconvenience in road network functioning, while degradable road network can be lead to increment in travel time (i.e. disturbance in the network induces increase in expected travel time). The study is not limited to one aspect; however capacity decrement is another considerable issue for functional vulnerability analyses. Clearly the studies for functioning vulnerability analyses are same as mentioned approaches such as capacity reliability and travel time reliability tasks.

 Apparently analyses attain to provide support regarding prophylactic and strengthening action.

2.3.4   Systemic vulnerability

The fact is when a link(s) or node(s) is/are attacked the probable losses, will not confined on the link(s) or node(s). In this situation the loss will spread to other parts of the network and road network vulnerability is sum of these losses in whole road network.

Systemic vulnerability notes how the system incline to damage or disturbance as a result of some kind of physical damage which has been happened on one component, but also as a propagation the indirect effect of some physical, functional, or organizational failure endure by it.

The vulnerability analyses faced in the worst case, while it comes from the combined function of road condition, network structure, traffic flow state, rescue center setting, resource scheduling, recovery strategies and etc. The below illustration reveals the formation mechanism of road network vulnerability:

Figure 2-12-Formation mechanism of road network vulnerability

In a disrupted link in case of attack, which could be reason of an accident, traffic officials take measures immediately. However at the same time the imposed loss is transferring and propagating to the other part of networks (i.e. other unit will suffer the loss), the accident may lead on changing traffic flow, the recuing process, even road connectivity and some other probable factors. The vulnerability has been offended by the loss propagation. The process will continue till to back to normality, and this network

inconvenience from the first accident and loss transferring to other units can be defining in this concept. Therefore vulnerability assessment should be measure the total loss of the whole network. (Loss could be referring to decline in road connectivity, traffic efficiency and etc).

Consider X_i as the network loss when link i has been failed, and I as the total number of links; let K be the number of the failure links under the situation and k shows the kth failure link and x_k reveals the loss of the link k. Then,

$$X_i = \sum_{k=1}^{K} xk \ (k= 1, 2, 3 \dots, K, i= 1, 2, 3 \dots, I)$$ **Equation 2-7**

The loss of the link k, has a relationship with upstream link loss and if rescue characteristic is available it also has a relationship with rescue technology of link k, assume that the unit loss transfer one by one, so let consider $k-1$ as the nearest upstream link and R_x shows rescue technology of the link k. Then,

$$x_k = f(x_{k-1}, R_k)$$ **Equation 2-8**

At the end vulnerability of the network could be measure based on the most significant loss of whole network because of the failure of the corresponding road network link.

$$V = max \ X_i \ (i= 1, 2, 3, \dots, I)$$ **Equation 2-9**

What we can get from general definition for vulnerability in different majors is that, it can be proposed as a contextual term which the attitude of the assessment could be different case by case with respect to perspective of study. Not only in general definition for vulnerability, but also in our specific case road transportation network, it can be varied regarding to the study case and introduced indexes. In road transportation network, the task of vulnerability assessment derives based on specific cost factors and the studies are developed considering relevant indexes. Although in complex systems the difficulties in vulnerability measurement induced engineers to simplify some cases and avoid considering all factors together. The fact is in all definitions and approaches everybody looking to enhance the weaknesses by identifying them, the focus is on susceptibility of the network in case of defined incident and the common thing is the reduction in functioning terms.

Here one of the sensible differences between general vulnerability approaches in other science can be compared to the road transportation network vulnerability studies:

<div align="center">**Table 2-4-Vulnerability comparison in road network respect to other science**</div>

Aspect	others	Road Networks
Incident magnitude	In case of catastrophic and significant event	Even predictable or planned event

2.4 Methodological overview of network vulnerability analysis

Necessity and importance of evaluating and assessing network infrastructures for identifying potential vulnerability is discussed and mentioned in previous sectors. Where it is considered as a significant ingredient of strategic planning; both in case of managing and also mitigation services. What it is interesting is how to analyze and evaluate the potential vulnerability. Many methods have been designed in case to simplify such studies. While these methods have a critical role to the road system planning, and requires an explanation of infrastructure vulnerability to conduct such analyzes.

Evaluations and methodologies initially are classified based on the way of approaching to vulnerability assessment as; *Scenario-specific, strategy-specific, simulation* and *mathematical modeling* methodologies. Traditionally mentioned methodologies are used separately without considering of the others; to avoid complexity and simplification on analyzes. However, thereafter studies and investigation reveals that in order to have the most effective contribution in dealing with complexity of the real world, it would be more efficient to go beyond using singular methodology.

In an attempt to decompose the analytical elements that form a multimethodological framework, (Mingers & Brocklesby, 1997) make distinction among *paradigm, methodology,* and *technique.* The nature of perspective of a research is considered and generalized by paradigms. However methodology is a structured set of operating principles that assist in the research process. Methodologies typically embody the philosophical assumption of their paradigm. Techniques are specific research activities that fit within the methodology.

Again, the fundamental value in multimethodology is the ability to provide a spectrum of solutions to planning problems and their interventions by incorporating a diversity of methods and techniques (Jackson & Keys, 1984).

The principal of different approaches are related to the way of defining a disruption scenario; it contains the degree of functionality, imposed critical facility, and operability of the network. (e.g. link/node capacities). In some cases, degradation may lead to a lesser degree of a link(s) where just some of the functionality may be lost, for example an accident which blocks a single lane of an interested link(s). After defining degradable link(s), it means disruption scenario then impact assessment is possible. Impact can be considered as a direct associated with network functions, such as connectivity, flow or capacity reduction, to more complex associations, like economic impacts.

2.4.1 Scenario-specific assessment

Scenario-Specific approaches consider a potential split for a specific scenario or small set of scenarios. This kind of approach can lead you to a particular disruption, where probable conditional situation would be under analysis. In this approach the interest of author will be studied under defined scenario, for example impact of bridge collapse, losing a road segment and etc. Scenario-specific methodologies are probably the most common approach in practice; it is derived from its flexibility of application.

Scenario-specific approaches have been used regarding planning tasks mostly. For instance based on scenario-specific methodology, (Suarez, Anderson, Mahal, & Lakshmanan, 2005)consider the issue of

sea rise and resulting impacts to transportation performance in a coastal area. They define disruption scenarios based on the levels of sea rise anticipated in various planning periods.

2.4.2   Strategy-specific assessment and graph theory

Strategy-specific methodology consider to reach to answer a question that "how vulnerable is a network to structured or coordinated loss of facilities? Such approaches are precisely those of interest in much of the statistical physical research on infrastructure vulnerability. One common methodology is to rank network facilities (arcs/nodes) in order of their importance (usually base on their topological characteristics), then successively remove them, assessing the impact to network operation at each stage. (Albert, Hawoong, & Barabasi, 2000)

The method would be useful to assess the vulnerability of different network configuration to identical attack strategy. Although this method requires some assumption in order to see the way of network losses coordination. For this case relative importance index of network facilities and even different arcs with respect to network functionality are proposed before any analysis are operated. Such assumptions can produce misleading results as many network systems entail a complex mesh of interrelations between network components that are difficult to assimilate by evaluating the characteristics of individual facilities (Doyle, Alderson, Li, & Low, 2005).

G (V, E) is a finite direct graph in which every edge *(u, v) ∈ E* has a non-negative, real-valued capacity *c (u, v)*. If *(u, v) ∉ E*, we assume that *c (u, v) = 0*. It is the definition of graph theory for road networks, which has been used as an useful illustration to reveals connectivity and characteristics of a network.

2.4.3   Simulation assessment

Simulation assessment methodology can be feasible approach, while there is no need on prior assumptions regarding facility/scenario importance to degradable networks. In simulation-based approaches, the goal is to evaluate a suitable number of scenarios to obtain an effective characterization of the range of possible impacts (Matisziw, Murray, & Grubesic, 2007)

 Consider a network with *n* nodes, and the main planning relevancy is complete loss of one of the nodes, then the below equation indicates feasible scenarios exist;

$$\binom{n}{1} = \frac{n!}{(n-1)!}$$

Equation 2-10

In case of considering two points losses, then feasible scenarios change to;

$$\binom{n}{2} = \frac{n!}{2(n-2)!}$$

Equation 2-11

The complexity of this simulation will be happen when partial disruptions to network occur. In addition this methodology may involve characteristic of many other parameters, such as performance index used to measure disruption, probabilistic information and etc. The methodology is advantageous in the way

of defining the range of possible scenarios; it would be useful when complete scenario enumeration is not the choice. Regarding to this methodology and its overview, different scenarios can be prioritized and leads to disruption mitigation intention. Clearly many scenarios derived, but from the methodology comparison between scenarios can be seem; while by changing one scenario impacts on others understands respectively.

2.4.4 Mathematical modeling assessment

Generally in vulnerability analyzes interesting point is to identify the range of disruptive scenario, however mathematical modeling methodology is derived specifically to carry out the most vital component of the network. This approach is looking to identify the most affective scenario regarding to the loss of facilities. Mathematical approaches usually are common when there is a complexity in relation between infrastructure facilities and network activity, but also it could be useful for a case with wrapped topological network. It can be used instead of scenario-specific approach while consider the scenario within a wider, system-oriented perspective. Mathematical methodology are planned for detecting either minimal or maximal solutions and are used for different cases. To identify disruptive scenarios and their effect on network performance is considered as a perspective of this methodology beside the transport cost and flow influences. According to this concept (Ford & Fulkerson)notes theory of max-flow min0cut theorem, thereby methodology developed by assuming just one element subjected to failure. (Iida & Wakabayashi, 1989) Ratliff et al. (1975), Wood (1993) derives used the assumption and applied to various cases. Then (Israeli & Wood, 2002)developed algorithm that maximize the shortest path between two specific nodes when a certain amount of links can be interrupted, using a mixed integer program. A further layer of research with respect to this methodology takes connectivity as the objective measure.

(Bell M. G., 2000)represented game theory approach as a methodology for vulnerability assessment; the methodology developed by defining two player as an non-cooperative game between a user who looks for a least cost path, and a tester who is trying to maximize transportation cost or consequences by disrupting network components. The method developed base on Nash-equilibrium point where both user and tester cannot enhance their benefit by unilaterally changing their strategy. A bi-level non-zero-sum game represented by (Murray-Tite & Mahmassani, 2004) where the game is between an evil entity (tester) and a traffic management agency (as a seeker for least-cost path) to measure network vulnerability. The methodology defines vulnerability base on link closure where induce an alternative paths to exceed their capacity (considering player information and number of movement for each player). Furthermore other approaches are developed base on various characterization and study attitude; games defined based on defined different categories of applications (i.e. games against demon, games between travelers, game between authorities and a single traveler, and games between all travelers and an authority). (Matisziw & Murray, 2007) suggested an integer programming problem to solve the game between one player try to disrupt the network with limited resources and the other player seeking to maximize the flow and minimize travel time.

Clearly, transportation networks are more complex in case of their structure and operation compare to other infrastructures. This kind of methodology base on mathematical assessment would be computationally intensive as it may contain thousands of nodes and arcs.

3   Stakeholders and approaching to the problem

The road transport system, with its role of connecting people, business, services and activities separated in space, is a fundamental part of modern society. It is a fundamental lifeline, which with its wide range of operation and functionality weight importance for different purposes; all the people with different goals are in contact with road networks. This difference in objective uses makes studies with different aspects and perspectives. In previous chapter we have seen the vulnerability analyses in different aspects, in general it is presented why vulnerability analyses is important and to study the task it needs analyses and investigations on mentioned neighboring terms. We saw vulnerability definitions and its classification in different approaches to problem, although developed definition has been proposed based on studies perspective and relevant indexes with respect to purpose of different studies. As we saw vulnerability can be defined with respect to different cost factors, and in complex cases it would be from pooling of more relevant factors like travel time, capacity and connectivity. In recent methodologies complementary indexes can lead the study more in to detail; link importance index, exposure index or and rescue center location are from those. By defining pooling factors in comprehensive studies is combination of previous and studied factor, while by studying vulnerability with respect to traffic flow relation of travel time and capacity could be involved.

After general introduction of vulnerability task and recognizing the importance of the subject and probable problems, the studies are considered with different stakeholders' point of view. Since there is no doubt the transportation network is the most significant and most effective lifeline, therefore different stakeholders in different field will be in corporate with this lifeline. This corporation is considered separately with each stakeholder and for each specific purpose, distinct approaching to problems are investigated for each aspect.

The importance of a network is different base on location, sensitivity and network`s element, therefore you can not propose common stakeholders for all road networks. There are effective factor like availability of critical facility or important financial region orients some units more important with specific perspective. As an example in New York City they have specific stakeholder with orientation and focus on Wall Street, where it is the most critical financial region in New York with its own sensitivity.

In this chapter we are trying to find involved stakeholders in road network base on European commission division; and we will see stakeholder`s responsibilities terminates to which parts. It is interesting to see in which way and perspective road vulnerability assessment is remarkable for these stakeholders, in fact in which point of view the stakeholder approach to the problem? To achieve the goal it is a general view on probable stakeholders and their services. Then we will see in detail the involved stakeholders in the case of European roads network, related cost factor with respect to their approaches and to see separate objectives for each of them.

Table 3-1-Probable involved stakeholder and their approach to the problem

Stakeholder	What is the Problem and why the Vulnerability is studying?	Description and how to approach to problem
Civil Protection	Civil Protector activities are: 1-Forcasting and prevention 2-rescue and resistance to the population 3-overcoming the state of emergency and recovery of the socio-economic activity	Vulnerability assessment is required for the case No 2, which link connectivity (means accessibility) and travel time in case if there is a congestion in emergency are the factors, and the monetary value is important for 3 in case socio economic aspect (Terminal Relia all case)
Traffic Planner	Describing general traffic flow and attributes resulting in flow decrements (like daily rush hour, weekend highs...)	To assess Vulnerability in this case the factor could be capacity, travel time reliability to avoid traffic flow decrement
Environmental	The incident could be nature given incident, by maintaining infrastructures and avoid building new rout ... to avoid environment changes. The topography and terrain that traverses.	Capacity reliability to remove the congestion and decrease pollution & health problem, topological aspect
Government Agencies and Security Sector	enhancing security and reducing risk, improving the efficiency and effectiveness of organizations mission, strengthen interactive stakeholder partnership	availability of the link is crucial (connectivity & accessibility), if congestion is part of the emergency "travel time" will be added, and also topological contribution
Economic development	business organizations, economic development association, to see if costs exceeds benefits the society will experience loss of welfare, to see if reliability improvement is acceptable	exposure and link criticality , it depend on critical facility and link importance, it defines according to importance index
Users	to avoid any inconvenience in normal activity, like shopping, pick up children , appointment, so the time of arrival is issue	Travel time factor is crucial here, analysis is based on delay time
Civil Constructor	It is concerned in terms of structural vulnerability of road network; it is not only in terms of topology but also in terms of physical body of the road, width, curvature, tunnels bridges….	physical connectivity means availability of the link , not accepted any collapsing or failure, connectivity or terminal reliability issue

The first step of studying is focused to find probable majors and field of services for each stakeholder. As it has been seen in above table, basically stakeholders relating to road networks analyses can be various in case of importance and network`s characteristic. The organization and involving institutes can also be divided in two groups:

- **Public**
- **Private**

Normally the first group relates to government and mostly requires more administrative procedure. (i.e. in some special cases it may be more rigid in front of changes and needs predefine process for functionality.) Government agencies and security sectors are relates to this group as well.

However in private group it could be a profit association which analysis and vulnerability assessments are carrying on to avoid any problem in functionality of the system and malfunctions. (As an example we can mention the owner of a road network which their profit could be on toll charges.)

The interesting point for this division major is how to coordinating different organization with different perspective in order to reach the same goal which has been reduction in road network vulnerability. It can be from planning part to emergency case or even in real time programming.

In this part we will see a brief description and survey on involved organization or partners especially in European road networks. The European Union Road Federation (ERF) as a non-profit association, which coordinates the views of Europe's road sector and acts as a platform for dialogue and research on mobility issues, the association has a correlation with other stakeholder involves in road network task and base on EU regulation has a responsibility for coordinating different units. However ERF contains wide cross-section of the major stakeholders active in different fields such as constructions, equipment and operation of Europe`s road network. The general responsibility is to increase awareness on the importance of roads for all citizens contributes to European research initiatives with view to enhancing the overall efficiency and safety of the road transport system. They gives the road infrastructure community a consistent and united voice in all road transport areas by promoting and coordinating Programmes and working groups such as:

- Socio-economic contribution of roads to society
- Sustainable road infrastructure
- Intelligent road & financing safer road engineering
- Urban mobility

The (European Union Road Federation) derives from associated members' agreement as effective stakeholders, which involves in different field and co operating in different attitudes.(Such as; Centro Rodoviário Português (Portugal), Road Users Alliance (UK), Union Routière de France (France) and etc).

Here we are going in to detail for different stakeholders to study all their responsibility, subsets, approaches to the problem and specifically the crucial cost factors in different situation.

3.1   Civil protection

Civil protections are considered as a community co-operation, whom always trying for better supply in case to protect people, environment, property and cultural heritage in the each incident (natural or manmade disaster occurring). The international work of European countries in the preparation of civil protection assistance is enhancing one emergency after the other. All the members and involving institutes are working together and increase in their reliance on co-operation for the preparation of civil protection assistance than to enhance their assistant as much as possible on the site of disaster. Such a co-operation leads to use all the potential and make to pool resources and maximizing the collective European effort on site.

3.1.1   Prevention, preparedness and response

In order to achieve an effective civil protection operation three main action would be affective: prevention, preparedness and response.

- **Information**: is considered as a key issue in order to enhance success in co-operation in civil protection matters. Civil protections are not notices just in their own stake role but also as public at large, which they could be a victim to a disaster as well. However appropriate distribution of information during emergencies is also a necessity. (How malfunction in network may spread to other parts, availability of links, how long takes to go back in normality). Apparently pooling information to see capability of civil protection, military and medical resources.
- **Intervention**: potential of mobility in order to intervene other rescue team, expert and other resources on request in major emergencies. (Mobilization of other rescue teams, the probability that a road network can host them in an appropriate time).
- **Post-disaster analysis and recovery**: the time which the situation can back to normality indicates to define severe of vulnerability. After operation to for rescuing and sedation has been applied, then civil protection works on further information sharing. They also admit for financial assistance to the affected state.

There are defined action program for civil protection, that dealing with prevention, preparedness and response to distaste:

1. Preventing the risks and damage to persons, property and in so doing environment, in the event of natural and technological disasters.
2. Increasing the degree of preparedness of those involved in civil protection in the member states, in order to increase their ability to respond to an emergency.
3. Detecting and studying causes of disasters.
4. Improving the means and methods of forecasting, techniques and methods of response and immediate aftercare after emergencies.
5. Public information, education and awareness, so as to help citizens to protect themselves more effectively.

3.1.2 Objectives and approaching to vulnerability

In the table below indicates the rolling plan and civil protection attitude in general, which has been proposed by European commission:

Table 3-2-Civil protection attitude base on (European Union Road Federation)

Title	Objective
Information to the public	A major project and/or a workshop to identify best approaches intended to raise citizens' awareness and information on safety behaviors in case of major risks.
Maximization at EU level of lessons learnt following Civil Protection emergencies in areas involving highly confidential information (e.g. terrorist attacks)	An EU-restricted workshop on how to maximize, at EU level, the exchange of information, experience and lessons learnt following Civil Protection emergencies involving classified information - such as terrorist attacks - while fully respecting the confidentiality obligations. The workshop should involve the responsible authorities of the Member States.
psycho-social aftercare	A major project and/or a workshop involving national psychosocial after-care providers from various Member States/participating countries, focusing on one or more of the following aspects : a) a general exchange of knowledge, experience and good practice on psycho-social aftercare following major emergencies; b) psycho-social after-care for rescuers; b) dealing with multinational groups of victims.
risk assessment/ risk management	A major project and/or workshop on risk assessment and/or risk management methodologies in at least 3 major risk areas of common concern to at least 3 different countries. The project should take into account the current scientific knowledge and state of the art.
Safety of specific vulnerable groups	A major project and/or a workshop on best practice regarding the safety of vulnerable groups against major emergencies, such as severe climatic conditions due to hydro-meteorological events.
assessment methodologies	A major project on the development of assessment methodologies to be used in the context of various types of major emergencies. The project should take into account existing guidelines and aim at the drafting of operational recommendations.
Follow-up of completed projects or workshops	In view of the winding up of the Action Program, one-off follow-up actions for completed projects or workshops (in compliance with § C.2 of the Annex to Decision Nr 1999/847), concerning all Member States or a significant number of them. The proposed actions should preferably cover one of the following areas : information to the public, psycho-social aftercare, disaster medicine, general contingency planning.

As it has been seen civil protection`s responsibility is not limited to rescue assistance during emergency and their issue is not focused just on the matter. The activity from attaining information in a planning time since emergency and recovery would be carried out. Clearly different field from communicating, safety analyzing, risk assessment, psycho-social aftercares and specifically road vulnerability analyzes would be under study and measurement.

The task of vulnerability assessment for road networks is a controversial issue for civil protection. To host and transport assistance group to affected area may see obstacles and blocks for providing rescue activities, in some cases high cost and the lack of accessibility would be the main problem.

The following table reveals the whole framework of looking at civil protection attitude in which way the matter of road vulnerability assessment is significant task. According to civil protection rolling plan and their objective base on European commission the study can be divided in to two subsets as an emergency period and also planning and forecasting time. While different object will be faced its own problem, therefore there is not any uniqueness in case for approaching to solve the problem. With respect to vulnerability classification different indexes and cost factors indicates the way of approaching and appropriate methodology.

Table 3-3-Civil protection approaching to vulnerability assessment

Stakeholder	Subsets	objective	Description	Cost Factor	Vulnerability classification
Civil Protection	Emergency	Rescue	Possibility to reach to the disaster area	Accessibility	Physical
			In case of major disaster, secondary incident would be probable (congestion)	Travel time	Systemic & Functional
		Evacuation	Choose appropriate alternative routes to avoid secondary incident	Safety	Systemic & Functional
			to evacuating the disaster are in proper time	Travel time	Systemic & Functional
			prioritization of the exposed population based on the most vulnerable zones	Exposure Index	-
		Real time monitoring & intelligent technology	to conduct the external users to alternative routes	Safety	Social
			to avoid congestion & its propagation	Capacity	Systemic & Functional
	Planning & Forecasting	Network Planning	incrementing the redundancy of the system by considering cost- benefit issue	Accessibility	Physical
			increasing the Capacity of the System with respect to cost benefit issue	Travel time	Systemic & functional
		Training & exchange of experts	Cooperating with other organizations & develop a common emergency plan	safety	Organizational
		Developing technology (EWS,ITS,etc.)	Using EWS & ITS to prevent the disaster and mitigating the impacts	safety	Social/ Systemic & Functional
		Cost-Benefit	Decision-support in cost benefit analysis	Importance Index	-
		Monitoring information Center	Communication hub, Information Provision, Coordination	safety	Systemic & functional / Organizational

Table – Civil protection approaching to vulnerability assessment

In literature review we saw how vulnerability can be classified in separate group in general and also for our specific case road networks. Some consideration has been applied to create the above table; as we saw functional vulnerability and systemic has been allocated in different group, however by analyzing and studying these two types we can see in most cases these types are somehow behave similarly. In order to avoid complexity in attitudes, functional vulnerability and the systemic one are considered as a same group, and it can be also contained the organizational vulnerability assessments.

On the other hand the topological vulnerability has been pooled with physical vulnerability; while related cost factors indicates same perspective and it happens on the way of classification simplicity.

Since studies on vulnerability and reliability issue for road networks represents a range of cost factors, which indicating analyses in order to approach to the problem. Travel time, capacity, connectivity are as the mentioned factors, but also in specific cases by defining the framework more in detail different relevant indexes are introduced to solve the problem. Importance indexes, exposure indexes are as an example of some of those. Here another significant task is considered as a cost factor which may consist different aspects and requirement. Here in the above table *safety* of road networks is considered as a perspective in vulnerability studies, and contains its own characteristics.

In general and in different countries civil protection can have a wide range of responsibility not only in emergency phase. According to European commission these responsibility has been divided in two separate time period, planning and forecasting and also emergency phase. Clearly the attitude and their subsets would be different objectives. While in emergency phase it can be divided in:

- **Rescue:** civil protection goal is be able to reach at damaged area, in the very beginning they just want to have their accessibility and analyzes are interesting in this point of view. However during the emergency congestion and also secondary incident may lead to delay and make obstacle for civil protection to be on site in a proper time; travel time issue would be important task in this case.
- **Evacuation:** In this case most affected and vulnerable area has been detected, in order to do the services based on prioritization; it has been studied based on exposure indexes. It is clear in emergencies based on the situation and type of the incident, while evacuation has been chosen as a solution; factor of time play important role. How long it takes to evacuate the area, to equip civil protection, in case of temporary shelter necessity the way of equipment in a proper time. In fact civil protection themselves are in danger, which the safety of civil protection is an important issue to keep them safe during the operation, proper choice for alternative route decrease probability of secondary incident especially in civil protection services.
- **Real time monitoring and intelligent technology:** it can be called as the operational heart. After the disaster it starts to work and will be in contact with civil protection, update them in real time. On the other hand intelligent transport system in the case of emergency can lead upcoming traffic to alternative route to avoid congestion.

In addition in planning and forecasting phase civil protection responsibility can be divided in: (Humanitarian aid and civil protection)

- **Network planning:** In peace time the studies also focus on accessibility of degradable systems, while according to cost benefit analysis the redundancy of networks are under investigation. It can be base on developing the network, road expanding for link`s capacity increment.
- **Training and exchange of experts:** The communication is controversial issues for civil protections during emergency, coordination between different experts are doing during planning. By developing common emergency plan it leads to safety improvement. The aim of the civil protection mechanism training program is to reinforce and facilitate co-operation in civil protection assistance intervention. Experts who have trained together can interact better out in the field; in addition, they will be more knowledge about the particular requirements of a European civil protection mission, such as coordination and assessment.
- **Developing technology:** studies and investments are in process in the development of technologies linked to the prevention of disaster or the mitigation of their impact. It has also aim to implement information services in support of environment policies and security issues. Early warning system and intelligent transport system are from those which have a significant impact in increasing the safety. By monitoring the network information about degraded link spread for users and specifically for civil protection to make the best decision.
- **Cost benefit:** usually relates to analysis with comparing the project cost against the benefits of the project. At first it requires weighting the costs and benefits, then if the costs exceed the benefits, society or in specific case civil protection will experience a loss of welfare. In this case any vulnerability of the transport system cause degraded link that cause costs, vulnerability here is thus a cost that is quantifiable. The importance of a link leads to weigh the link more and have a significant effect on decision makings.
- **Monitoring information system:** this attitude of civil protection will make an increment in the safety of whole process. It allows monitoring the situation of the network in order to have a reliable knowledge of disaster and changes in real time. It is more sensible in road weather monitoring to update civil protection to have clear forecast about the situation.

Figure 3-1-Monitoring informatio

3.2 User

Users as another significant stakeholder are involved with the task of vulnerability assessment in different perspective and orientation. They also approach to the problem in order to achieve their goal; form travelling to business transportation issues in a efficient and reliable ways. The link importance would be one of the key factors for vulnerability assessment, in which to reduce the risk for them (for different undesired reason such as link capacity and its consequences).

Importance of users can be dividing in two attitudes of study; the first is the way which users themselves are under study as an affecting factor on road network vulnerability and road safety analyses, the second is as a stakeholder who needs road network vulnerability measures with respect to operability of the road network.

The first side is one of the considering issues under road safety research and analyzes. While different factors relating to road users may be caused to avoid links operation with full capacity and result to malfunctions. The table below reveals the mentioned issue;

<p align="center">Table 3-4-Users behavior as an affecting factor on road safety</p>

Road Safety Knowledge	
User dependent factors	**Description**
Speed	the impact of speed enforcement on road safety
Alcohol	Reaction times
Seat belt	wider seat belt use could save up more
Others,	elderly, pedestrian, trucks, cyclist, Helmet, …

However, regarding to this thesis the interesting point for us is in which point of view the vulnerability analysis would be attractive for this stakeholder and how it is classified in vulnerability types; in order to approach to the problem in this point of view. In the next sector we are going to study and answer these questions.

3.2.1 Objectives and approaching to vulnerability

The issue of vulnerability assessment is a discussing context with respect to user perspective and attitudes. Where it can be derived for different purposes as in this thesis it is restricted to Freighting, travelling and every day journeys. Same as the civil protection to reach to vulnerability assessment; it requires to identify the type of vulnerability and for this principle related cost factors are characterized and distinguished.

For the purpose of freight goods, the desire fact is to deliver the good in expected time; malfunction in this part may propagate the problem to other sectors and members as it has been defined as a systemic and functional vulnerability. With the same purpose the way of transportation is a significant issue, in which for specific trucks limitations in tunnels, topological road characteristics are considering factors.

For travelling issue the destination is the only goal which user wants to reach his destination, clearly from the definition the cost factor would be accessibility and it is characterized as an physical vulnerability.

As a general perspective for users on the task, every day journey can be mentioned, while it is divided to normal activity such as work, school, pick up children and so on. For all discussed activity users require to reach their destination on time, certainly travel time factor would be the most reliable one as cost factor in this section of analyses.

Table 3-5-User approaching to vulnerability assessment

Stakeholder	Purpose	Description	Cost Factor	Vulnerability classification
User	Freight	In order to deliver goods in desire time	Travel time	Systemic & Functional
		Heavy vehicles, especially dangerous goods have some limitation with respect to topological characteristics of roads & Restriction in some tunnels	Accessibility & Safety	Physical
	Travel	In order to reach to the given destination	Accessibility	Physical
	Every day journey	To reach the destination on time (work, school, pick up children, etc.)	Travel time	Systemic & Functional

3.3　European road federation

Clearly, roads are an irrefutable source of socio-economic welfare; it has a significant role in the transport of goods and people. The European Union road federation besides other stakeholders offers its expertise and support studies and researches in order to reach a reliable road network.

3.3.1　Objectives and approaching to vulnerability

It includes a wide cross-section of the major stakeholders' active in the different parts such as construction, equipment and operation of road networks. For different subsets with their own objective the way of approaching to vulnerability assessment is characterized. The table below reveals the study of this stakeholder.

Table 3-6-– ERF approaching to vulnerability assessment

Stakeholder	Subsets	Description	Cost Factor	Vulnerability classification
European Road Federation	Constru ction	Improve redundancy of the network	Accessibilit y	Physical
	Mainte nance	ex. Bridge Collapse	Importanc e Index	Physical
		Reduction of Capacity imposed by closed lane during maintenance	Capacity	Systemic & Functional
	Equipm ent	preparation necessary equipment & allocate rescue centers	Safety	Systemic & Functional

Construction can be performed after redundancy analyses where the need of new route was required, it is also considered as an improvement in former routes like widening postulate paths.

In road networks structure maintenance is one of necessary works, which in this way it is avoid from probable bridge collapse or malfunction in tunnels or other structure. The issue needs prioritization and it carries out with respect to link importance. On the other hand during maintaining procedure it may lead to reduction in capacity where the study will be held regarding this perspective and clearly consider as systemic and functional vulnerability assessment.

In planning time and in order to have a reliable and secure service during emergency, the equipment sector prepares rescue centers and equipped necessity of them. In the case of shortage of rescue center, the sector will allocate the new one. These processes are carried out to enhance safety, which has been defined as one of the cost factors.

4 Case Study: the road network of Tehran

4.1 Geographic Context

Tehran is the largest urban area and city and it is capital of Iran as well. It is also the largest city in western Asia and the 5th-largest city globally. Tehran has been subjected to mass migration of people from all around Iran, because of the more job opportunities. Therefore it becomes one of the most populous cities even in the world; approximately with a population of 12,223,598. (Wikipedia)

Province of Tehran covers an area of 18,956 square kilometers, although the city itself as central of this province has covered on area of 730 square kilometer. It is divided in to 22 regions, 134 zones and 370 districts. This city is located to the north of the central plateau of Iran; the capital of Iran is located on the foot of the Alborz mountains range with high range of earthquake potential.

Figure 4-1-Tehran and the Alborz mountains

From the north Tehran lies on towering Alborz Mountains district, however form the south it is covered by central desert area. Therefore in north and south has a different climate condition. Northern area has a cold and arid weather and the southern part it is warm and arid. But generally Tehran features a semi-arid, continental climate. It can be generally described as mild in the spring and autumn, hot and dry in the summer, and cold in the winter. The large extend of the city because of sensible differences in elevation among various districts, apparently the weather is often cooler in the hilly north than in the flat southern part of Tehran.

Administrative structure of Iran is located in Tehran. Almost half of industrial activities are located in this province and it is the most important economical point of Iran. Near half of workers work for the

government and the remainder of workers are factory workers, shopkeepers, laborers, and transport workers. There is an oil refinery, south of the province. Tehran province has four airport: Mehrabad International Airport, Tehran Imam Khomeini airport, Ghal`eh Morghi airfield and Doshan Tappeh Air Base. Basically Mehrabad Airport is used for domestic flights and also charters. It is located in the western part of the city. Imam Khomeini International Airport located south of the city with distance of 50 kilometers and all international flights are from this airport.

Population of Tehran (1956 - 2006)

Figure 4-2-Population of Tehran from 1956 to 2006

It is mainly relies on private cars, buses, motorcycles, and taxis and the city is strongly car-dependent even one of the most in the world.

According to the head of Tehran Municipality`s Environment and sustainable development office, Tehran has a capacity for 700,000 cars although now ruling more than 3 million cars are on Tehran`s network. Tehran has also railway facility which is connected to the most cities of Iran; A Tehran-Europe train line is also running.

Tehran`s transport system contains normal buses, trolleybuses and Bus Rapid Transit (BRT). The bus transport network includes 4 main stations on the South, East, West and central North. Highways of the city has a huge network around 280 Km and also the road network contains interchanges, ramps and loops around 180 Km.

Figure 4-3-A satellite view of Tehran

Tehran`s metro network has been designed for nine different line, however currently just four lines are working. As the below illustration shows the current four line (purple, red, green and blue line).

Figure 4-4-Tehran`s metro map

4.2 Methodology

When an accident happens in a specific place, the primary point for civil protection is to see the accessibility and recognizing the best route to reach to the effective element. Regarding to importance of access travel time and the stability of relief process, to find the optimum route from rescue center to effected area in a real network; considering continuous changes on traffic condition while civil protection may face unpredictable incident like an accident during rescue process. Usually this kind o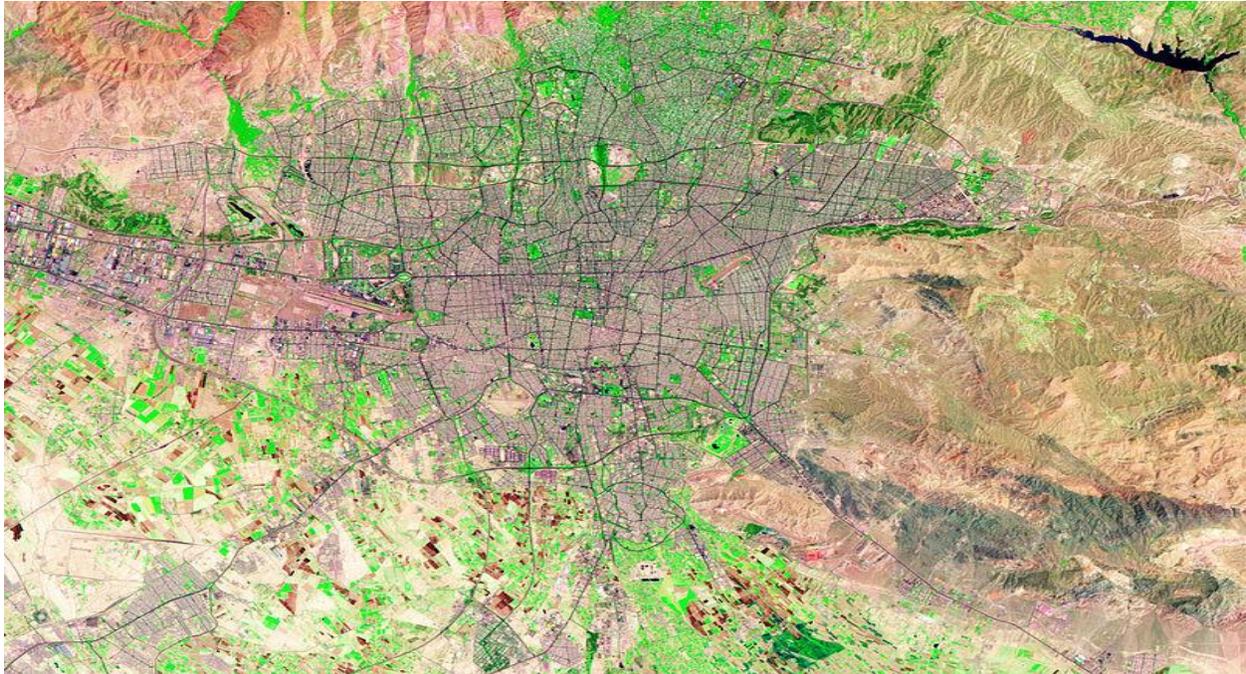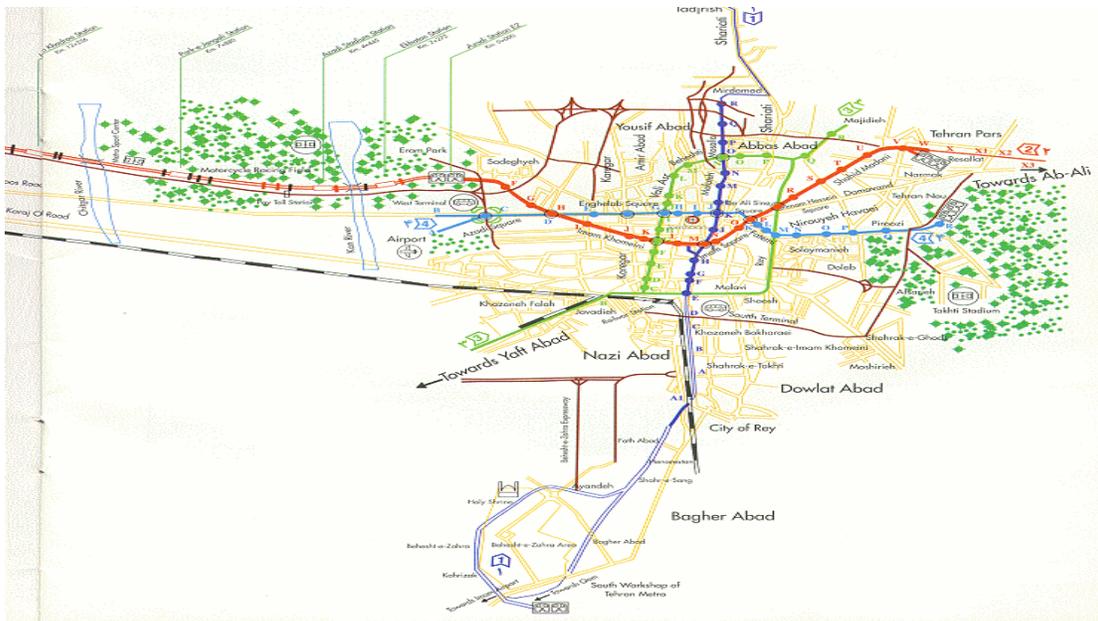f routing is one of the most complex one compare to other transportation`s routing process. In this routing process, dynamic effects in network should consider regarding reduction in travel time and also recognizing reliable routes with respect to traffic condition changes. The base of analysis is on detecting routes with minimum travel time accessibility, and maximum stability; which define reliability incase of civil protection attitudes.

Therefore, first of all recognizing the routes with stability on travel time would be the issue. In this way, probable routes are recognized for civil protection tasks during an emergency. To reach the goal risk parameter is defined considering to geometry and topological characteristic; apparently the less vulnerable route with high stability is the one with the minimum risk. Thus, by defining the risk parameter for each arc and specification for different routes, then the civil protection`s routing will not defined just base on objective function, however it could be base on the route with the minimum defined risk. Clearly, the route from this approach has significant travel time stability in compare to other routes; however it is possible that the selected route is not the best one in case of travel time.

In this chapter, we will see the level of network reliability in order to determine appropriate routes for civil protection; below flowchart reveals the way of study on this matter.

Start

Important Factors identification in emergency network`s routing

Definition of quantitative indexes from identified factors

Network implementation on GIS

Determine appropriate process

Risk indexes ident

Routing indexes

Appropriate Number of samples

Designing questioners

Questioners distribution & collected

Database processing

The Data analysis

Risk Modeling

Assignment of quantitative indicators

Best route base on risk index

Best route determination base on travel time

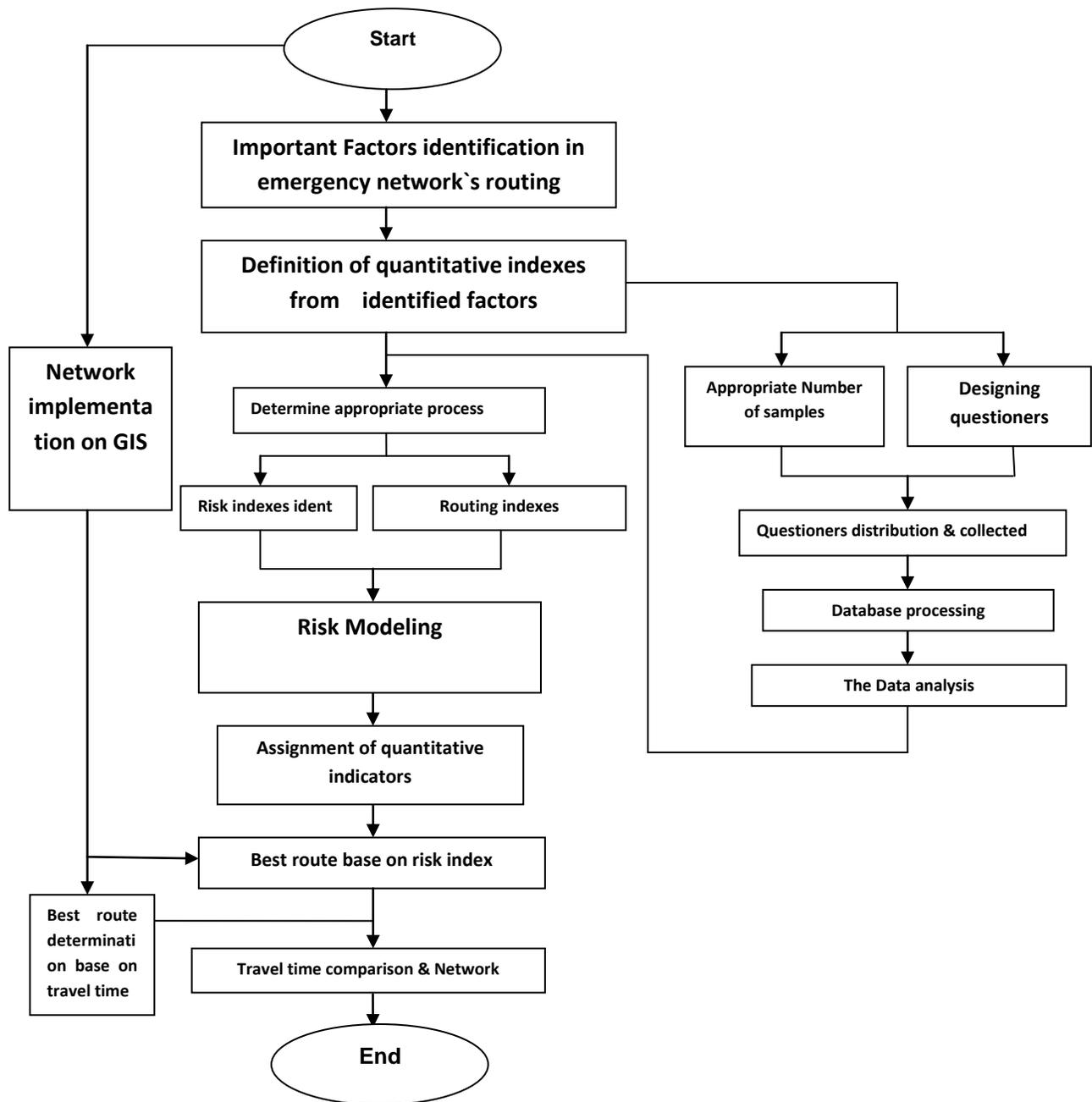**Travel time comparison & Network**

End

Figure 4-5-Study procedure to identify vulnerability of the network in case of emergency

4.2.1 Identifying important factors in network`s routing in case of Emergency

One of the most important steps in degradable networks routing, is to identify important factors to reach for implementation the degradable network. In this case it is necessary to identify arcs with high potential in order to use in case of emergency.

Because of multiplicity in important factors from different point of view, and lack of comprehensive study to identify significant factors regarding its importance, then it can be more appropriate if the factors carry out from questioner processing by distribution among experts and professionals.

From questioner part we can reach to two main goals, on the one hand experts leads us in order to identify important factors. On the other hand, from two by two comparison the weight of each arc will be identified.

In the first step, based on proposed methodology for polling process designing a questioner is required. In the questioners we have asked about effective factors on routing process for civil protection and rescue services during an emergency for degradable network.

After designing questioners, it has been sent to experts email address and also some of them fillet from telephone discussions. Early the relevant stakeholders and departments are identified as below:

- National disaster management organization
- Prevention and crisis management agency in Tehran
- Fire station agency
- Police
- University professors and students

From filled questioners by manager and experts in different departments, then by analysis on answers and classifications with respect to former studies; a set of effective factors are distinguished for routing process during an emergency.

To sum up, as a result from filled questioners; characteristic of network is derived in order to do rescue procedure during an emergency.

- ➢ Network`s accessibility regarding rescue centers and also police stations in order to crisis controlling.
- ➢ Possibility of network access to reach the degraded links (i.e. persuaded accessibility to damaged components)
- ➢ Regarding the speed of accessibility to damaged element and starting rescue process which is one of the important facts; which represents rescue process as a successful one. Then for this goal, selected links should be the shortest one between rescue centers to damaged point.
- ➢ Usually this approach for considering shortest links may face to some limitation like traffic direction, traffic congestion. Therefore, to make possibility of civil protection accessibility with respect to shortest path it requires traffic direction management in emergency in order to do

rescue procedure as fast as possible. (In some cases while there is no accessibility by vehicles to effected elements, the rescue plan may include other ways like walking in some parts.)

➢ Selected links should cover appropriate and sufficient width. This link`s characteristic consist the possibility of civil protection transition. In this study and from questioner results the width limitation considers 12 meter.

➢ All involved stakeholders prefer to use known links during emergency, thus in routing process it is recommended to use main links and passage in the plan.

➢ Priority is on selecting highways and freeways in the routing emergency plan, where it has the possibility of controlling and planning. Because access to highways and freeways compare to paths with numerous accesses has limitation and also regulation on these paths are more applicable and easier.

➢ The other factor on link selection relates to level of service, where priority is with links which most of them have a level of service more than E in each day (i.e. duration of containing this level of service will be more than the others). It is even possible to use some routes which are less well know compare to other parallel routes, but sensible difference in traffic condition makes them as a part of routing in emergency.

➢ The other important factor in routing process during an emergency is consider as instability factors; as an example low accident history leads to avoid probable changes on selected links.

➢ Evacuation probability of selected link is another effective factor, while availability of junctions (also exits and entrances) helps to evacuate other vehicles from selected route to make civil protection transition easier.

➢ The routs which host more travel with direction to damaged area, have more potential in order to consider as part of routing for rescue process. The fact would be the same for number of travels from the links that represents arc`s importance; then the potential here would be the same as well.

➢ In routing process it should be under consideration that travel time variation for civil protection groups cannot be violated more than 15% base on rescue standards.

➢ Direct routes are more feasible compare to route with changing on direction; other stakeholders would be more practical in these cases.

From questioner's results and above description base on professionals and experts attitude to problem below interesting factors can be summarized;

Table 4-1-Effective factors in routing process during an emergency

Effective factors in routing process during an Emergency
The width of routing components
Traffic condition variation of routing components
Path shortness in terms of travel time
Path shortness in terms of distance
Number of intersection on the path
Routing component`s characteristic
Accident history on routing components
Availability of alternative route in case of outgoing from selected path
Availability of parallel elements with low violation in travel time (travel time stability)

4.2.2 Numerical indexes for important factors

In previous section significant effective factors on routing for civil protection rescue process are carried out. Here the next step is to determine numerical indexes in order to evaluate each element base on derived factors. To reach the numerical index for each factor a different study and attitude will be discussed, which in following the studies are explained;

4.2.2.1 *Width of the route`s component (WID)*

The desire width should be appropriate and enough for civil protection`s vehicle transition. According to results and base on transportation standard; the width should be 12 meter at least, otherwise it cannot be consider as a route component for rescue procedure.

4.2.2.2 Traffic condition variation in rout components (LOS)

In routing process as it is mentioned before those elements are more desirable to consider as a component of rescue route during an emergency which host more hour in a day a traffic without any criticality. Here to identify this factor, level of service represents the require index for each link. According to peak hours on the one hand and no traffic condition criticality from 22 to 6 on the other hand, thus the study just consider from 6 to 22 as a traffic congestion period. The network is applied in EMME2 software to eliminate links with "*critical*" and "*slow*" traffic condition from routing components.

4.2.2.3 Travel time index (TIM)

In routing process during an emergency, one of the significant factors is consider as travel time. The way of selecting routing components should be so that provides path shortness in terms of travel time. In this study, to evaluate travel time for each link the peak hour is considered where the demand matrix in peak hour is applied to reach to this evaluation.

$$TIM_i = \frac{T_i - T_{min}}{T_{max} - T_{min}}$$

Equation 4-1

Where;

T_i : Shortest travel time from a rescue center to damaged point passing through link *i.*

T_{max} : Maximum T_i factor for different *i.*

T_{min} : Minimum T_i factor for different *i.*

Dijkstra`s algorithm, "is a graph search algorithm that solves the single source shortest path problem for a graph with non-negative link path costs, producing a shortest path tree" from Wikipedia. Clearly to evaluate T_i in this study the mentioned algorithm is applied to EMME2 software.

4.2.2.4 Length index (LEN)

Selected links should provide the shortest distance from rescue center to damaged point as well, it leads to shorter travel time with respect to link`s direction of motion planning and management. In order to evaluate the length of each link, the link`s data base including geometric properties of them will be useful. Then we have:

$$LEN_i = \frac{L_i - L_{min}}{L_{max} - L_{min}}$$

Equation 4-2

Where;

L_i : Shortest travel distance from a rescue center to the damaged point passing through the link *i.*

L_{max} : Maximum L_i factor for different *i.*

L_{min} : Minimum L_i factor for different *i.*

The way of evaluation the L_i factor will be the same as T_i using Dijkstra algorithm and applying it into the EMME2 software.

4.2.2.5 Routing components characteristic (TYP)

The link characteristic and typology is another effective factor, in which prioritization on link selection is relates on the one with possibility of monitoring and controlling. As it is discussed before *accessibility* during an emergency is the most crucial fact for civil protection, with considering this issue those links with high level of functionality and performance are desirable to select as route component. Basically familiarity of stakeholders is more probable with such a links with high level of performance compare to others. Regarding to studies and respect to road network standards the below table indicates the value of the index as following.

Table 4-2-The value of component characteristic index

Component`s type	Value
Highway & Freeway	*0*
Main roads	*0.4*
collector & distributor links and local	*0.6*

4.2.2.6 Number of intersections index (INT)

The number of intersections on the proposed route for civil protection rescue procedure during an emergency is considerable, in order to provide evacuation other vehicles from the route.

In this study, the available data base is also useable here to obtain this index as well. Where with availability an intersection at the end of each link, number 1 is considered for the related link otherwise the dedicated number will be 0.

4.2.2.7 Accident history on routing components (ACD)

An accident has a direct influence on stability of travel time and respectively on reliability of the network. From available data base on Tehran network and regarding to below formula, the accident history index will be evaluated for each link.

$$ACD_i = \frac{C_i - C_{\min}}{C_{\max} - C_{\min}}$$

Equation 4-3

Where;

$C_{\max}$: Maximum number of accidents among the links.

C_i : Number of accidents on link *i*.

C_{min} : Minimum number of accidents among the links.

4.2.2.8 *Multiplicity of alternative routes in case of outgoing from routing path in emergency (ACP)*

In case of unpredictable incidents, civil protection or other stakeholders may force to leave the selected rout which had been planned in peace time and continue their activity to the damaged area from probable alternative routes. Apparently multiplicity of available alternative routes describes the index. In this study to identify the number of appropriate routing from each link to damaged point, EMME2 software will be used. The base of study is on the number of appropriate route from the node at the end of each link to the damaged nodes should be in way that travel time of these routes cannot be more than N percent of the minimum travel time from the desire link to damaged nodes.

To identify the discussed index below formula will be useful.

$$ACP_i = \frac{AC_{max} - AC_i}{AC_{max} - AC_{min}}$$
<div align="right">**Equation 4-4**</div>

Where;

AC_i : Number of probable routes from a link *i* to the damaged area.

AC_{max} : Maximum number of appropriate routes from the links to the damaged area.

AC_{min} : Minimum number of appropriate routes from the links to the damaged area.

4.2.2.9 *Multiplicity in availability of parallel components (PAP)*

The most important issue for civil protection in routing process during an emergency is *reliability* of the network and also stability in *travel time* factor even if unpredictable incident occur. Therefore the proposed route should contain numerous appropriate paths from rescue centers to the damaged nodes.

In this study to reach to this number first of all characteristic of appropriate route will be identified and these routes will be applied to EMME2 software, then the number of identified routes from each link will be count.

Appropriate routes are those which travel time on them will not be more than K percent of travel time on the main route.

$$PAP_i = \frac{PA_{max} - PA_i}{PA_{max} - PA_{min}}$$
<div align="right">**Equation 4-5**</div>

Where;

PA_i : Number of identified appropriate routes from rescue centers to damaged nodes through the link *i.*

PA_{max} : Maximum number of identified appropriate routes through the links.

PA_{min} : Minimum number of identified appropriate routes through the links.

4.2.3　Weighting the important factor

In two last sections we saw how to identify important factor or cost factors for civil protection from involved manager and experts attitudes. Then the way of converting the factors to numerical indexes was mentioned base on EMME2 software and defined formula, where Tehran`s network database with all links characteristic had been applied on EMME2 software.

This part of the study represents how it is possible to weight the identified important factors. To approach to this problem an analytic hierarchy process (AHP) will be applied. The analytic hierarchy process is "a structured technique for organizing and analyzing complex decisions" Wikipedia.

Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time, with respect to their impact on an element above them in the hierarchy. In making the comparisons, the decision makers can use concrete data about elements, but they typically use their judgment about the elements` relative meaning and importance. The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes AHP from other decision making techniques (all AHP description from Wikipedia).

Since in this method all parameters is not compared with each other and it has been done two by two, the results for weighting should be more precise. An advantageous of this method is possibility to see consistency or inconsistency of decisions, which is a profit of multiple criteria decision making.

This method has a different way of application, one of the important which we have used for this study is nine degree AHP. In this method parameters compare two by two, and the importance of each one is compared relating to the other one. In order to reach the relative weight, a relative importance has been defined. The table below indicates the relative weighting.

Table 4-3-Expressions defines importance and its equivalent rating

A parameter`s importance with respect to the other one	Equivalent rating
Extend Perfected	9
Very strongly perfected	7
Strongly perfected	5
Moderately perfected	3
Equally perfected	1
Interval importance	2, 4, 6, 8

As the above table shows, each expression changes to scores from one to nine. The numbers represents relative weights, which can consider individually or combination of expert's opinions that in the second case requires geometric mean to reach to one answer as well.

After mentioned two by two comparison and applying geometric mean to make the average of expert`s opinions, then compared each double digits will be presented in matrix form. The matrix called comparison matrix. In this matrix, a_{ij} element, indicates the comparison between *i* th criteria and *j* th criteria with respect to the above table while satisfies below invariants and logical relations.

- Elements on main diagonal are equal to 1.
- Analogous elements on the side of main diagonal have inverse weight.

$$a_{ij} = \frac{1}{a_{ji}}$$

<div align="right">**Equation 4-6**</div>

- There is no infinity or zero value for matrix`s elements.

As it is mentioned, possibility of analyzing consistency and inconsistency on decisions in this method; represents if the decision is accepted or not. For instance assume A is two times more than B, and B is 3times more than C. Then if A`s importance be 6 times more than C, therefore the judgment called consistence. But in reality human decisions usually will not be like that with judgment consistency. For example, for someone that A`s importance is two times more than B, and B`s importance is three times more than C, there is no rule that this person consider A`s importance six times more than C`s importance. There is definition of inconsistency in decision.

To approach to this problem, consistency ratio (CR) is defined. It is an appropriate criteria, which is defined as a criteria to compare comparison matrix with condition that is filled randomly.

$$CR = \frac{CI}{RI}$$

<div align="right">**Equation 4-7**</div>

Where;

RI : Ratio index for the matrix which has been filled randomly.

CI : Consistency index for the matrix which has been filled by decision maker.

As it is clear from the above equation, in order to evaluate consistency ratio firstly it requires consistency index. Then;

$$CI = (\lambda - n)/n$$

Where;

λ : Maximum Eigenvalue of comparison matrix.

n : Number of elements

The below table reveals random index for matrixes with different dimensions, which is consistency index when the comparison matrix filled in by random.

Table 4-4-Consistency random index with respect to matrix dimension

Dimension	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Based on studies and mentioned concepts, lower value of *CI* and respectively *CR*, represents higher level of consistency in the comparison matrix. From the literature for *CR* more than 0.1, studies were not be satisfied and it requires new information.

Till now, comparison matrix with acceptable level of consistency is derived. In this part we are going to weighting parameters regarding Eigen Vector approach. The weighting process will be done, after all mentioned and required evaluation.

$$\{(A - \max \lambda \times I) \times W = o\}$$

$$\sum w_i = 1 \quad w_i \geq 0 \quad , i = 1, 2, ..., n$$

Where;

I : Identity or unit matrix *n x n*

A : Comparison matrix *n x n*

W : n – dimension column vector from criterion`s weight

w_i : An element of ith row from *W* matrix.

According to the base of this approach, comparison matrix should be filled in by experts, researcher and etc. regarding to comparison two by two of parameters, in case of increase in the number of these factors, thus the dimension of comparison matrix would be more as well. Because of complexity to fill in the enhanced matrix, the related factors are classified in different level to analyze them separately with its own matrix.
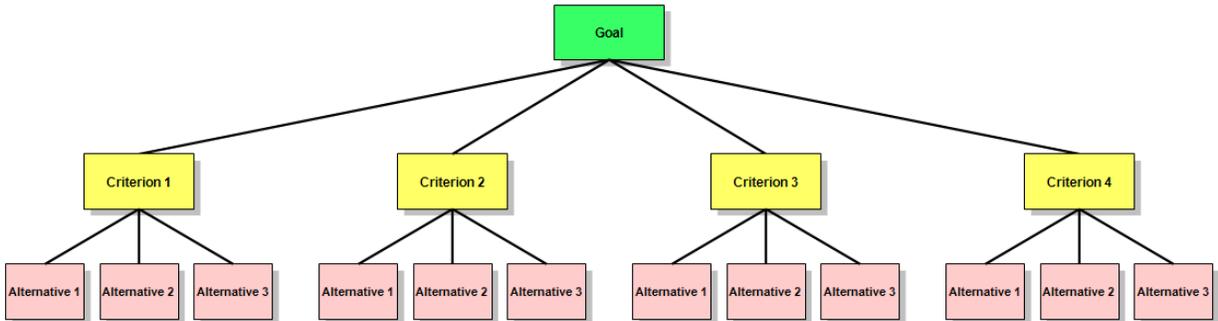

Figure 4-6-an overview of related criteria to reach to goal (base on AHP- source Wikipedia)

Base on mentioned points and approaching to acceptable comparison matrix, three main criterions is derived based on experts idea and previous studies. Then identified important factors are located as a subset under these main criterions. Three main criterions are recognized as "possibility to provide a rescue route", "appropriate accessibility to damaged points" and "reliability of a rescue route".

The below figure illustrates a hierarchy process for main criterions and alternatives for civil protection routing during an emergency.
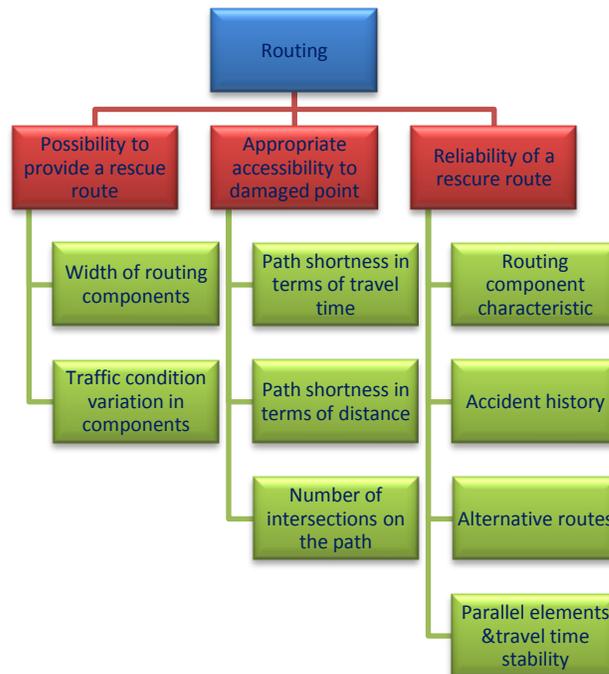

Figure 4-7-The hierarchy process main and alternative criterion for routing in an emergency

Base on AHP to fill in comparison matrix, questioners with respect to each criterion and its alternative subsets are designed. In this way each expert, manager, researcher or other relevant stakeholder member will fill in the matrixes, thus as a result the weight of important factors will be evaluated.

First of all in the first questioner we want to see the importance of three main criterions compare to each other. Where these three main criterions are: "possibility to provide a rescue route", "appropriate accessibility to damaged points" and "reliability of a rescue route".

Obviously equivalent rating which derived before indicates to choose the appropriate numbers.

Questioner No.1 – Identifying a rating value for effective important factors in routing process for civil protection in case of emergency

Expert`s Name: **Agency:**

Responsibility: **Academic Knowledge:**

This questioner is designed in order to compare importance of identified three main criterions; "possibility to provide a rescue route", "appropriate accessibility to damaged points" and "reliability of a rescue route", which has been recognized as three main factors in civil protection`s routing process during an emergency.

The value of importance for each of this triple criterion should be used according to the below table;

A parameter`s importance with respect to the other one	Equivalent rating
Extend Perfected	9
Very strongly perfected	7
Strongly perfected	5
Moderately perfected	3
Equally perfected	1
Interval importance	2, 4, 6, 8

Table - 1

Kindly compare the triple factor and fill in the below comparison matrix with respect to the above equivalent ratings.

Consideration:

- Analogous elements on the side of main diagonal have inverse weight.

$$a_{ij} = \frac{1}{a_{ji}}$$

- There is no infinity or zero value for matrix`s elements.

	possibility to provide a rescue route	accessibility to damaged points	reliability of a rescue route
possibility to provide a rescue route	1		
accessibility to damaged points		1	
reliability of a rescue route			1

Table – 2

Questioner No.2- Identifying a rating value for effective important factors in "reliability of a rescue route"

Expert`s Name:	**Agency:**
Responsibility:	**Academic Knowledge:**

This questioner is designed In order to reach the importance ratio of following four factors; "routing components characteristic", accident history on routing components", "availability of alternative routes in case of outgoing from the selected route", "availability of parallel elements with low violation in travel time (travel time stability)".

The way of comparison is same as description in previous questioner, base on equivalent rating on the table 1.

Kindly compare these four effective factors as a subset for *reliability of rescue route* criteria and fill in the below matrix.

Table - 3

	Routing components characteristic	accident history on routing components	alternative routes in case of outgoing from the selected route	Parallel elements & travel time stability
Routing components characteristic	1			
accident history on routing components		1		
alternative routes in case of outgoing from the selected route			1	
Parallel elements & travel time stability				1

Questioner No.3 - Identifying a rating value for effective important factors in "appropriate accessibility to damaged points"

Expert`s Name: **Agency:**

Responsibility: **Academic Knowledge:**

This questioner is designed in order to reach the important ratio of following three factors; "*Path shortness in terms of travel time*", "*path shortness in terms of distance*", "*number of intersections on the path*".

The way of comparison is same as description in first questioner, base on equivalent rating on the table-1.

Kindly compare these four effective factors as a subset for *appropriate accessibility to damaged points* criteria and fill in the below matrix.

Table - 4

	Path shortness in terms of travel time	Path shortness in terms of distance	Number of intersections on the path
Path shortness in terms of travel time	1		
Path shortness in terms of distance		1	
Number of intersections on the path			1

Questioner No.4 - Identifying a rating value for effective important factors in "possibility to provide a rescue route"

Expert`s Name: **Agency:**

 Responsibility: **Academic Knowledge:**

This questioner is designed in order to reach the important ratio of following two factors; "width of routing components", "traffic condition variation in routing components".

The way of comparison is same as description in first questioner, base on equivalent rating on the table-1.

Kindly compare these two effective factors as a subset for *possibility to provide a rescue route* criteria and fill in the below matrix.

Table - 5

	width of routing components	traffic condition variation in routing components
width of routing components	1	
traffic condition variation in routing components		1

4.2.4 Risk index evaluation

According to poll method and results from questioners, effective important factors in rescue routing process are identified. In addition in the second step each recognized factor is weighted, which takes an number from 1 to 9. Those with higher value of importance rating consider as a necessary component of the recue route for civil protection routing process, which is defined as "*feasibility criterion*". Then for links without minimum required condition then they will be eliminated from routing process. The elimination will be done by deactivating these links from the network in GIS software. Other identified criterions with lower importance weight compare to these factors are defined as "*risk criterion*" of a link.

After recognizing risk criterions and determination of different effective indexes in route`s risk, then in this part requires combination of values and appropriation of risk parameter to each link. There are many ways for these values combination and provide a unique function, however in this study linear combination is used to make the function for each link. In this way, the risk values for each link base on different indexes are combined with each other and turns to risk parameter for each link.

To reach to risk of each link according to weight function we have;

$$W_j = \frac{w_j}{\sum_{j=1}^{m} w_j}$$

Equation 4-10

Where;

W_j : normalized weight of factor *i*

w_j : weight of factor *i*, base on AHP

69

$_j$: identified factor as a risk criterion

Then in approaching to assess the risk, an appropriate index requires to produce a mathematical model to reach the goal.

$$RI = \sum_i W_i R_i$$

Where;

RI : Risk index for links

R_i : The index relates to risk factor *i*.

W_i : Normalized weight of risk factor *i*.

4.2.5 Appropriate route determination

According to the previous section, we have risk of each link in the network and now is the time to evaluate the risk for a route. It can be derived cumulatively from risk of each link. However the first step is to create the network, then in fallowing the way of determination an appropriate route with minimum risk will be presented.

4.2.5.1 A Network creation

Basically a network has a simple definition and formed by nodes and link, that topologically are connected to each other. All links are connected through the nodes, and transitions of vehicles occur via the links.

The network consider as a weighted graph. Transportation network is an oriented, weighted and connected graph.

According to the role and importance of travel time for rescue services in an emergency, selected route for civil protection service should prepare the shortness in terms of travel time from a rescue center to the damaged point. Therefore, routing for rescue services usually is compatible with shortest path in the network.

Basically, the shortest path is the one which the sum of each link`s weight is the minimum. In ideal condition, when there is no changes of traffic flow in time then it is possible to consider the link`s weight as travel time. In this method, for different time there is just one selected route. In case of traffic condition changes this method is not reliable at all. While, with respect to dynamism of the network and vehicle mobility in two dimensions of time and position; therefore these two factors consider as an significant parameter in routing process. But there is no way or so difficult to predict these two factor and apply to available methodologies. To solve the problem, a risk index is defined which is compatible with significant identified factors. It shows the probability of traffic changes in route from optimization.

In this study, the network with all required characteristic like intersections, motion direction and value of all important indexes is available and applied on GIS software.

As it is mentioned before, we have to eliminate some links which does not have appropriate condition with respect to studied criterions. The issue is done by deactivation of these links from the network in GIS software.

4.2.6 Dijkstra`s algorithm

To evaluate the most appropriate route in a network is a controversial issue. There are various algorithm bases on graph theory to solve the issue;

- **Dijkstra algorithm**: To find the shortest path for those with individual origin or destination and non negative weight.
- **Bellman-Ford algorithm**: To find the shortest path for those with individual origin or destination and negative weight.
- **Floyd-Warshall algorithm**: to find shortest path for all pairs in a weighted graph with positive or negative link weights but with no negative cycles.
- **Johnson`s algorithm**: to find the shortest paths between all pairs of vertices in a sparse directed graph.

As our transport network is non-negative link path cost, then Dijkstra algorithm is the best choice for the analysis. This algorithm is more appropriate compare to others, because in general case it uses in positioning information systems in (GIS) and it is also fast in calculations.

4.2.7 The Network reliability measurement

After identification of the best route, the next step is to see how the network is reliable in terms of rescue services to a damage area. To measure the reliability, we consider comparing travel time between proposed route and shortest route and analyzing the differences. Apparently, by decrement in these difference (proposed route is considered with travel time stability) the network would be more reliable and vice versa. If there is a sensible difference, it means the travel time in the route with minimum risk (proposed route) even if it has stability but the travel time is not desirable and the network for rescue services does not have good level of reliability.

$$\mathrm{Re}\,I = \frac{t_s}{t_r}$$

Equation 4-12

Where;

$\mathrm{Re}\,I$: Reliability index to the network

t_s : travel time in shortest travel time tree.

t_r **:** travel time in minimum risk tree.

5   Application of proposed methodology on the case study

In this part of the thesis, is the time to apply all part of proposed and discussed methodology to our case study which is the network of Tehran. It is assumed that an incident will happen in one of the crucial nodes which mean "Taleghani" metro station.

First of all the numerical values for identified important factors are calculated, in the second step as it is mentioned in methodology process is the time for weighting important criterions and it`s adjustment in following. After these steps each link requires its own risk index to approach to the most appropriate routes for civil protection services during an emergency.

For reliability analysis as we saw in the last section, after identification of the best route it requires travel time comparison in two routes; one with the minimum risk index and the other the shortest travel time accessibility. As we expect the difference of these two values represents the base of reliability study.

5.1   The case study area

"Taleghani" metro station is one of the main nodes in Tehran metro network. Park between the junctions with *Hemmat Expressway* and *Modares Expressway*. It is in Tehran Metro line 1, at the south of *Mirdamad Avenue*. The station host 90000 traveler each day, so consider as a station with high traffic. The below illustration reveals the position of this node in Tehran network.
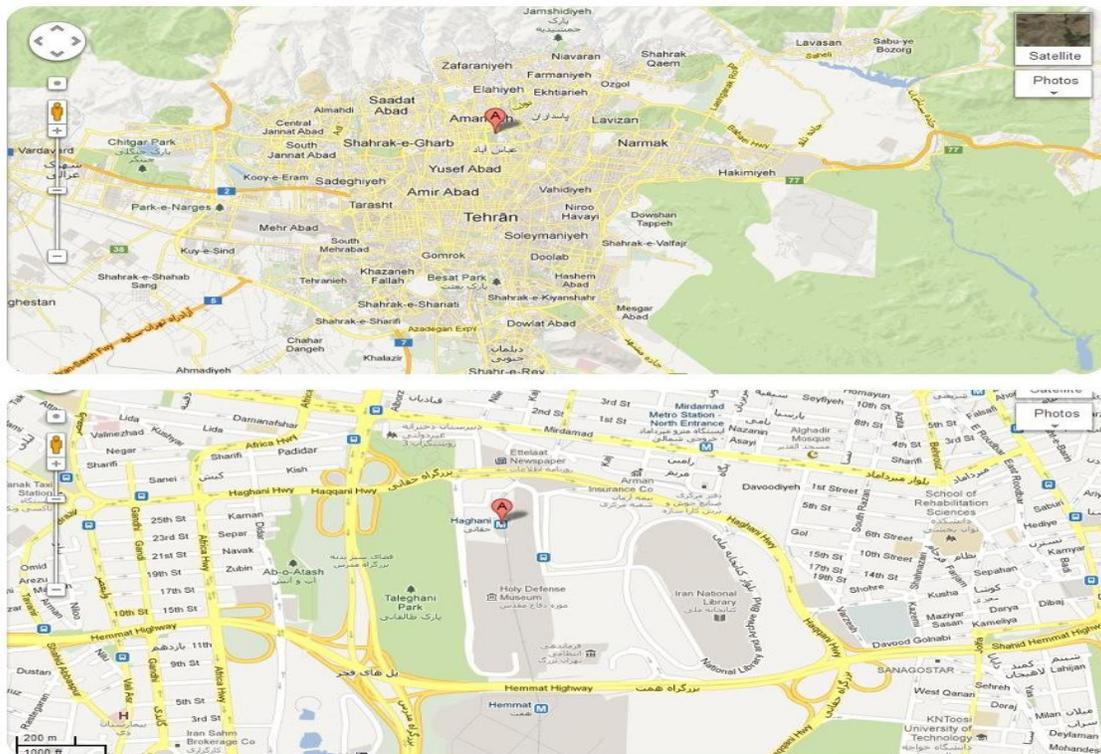

Figure 5-1-Haghani Metro station position in Tehran Network

5.2 Evaluation of numerical indexes for identified factors

According to interviews with relevant experts through the questioners and also with respect to previous studies nine effective factors on routing process are recognized which has been mentioned in previous section in detail.

To make these factors practical in the analysis, it is necessary to convert them from qualitative condition to quantitative one. Base on this concept numerical indexes are defined for each factor and the numerical values will be applied on the case study of Tehran network in order to routing and accessibility to *Haghani* metro station.

➢ **Width of the route`s component (WID):** In this study in order to reach to this factor`s numerical index value, it is used from Tehran network database in *Tehran comprehensive transportation and traffic studies Co.* Thus the file in txt format is available for this part. As the minimum width in routes for civil protection rescue process is 12 meter, then the links with less than 12 meter width in Tehran network are eliminated from routing process for civil protection during an emergency.

➢ **Traffic condition variation in rout components (LOS):** In this study in order to evaluate the traffic condition variation index, Tehran`s network simulation results will be useful. As the traffic condition in different hour of the day is a quantitative issue, where combination of that in different hour of the day in order to reach to a general condition of the network in a day is an impossible task. To solve the problem, an indirect methodology is applied; where it is done by dedicating the average volume of daily demand on the network. The demand matrices in different hour of a day are available from origin-destination database in *Tehran comprehensive transportation and traffic studies Co.* On the other hand because of flow condition with high level of service in the night (i.e. there is no limitation respect to this factor for routing process during a night) therefore, these averages are applied just from 6 to 22 as a high traffic condition. Tehran network simulation is available on EMME2 software and demand matrix is dedicated to the network on this software, the LOS information is applied as a txt file. At the end those links with defined level of service as "critical" and "slow" will be eliminated from Tehran network because they are not appropriate for routing process for civil protection services.

➢ **Travel time index (TIM):** In this study in order to reach to travel time in each link, desire travel time derives by dedicating daily average demand matrix where again in EMME2 is run and the outputs are in txt format. In the following from obtained results, according to Formula 4-1, the travel time index will be evaluated.

➢ **Length index (LEN):** For approaching to the shortest path length from the end of each link to the rescue centers Dijkstra algorithm on EMME2 software is used. Where the weight for each link is the length of the link, and is available on mentioned database of Tehran network. Results are dedicated for each link as a specific number in a txt file. From obtained results and according to Formula 4-2 we will reach to the length index.

➢ **Routing components characteristic (TYP):** In this part to reach to the numerical value, the Tehran network`s data base is used, which is available in *Tehran comprehensive transportation*

and traffic studies Co. The file relates to links characteristic and type is available in txt format and three specific number bases on the type of the link are defined as it shows on the table 4-2.

- **Number of intersections index (INT):** In this study in order to evaluate this parameter, Tehran network`s database is used, in case of intersection at the end of a link, the value 1 is dedicated to the link otherwise 0 value consider. It is notable that in the database, intersections are defined for nodes with at least three links.

- **Accident history on routing components (ACD):** In this study to evaluate this parameter, the data base of accident is used from *Transportation & traffic institute* of Tehran which is implemented in GIS environment. The number of accidents is derived by combining different layer`s information in GIS software. Then from the equation 4-3, related index for each links will be concluded.

- **Multiplicity of alternative routes in case of outgoing from routing path in emergency (ACP):** In this study to evaluate this parameter from dedicating results of daily average demand matrix in EMME2 software will be used. Therefore, at first it requires to evaluate the shortest travel time from each node at the end of each link to the damaged node. Then the number of routes will be calculated with travel time maximally 15 percent more than minimum derived travel time. To reach to this number of routes EMME2 modules is used, and it dedicated as an attribute to each link and the outputs are txt format files. Then at the end from final results and by formula 4-4 related index of each link will be calculated (15% is considered base on previous studies, experts choice, and related standards issues).

- **Multiplicity in availability of parallel components (PAP):** In this study in order to reach to number of accessibility paths from rescue centers to damaged area which pass from each link, same as other indexes from the results by dedicating daily average demand matrix in EMME2 is used. Base on it, shortest travel time from rescue center to damage point is calculated, and same as the previous index those routes with travel time maximally 15 percent more than minimum derived travel time are identified. To reach to this number of routes EMME2 modules is used, and it dedicated as an attribute to each link and the outputs are txt format files. Then at the end from final results and by formula 4-5 related index of each link will be calculated.

In addition, it is considered that till now we have compared different factors which are being done in a qualitative way (i.e. we have mentioned which link has a better level of service). Then in some cases important factors are identified with some values (i.e. they already have their numerical values, such as length, width) however interesting point here is to have all the values in a same manner because even numerical results are not comparable. For approaching to the problem normalization method is applied on all factors, all mentioned formula has done this interesting perspective and we will have all values between 0 to 1 and are comparable now, and all result are available as a txt file for each link.

5.3　Weight identification of the important factors

As it is described in methodology part, in this step the important task of weighting will be done. The weighting process is based on AHP methodology. The figure 4-7 represents whole scheme of this approach for this study, where three main criterions is defined base on researches and questioners. The weighting evaluation requires two by two comparisons, which is done through the designed questioners. To avoid any bias on each experts answer in factors identification, thus in this part new experts are used for filling comparison matrixes. Involved organization and stakeholders are used to fill in the questioners, however from their websites and also publications their attitude to the problem is studied as well (like Crisis management Institute of Iran, Prevention and Crisis management Institute of Tehran, Fire department organizations, Medical emergency, Police, universities and researchers).

Here there are all experts' results and some comparison matrixes are filled in by study researches and available from related studies. The point is we have different comparison matrix for each point of view, the interesting point is to approach to a unique matrix as a final result. It would be different methodology to merge these matrixes and get a one regarding all imposed opinions. From using some software such as Expert choice which usually use for nonlinear and complex AHP models, to simple geometric mean for linear and simple AHP models. Here we are working with a simple and linear AHP model so we can use the below formula to reach to geometric mean.

$$a^f_{ij} = (\prod_{k=1}^{m} a^k_{ij})^{\frac{1}{m}}$$

Where;

a^f_{ij} : Which is an element in the row *i* and column *j*, in the final comparison matrix.

a^k_{ij} : Which is an element in the row *i* and column *j*, in the comparison matrix of Kth questioner.

m : Number of comparison in questioners which is compatible with final matrix.

In this way with respect to weighting analysis, final results of important weights factors are derived respect to the below table.

Identified Important factors in routing process	Index	Main criterion index	weight of subsets	weight of main criterion index	Final important weight
Routing components characteristics	TYP	Reliability	0,071	0,156	0,011
Accident history	ACD		0,113		0,018
Availability of alternative path	ACP		0,573		0,089
availability of parallel path	PAP		0,243		0,038
Path shortness in terms of travel time	TIM	Accessibility	0,607	0,343	0.198
Path shortness in terms of length	LEN		0,223		0,076
Number of intersections	INT		0,17		0,058
width of routing components	WID	Possibility	0,567	0,501	0,284
Traffic condition	TRF		0,433		0,227

Clearly from the above results, two factors "width of routing components" and "traffic condition variation in routing components" are recognized with more importance respect to others. Thus, considers as the most important factors for routing process for civil protection services during an emergency. These two factors are subsets of possibility main criterion, where there are defined as feasibility indexes.

5.4 Risk index identification

As it is derived from the previous section, two factors "width of routing components" and "traffic condition variation in routing components" mentioned as the most important factors, because of higher weight respect to others and they called *feasibility indexes.* Those links which could not satisfy both feasibility indexes requirement then will be eliminated from the routing process. The other seven factors, which have lower weight respect to feasibility indexes, are characterized as a *Risk indexes.* For approaching to indentify risk parameter in each links, it requires linear combination of these risk indexes regarding to refined weights.

It is notable, risk indexes are derived from normalized weight of *risk indexes*; where two *feasibility indexes* are eliminated. The below table reveals the value of these refine weights.

Table 5-2 Refine weights of effective factors on risk of each link

Final weight	Risk indexes
0,023	Routing components characteristics
0,037	Accident history
0,182	Availability of alternative path
0,078	availability of parallel path
0,406	Path shortness in terms of travel time
0,156	Path shortness in terms of length
0,119	Number of intersections

Regarding to the above table we have risk index for each link as the below formula;

Equation 5-2

$$RI = 0.023\ TYP + 0.037\ ACD + 0.182\ ACP + 0.078\ PAP + 0.406\ TIM + 0.156\ LEN + 0.119\ INT$$

Therefore, to approach to risk parameter of each link it just requires the numerical value of each effective index to put them in the above equation.

5.5 Evaluation of shortest path

In previous sections the way of evaluating feasibility parameters for each links in routing process for civil protection rescue services has been done. In following, we saw how to reach the risk of each link with respect to evaluation of numerical value of risk indexes and important factors. There for till now the base of routing process has been done. Here GIS software would be useful for implementation of the network and analyzing all derived data and information. Therefore TransCad software has been chosen as GIS base software, where we can apply all the data relates to risk of each link.

TransCad is Geographic Information System designed specifically for use by transportation professionals to store, display, manage, and analyze transportation data. TransCad combines GIS and transportation modeling capability in a single integrate platform, providing capabilities that are unmatched by any other package. TransCad can be used for all modes of transportation, at any scale or level of details. TransCad provides:

- A powerful GIS engine with special extensions for transportation

- Mapping, visualization, and analysis tools designed for transportation applications

- Application modules for routing, travel demand forecasting, public transit, logistics, site location, and territory management

Base on Caliper Corporation in TransCad introduction.

In this way, all require data for evaluating risk of each links and also paths on GIS layers are applied on software`s environment. On the other hand, location of the rescue centers and Haghani station as a damaged point is implemented on it. All computations for routing process or other calculations will be done in TransCad software.

In following by study relating information to paths width as one of the feasibility indexes, those links with width less than 12 meters eliminated. This limitation is considered, because of impossibility of civil protection`s vehicles transition in paths with this characteristic.

The second feasibility index had been identified as a traffic condition variation, here from information column relates to this index, all links which host "critical" and "slow" traffic condition are eliminated. This limitation is considered, because of congestion in these paths and impossibility of changing the lanes for other vehicles to make possibility for civil protection transition.

At the end, regarding the defined risk index for each link, the best tree path will be presented. The best tree path is derived, base on the minimum risk from all rescue centers to Haghani station as the damaged node using Dijkstra algorithm.

6 Results

The accident history as one of the important identified factors, can be presented according to putting different information layer and the final results is derived as the below illustration which is TransCad software. Higher number represents a link with more accident history. The data are collected from (Transportation & traffic institute).
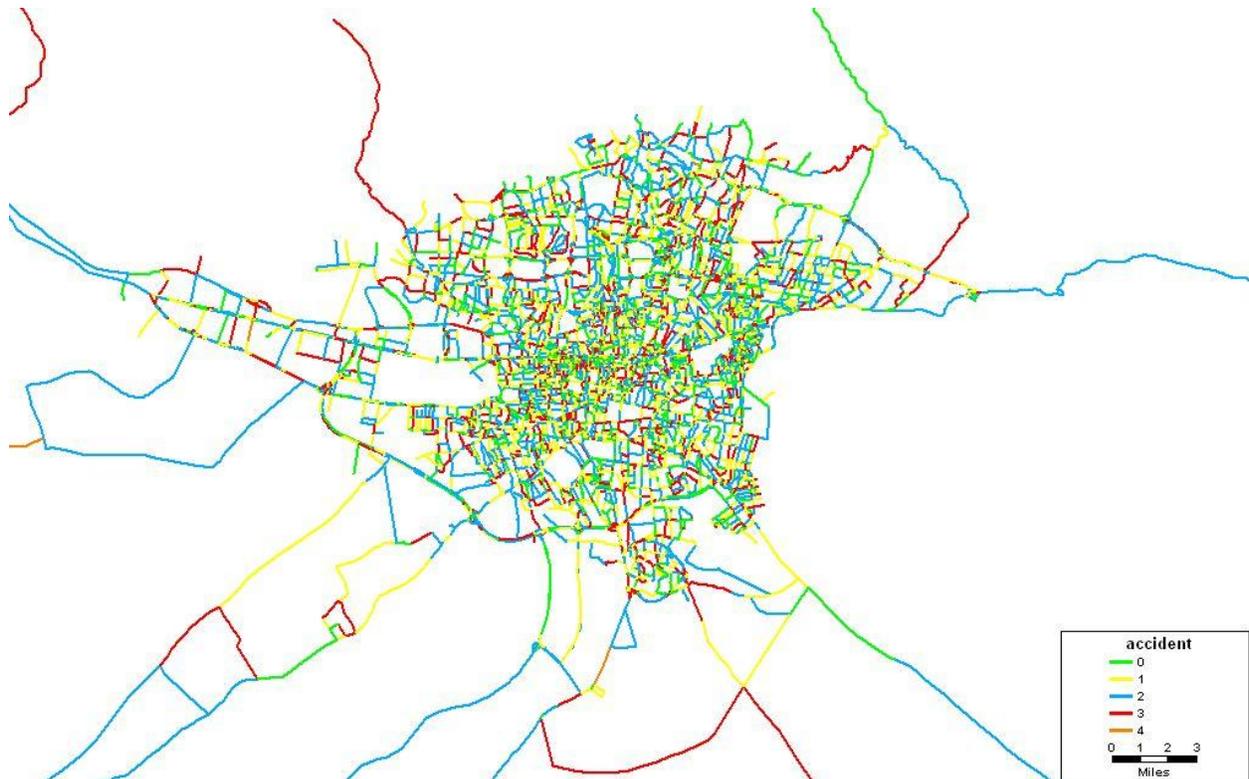

Figure 6-1 Accident history on routing components

The limitation of width for each link is applied on the network, where the links which has width less than 12 meter is eliminated because it is consider as a required condition for possibility of routing process in emergency for civil protection. The below exported illustration indicates the links with appropriate width and none appropriate which does not have enough width.
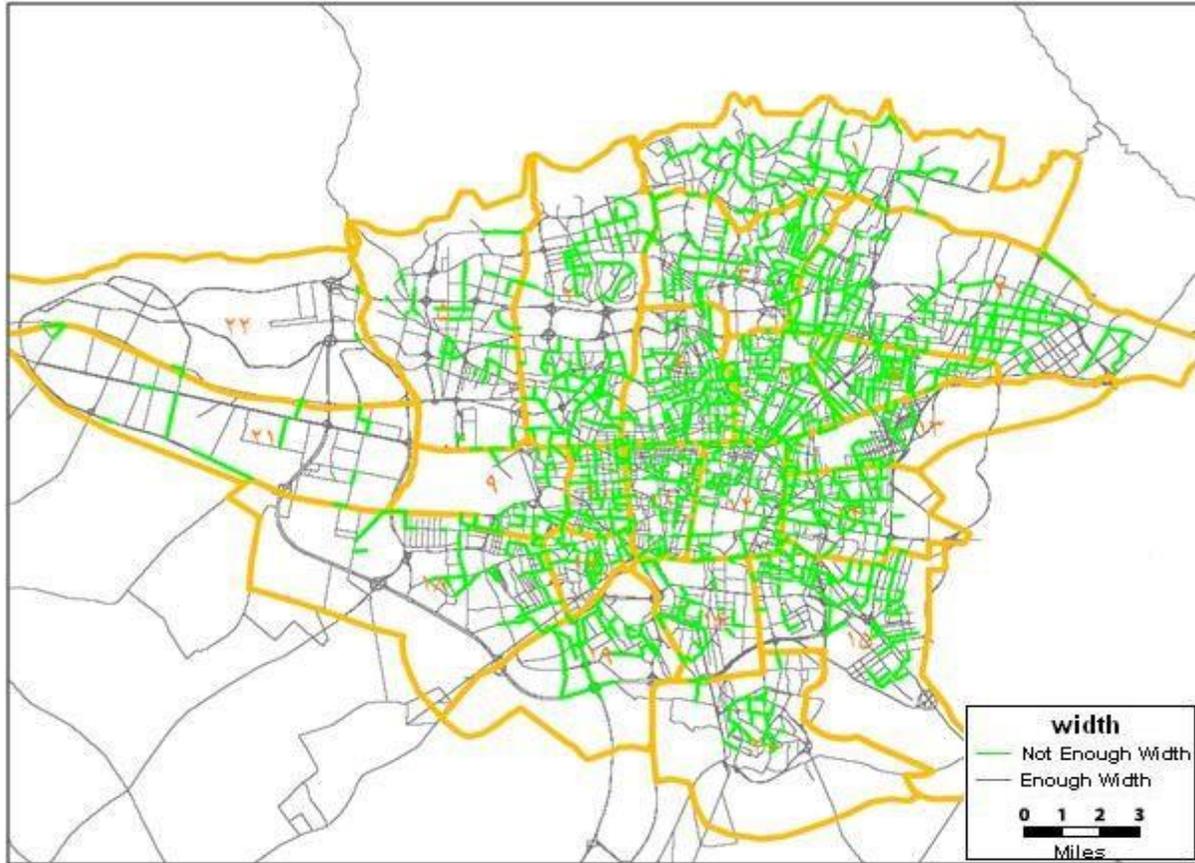
Figure 6-2 eliminated links and appropriate links respect to the width factor
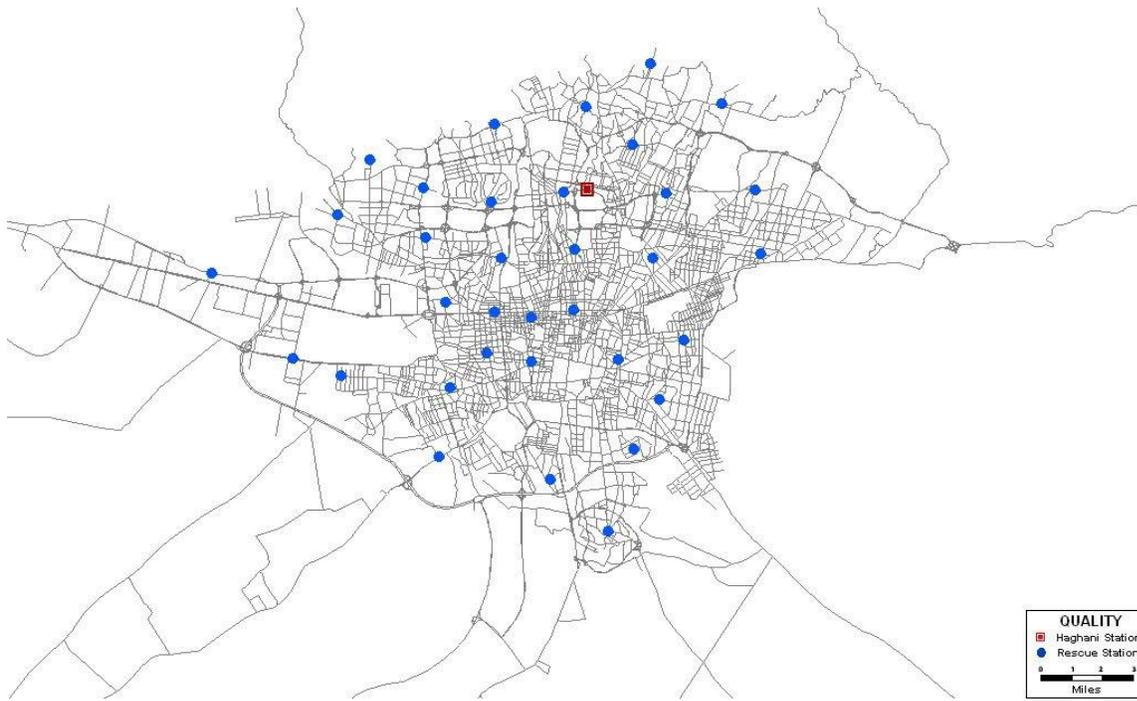

Figure 6-3 location of all rescue centers and Haghani station

80

The above map represents the position of the damaged point (Haghani Metro Station) and all rescue centers in Tehran network.

The second significant factor, which is carried out from weighting process is identified as traffic condition variation on each link. The factor has higher sensible weight, which links without appropriate level of traffic condition cannot be as a path`s component.
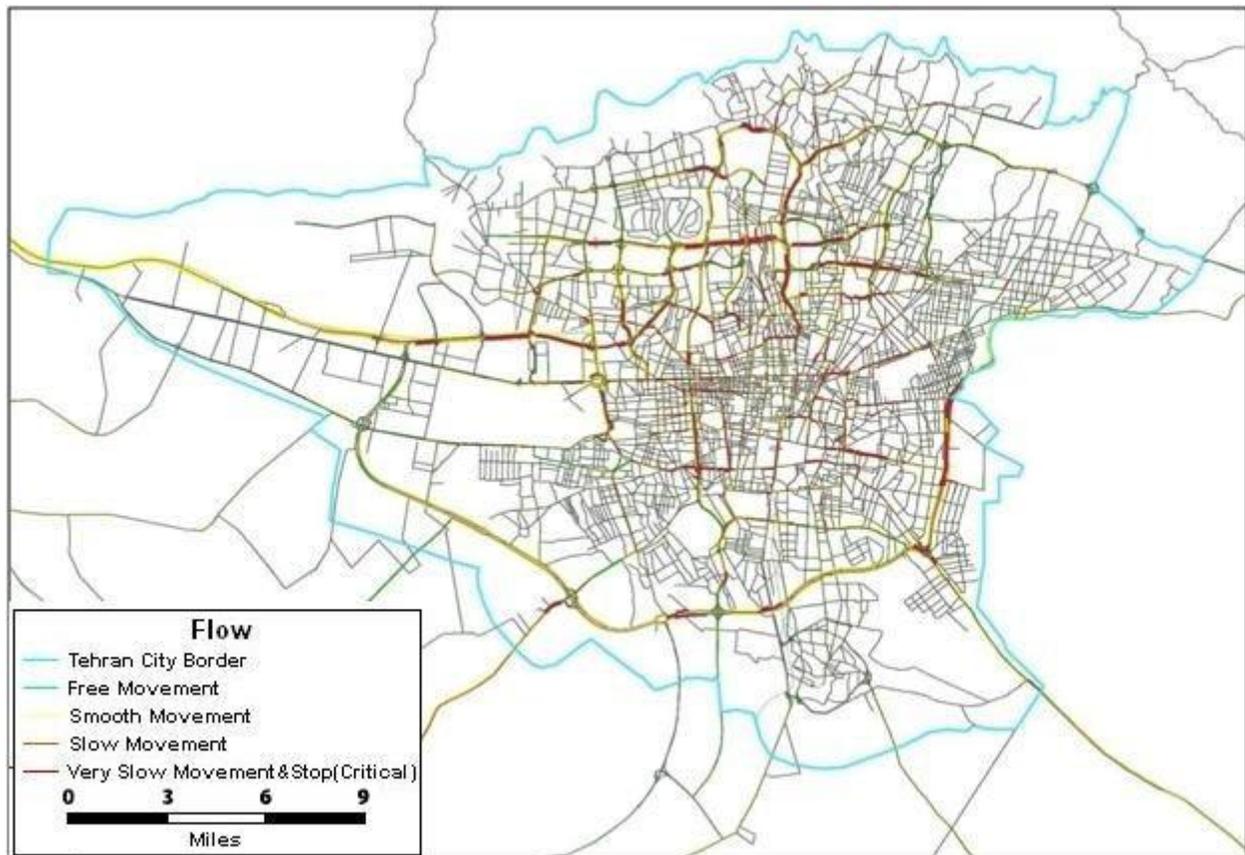

Figure 6-4 Traffic flow condition in Tehran network

By eliminating two *feasibility index,* and weight normalization we saw how it is possible to reach to the *Risk index.* The formula is derived to calculate the risk of each link, by applying the formula on TransCad as a table, the index can be presented in two way, by colors and by link`s thickness.

The two following maps represents risk index for each link with the two mentioned presenting way.

Figure 6-5 Risk index represented by colors

Figure 6-6 Risk index represented by thickness

From the final results, base on defined risk index on TransCad; the risk parameter of the most appropriate tree path from rescue centers to the damaged node calculated as 1487. Then the travel time for the tree path is calculated equal to 562 minutes base on proposed methodology.

On the other side, travel time for the most appropriate tree path but just base on travel time is derived as 492 minutes. By comparing these two travel time, it is clear that the difference is about 14.2 percent. From civil protection standards which are studied in Tehran this difference could be maximum 15 percent.
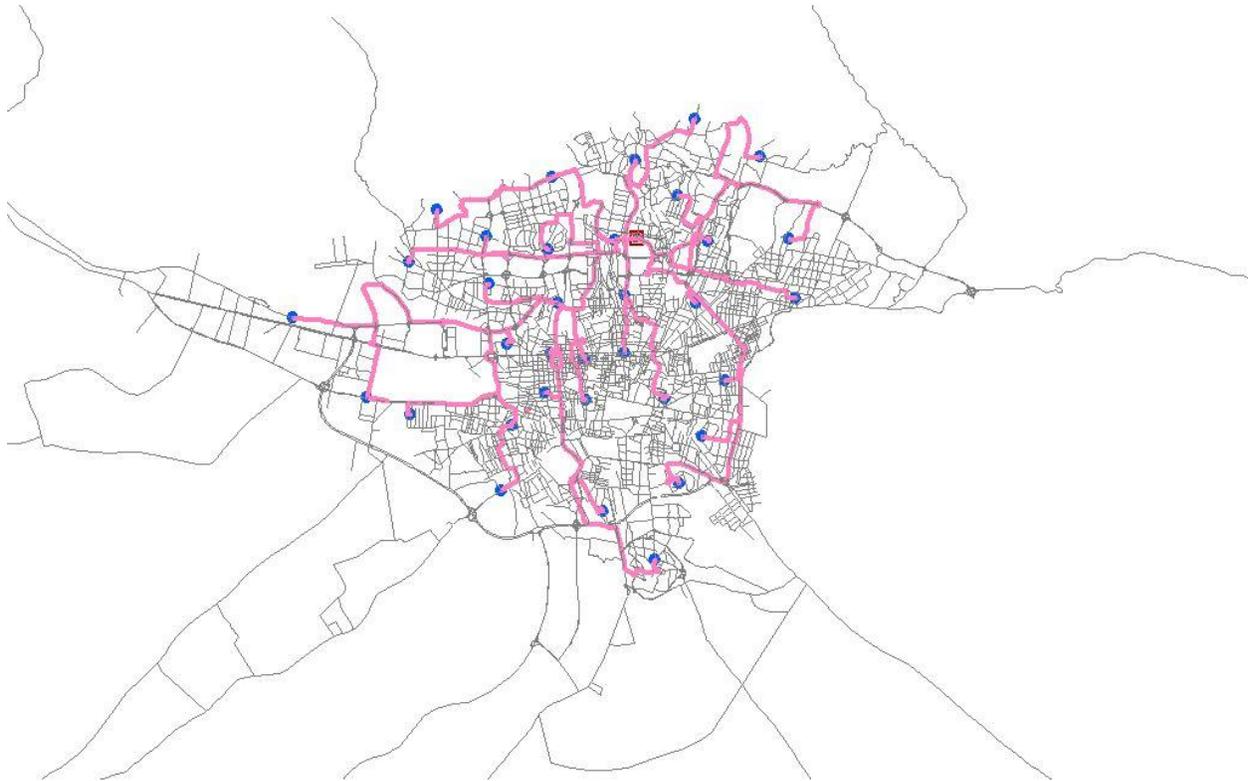

Figure 6-7 Tree path base on links risk index

Therefore, the proposed methodology can be considered as a practical approach. Which identified paths make accessibility to the damaged area in a reasonable travel time and also regarding to the motioned difference between the path respect to travel time and the other respect to minimum risk the chosen path consider with high level of reliability.
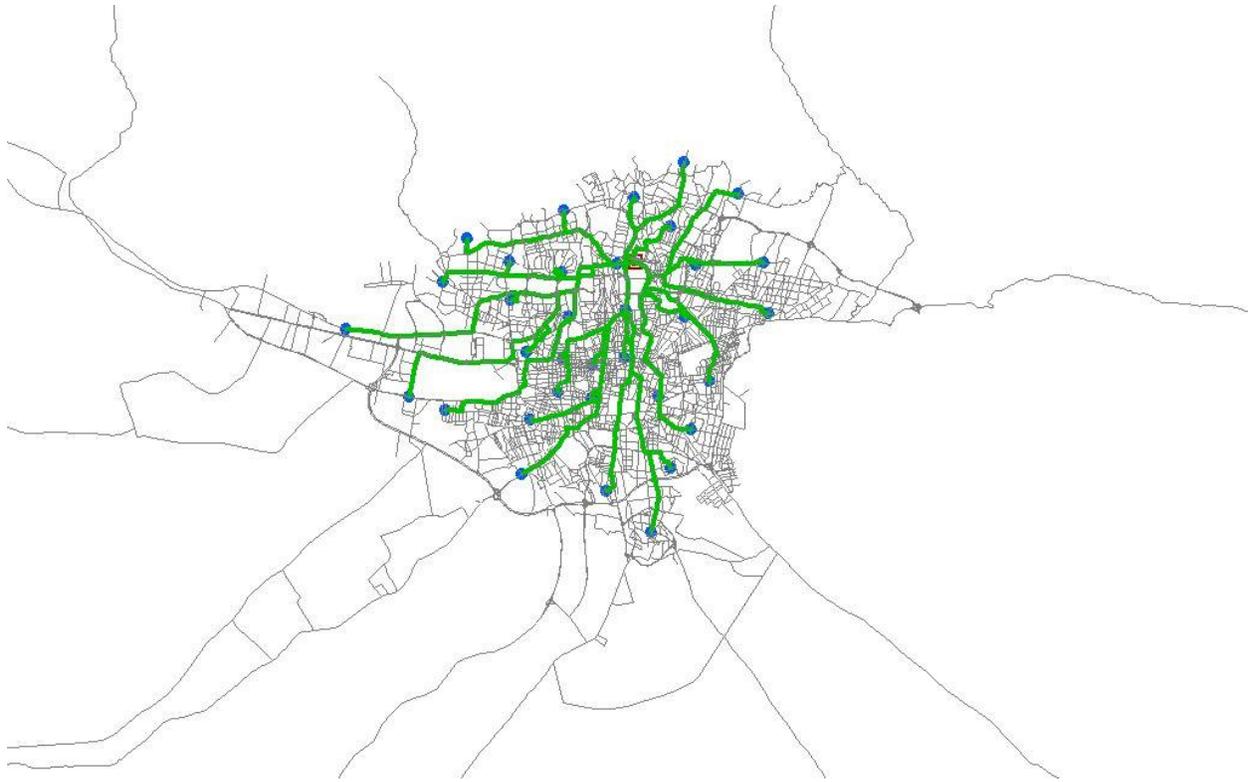
Figure 6-8 Tree path base on shortest travel time

The difference between the tree path base on shortest travel time and minimum risk represents appropriate reliability of the proposed methodology.

Regarding to the topic of this study it is interesting to also have an idea about vulnerability condition of the links in Tehran network. Since all important factors are identified and base on AHP subsets are classified, then the below map carried out with the lack of required factors. The link that does not have these characteristic; is more susceptible to any *incident,* thus it lead to considerable malfunction and reduction in the network serviceability.
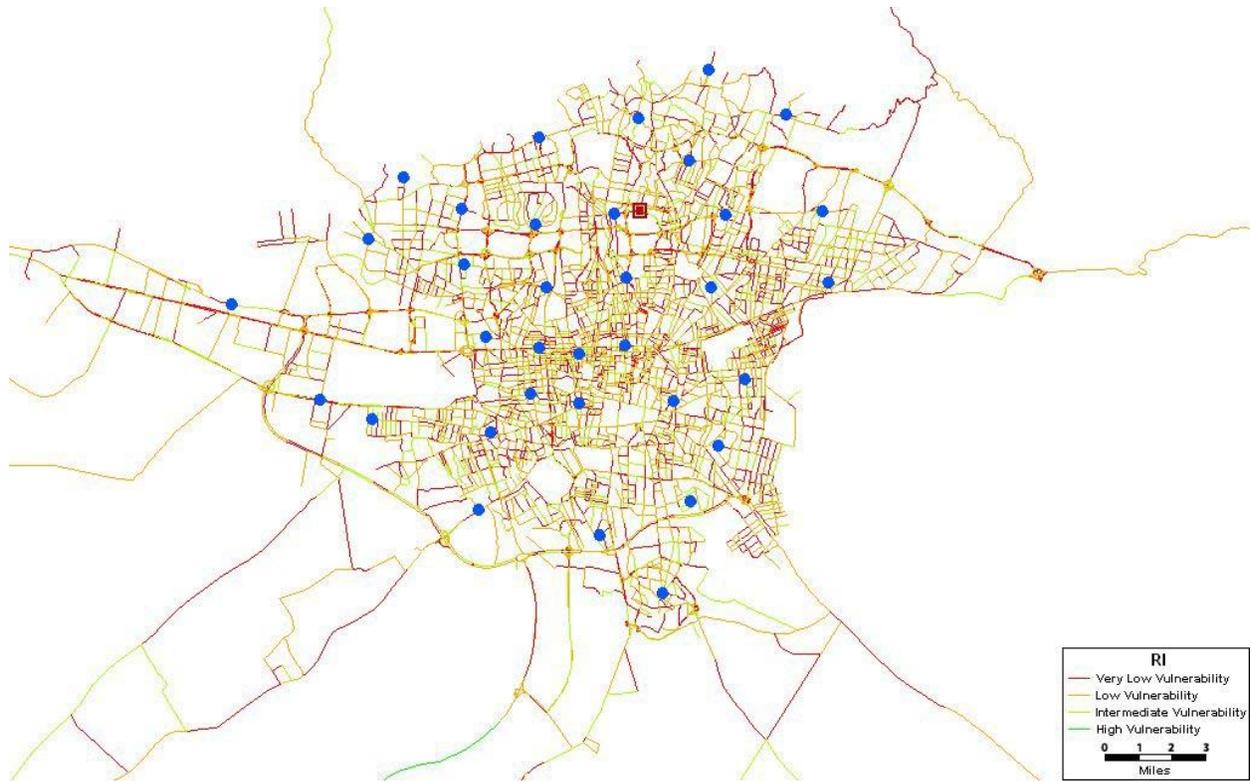
Figure 6-9 Tehran road network vulnerability

7 Conclusion

Road network vulnerability assessment is not long time which attracts studies on itself. Not only as hosting people with the goal of usual transportation but also in maintaining, scouring and repairing aspects. A Road network considers as an assist for other infrastructures, and during an emergency it has a crucial rule. In degradable road network the study is not just for major disasters. The importance of the road networks requires comprehensive study to see how the road network can work in different aspects, how sustainable it is; level of reliability of components and what is the weaknesses and strength of the network for reaching the goals.

This study represents the concept and the way of approaching to the issue. Although qualitative attitudes requires for understanding the notion of vulnerability but the key point is the way of thinking for each stakeholder to reach to the problem. By adjusting all participants with their own way of approaching to the problem – on different steps like managing, constructing and planning – the goal of welfare society would be more touchable.

The proposed methodology contains assumption and hypothesis base on studied information, where sensitivity analysis can apply on discussed factors; in order to see probable differences on weighting results and routing process. Thereby, for road network vulnerability assessment charge of different stakeholders it is inevitable so it makes complexity of the issue. It requires identification of essential components for approaching to vulnerability analysis.

At the end, such a study for vulnerability assessment on road networks is done in order to determine the degree of fragility on the defined incident. In a large scale, to see robustness of the road network and all relevant stakeholders; in order to react and withstand in case of disaster.

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