Evacuation Times Estimation with Dynamic Simulation Systems: The case of a Nuclear Power Plant

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Signed Univ.-Prof. Dr.-Ing. Fritz Busch
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ABSTRACT

Since the unfortunate incidents in Three Miles Island, Pennsylvania in 1979 and in Chernobyl, Ukraine in 1986, emergency preparedness and evacuation plans concerning Nuclear Power Plants (NPP) have aroused increasing attention of transportation agencies. These emergency evacuations cause significant levels of congestion inside the disastrous area of the NPP, alongside the evacuation routes and nearby the evacuation destinations (shelters, hospitals, relatives etc.). This master thesis describes a general methodology of an Evacuation Times Estimates (ETE) study regarding a NPP using dynamic simulation systems. Although most of the recent studies focus on traffic problems nearby the area of a Nuclear Power Plant, the current paper examines the framework under which effective strategies of managing traffic would be feasible to reduce the congestion levels of the wider area by performing the mesoscopic simulator. This study adopts the dynamic user equilibrium and the dynamic traffic assignment based on the mesoscopic traffic network planning and simulation model of Aimsun and applies the model to a network where a NPP is located. The paper then presents the effectiveness of traffic control and management strategies including intelligent transportation systems and contra-flow operations based on an assumed scenario in which evacuation traffic of the Emergency Planning Zone heads towards the highways and the major streets in case of an incident in an NPP.

Scope: The paper deals with the technical and operational aspects of an ETE study, suggests a new dynamic simulation method in accordance with nowadays necessity of worldwide regulations in order to help transportation agencies in improving emergency preparedness plans for their networks to receive possible emergency evacuation traffic.

Objective: The objective of this paper is to suggest an ETE methodology using dynamic simulation systems and to evaluate the effectiveness of various Traffic Management Strategies (TMS) implementation.

Approach: This paper uses the case study to present and identify the previous ETE results, to apply a new dynamic simulation method performing the mesoscopic simulator of Aimsun and to evaluate its effectiveness through the determination of various demand scenarios and TMS. Finally, it follows the comparison of the current ETE results with the results of the previous ETE report.
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INTRODUCTION

1. INTRODUCTION

Human populations are in danger from various hazards caused either by man-made activities or natural phenomena. Nevertheless, in the case of an accident, emergency preparedness plans play a vital role in ensuring safety, security, and efficiency of an urban area transportation system. As Pidd quotes, in order to cope with such hazards, three possible approaches can be followed: (a) better and safer designs, (b) installations in a reasonably safe distance from population centers, and finally (c) well-tested plans in case of emergency, such as the Evacuation Times Estimates (ETE) studies (Pidd et al., 1996).

After the unfortunate incidents in Chernobyl, Ukraine in 1986 and in Three Mile Island (TMI), Pennsylvania in 1979, it has been proved that every nuclear industry takes its toll not only on the nearby region, but also on the wider area of each Nuclear Power Plant (NPP). The World Health Organization states that in the nuclear accident of Chernobyl, apart from the fatalities due to the Acute Radiation Syndrome (28 persons died in 1986 and 19 in 1987-2004), there will ultimately be a total of 4,000 deaths, due to increased cancer risk (WNA, 2010). In addition, about 116,000 people, who reside at the areas surrounding the reactor, were evacuated immediately (WHO, 2006). In TMI, even if there were no immediate deaths or injuries caused by the accident, a study conducted by the University of Carolina found that lung cancer, infant mortality and leukemia rates were two to ten times higher downwind of TMI than upwind. Schools were closed and residents were urged to stay indoors as well as pregnant women and pre-school age children advised to evacuate within a five-mile radius of the NPP. In total, 140,000 people had left the area (U.S.NRC, 2009). Since then, all local, regional and state authorities sought to develop emerging planning procedures related to nuclear incidents.

The reasons behind the development of emergency plans when it comes to NPP are obvious yet very much important. Their objective is to help avoid any incident or in case an incident occurred, to eliminate the radiation exposure to the public (Cutter, 1984). In the latter case, a probable restraint of the subjection to harmful chemicals can be achieved through actions that aim to restrict the intensity of these phenomena, to mitigate their duration and to establish protective measures for the employees and the population. In order to struggle with such panic and chaotic situations, aside from protective actions, such as providing sheltering or medical precautionary measures, the evacuation of the population from the exposure area may be obligatory. During the last years, several studies suggest a further multidisciplinary research in organizational, technical, scientific and psychological issues in order to enlighten the decision-making process of the planners (Georgiadou et al, 2007).
At the most fundamental part, ETE analysis aims to estimate the evacuation traffic demand and compare it with the roadway capacity. According to the Nuclear Regulatory Commission (NRC), ETE studies must be conducted for all existing and future-planned NPP. It is the aim of the ETE study to predict the time required for partial or entire evacuation of populations within 10 miles radius of the facility. The general objectives of an ETE analysis are: (a) to provide data to emergency decision-planners in order to assess whether the evacuation of an area is mandatory or not, (b) to determine whether the evacuation process is considerably influenced by unexpected events such as adverse weather, and finally (c) to assess the effectiveness of various Traffic Management Strategies (TMS) (Urbanik, 2000).

An ETE analysis is associated with various network topologies and population numbers and it is a time-demanding process. In order to improve the efficiency of the computational methods in terms of time and results, the emergence of multiple-level simulator models (Micro, Meso and Macro), proved that it can achieve such goals while allowing the configuration of different scenarios. In order to execute such a procedure, it is not only the quality of the input data that should be calculated and imported carefully into the model, but also the estimation of the different scenarios concerning the demand as well as the potential implementation of various TMS.

It is the goal of this project to explore the framework under which the evacuation time estimations regarding a NPP is feasible by setting up a general methodological approach using dynamic simulation models. The paper will shed light on the appropriate conditions needed to force a dynamic simulation process for evacuation by defining different demand scenarios of uncontrollable and controllable variables (travel demand, roadway capacity, road characteristics, route choice behavior etc.) in combination with a certain amount of potential TMS. In addition to that, the current limitations using static simulation models will be reported.

The methodology is then applied in a specific case study, where an NPP is located. The information about this case study is confidential and therefore specific information regarding the location of the NPP is not allowed to be published. The mesoscopic model with dynamic simulation characteristics, Aimsun was used to perform the dynamic simulation process. Two different demand scenarios of a representative day (morning peak hour and night) were defined, analyzed and compared with previous ETE study results (static simulation methods). Furthermore, various TMS were implemented. Aside from the Do-Nothing scenario, two more scenarios were concerned: a) the Manual operation scenario (Road Closures) and b) the Advanced TMS plan for emergency situations (plus Contra-Flow operation). All simulation tests results of the previous and the current ETE study have been presented, analyzed and compared among them.
2. STATE OF THE ART IN EMERGING PLANNING IN NUCLEAR POWER PLANTS

2.1. Definitions and History of the Emerging Planning in Nuclear Power Plants

Prior to 1979, procedures for emergency planning and preparedness in Nuclear Power Plants (NPP) were not fulfilling all the appropriate operational criteria. In addition, since the nuclear energy accidents in Three Mile Island, Pennsylvania on March 28th, 1979 and Chernobyl, Ukraine on April 26th, 1986, the emergency planning and preparedness process is considered as prerequisite for any nuclear power industry. Moreover those harmful accidents, the terrorist attack on September 11th, 2001 in United States, the bombing incidents in Bali as well as the London wildfires determined emerging planning and preparedness plans more important than ever. International Atomic Energy Agency (IAEA), published a report which defines when emergency planning in a nuclear site is necessary: “The sequence of events where the well-established standards, rules, regulations and procedures governing the use of radioactive materials and the normal operation and maintenance of a facility are no longer being satisfied” (IAEA, 1982).

Emerging planning and preparedness includes procedures to evaluate the evacuation time that the population of an area needs to evacuate once an emergency occurs. Federal Nuclear Emergency Plan (FNEP) of Canada defines nuclear emergency as: “any event which has led or could lead to a radiological threat to public health and safety, property, or the environment” (FNEP, 2002). In light of such an event, emergency planning and preparedness is being strongly associated with all transportation responsive measures that should be imposed after the notification release of an incident until the full recovery of the abnormal conditions. During that period the normal rules will no longer exist and therefore the appropriate decisions will play a fundamental role in order to minimize the risks and avoid any adverse implications in any residential areas in vicinity to a NPP (Collins & Emmerson, 1982).

From the institutional point of view, all emergency plans should comply with the guidelines and criteria of local, state, federal and international agencies with jurisdictional authority. The first endeavor, which was conducted by Nuclear Regulation Commission (NRC) in cooperation with the Federal Emergency Management Agency (FEMA) addressed as NUREG-0654/FEMA-REP-1, provided only limited guidance on Evacuation Times Estimates (ETE) preparation. The fundamental development of guidelines by these two agencies was divided into 16 categories, each of these, includes a certain number of evaluating criteria (81 for
local plans, 98 for state plans). During the last years, several regulations and guidelines have been imposed mainly by the U.S.NRC. Table 1 displays the entire history of U.S. federal regulations in a chronological order.

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<th>Year</th>
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<td>1946</td>
<td>AEC Congress first established in the Atomic Energy Act</td>
</tr>
<tr>
<td>1954</td>
<td>Replacement of the law Atomic Energy Act and the development of commercial nuclear power possible</td>
</tr>
<tr>
<td>1960</td>
<td>High number of critics against AEC regulations that were insufficiently rigorous in radiation protection, reactor safety, plant siting, environment protection</td>
</tr>
<tr>
<td>1970</td>
<td>AEC issues first rules requiring discussion of on-site emergency plans</td>
</tr>
<tr>
<td>1973</td>
<td>AEC issues WASH-1293 giving guidance to state and local governments n preparation of non-mandatory off-site plans for the LPZs</td>
</tr>
<tr>
<td>1975</td>
<td>NRC reissues WASH-1293 as NUREG 75/111</td>
</tr>
<tr>
<td>1977</td>
<td>NRC supplements NUREG 75/111 with 70 essential elements necessary for NRC concurrence</td>
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<tr>
<td>1978</td>
<td>NUREG-0396 concludes it is necessary to plan for a spectrum of accidents beyond DBAs, and recommends abandoning the concept of LPZs in favor of two EPZs with radius of 10 and 50 miles</td>
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<tr>
<td>1979</td>
<td>The Kemeny Commission recommends that FEMA take lead responsibility for emergency planning, and that licensing be conditional on approved off-site plans. President Carter embraces these Commission recommendations</td>
</tr>
<tr>
<td>1980</td>
<td>Federal regulations (10 CFR 50 and Appendix E) are amended accordingly. NUREG-0654 provides criteria for the development, review and approval of off-site plans</td>
</tr>
<tr>
<td>1987</td>
<td>NRC proposes relaxing the regulations for state and local government participation on off-site planning</td>
</tr>
<tr>
<td>1988</td>
<td>NRC published a rule for decommissioning of plants</td>
</tr>
<tr>
<td>1990</td>
<td>NRC published a policy statement to establish rules and procedures by which small quantities of low level radioactive materials could largely exempted from regulatory controls</td>
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<tr>
<td>1991</td>
<td>NRC voted to issued regulations for required adequate programs of all commercial nuclear plants and approved regulation on the technical requirements for license renewal</td>
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<tr>
<td>1995</td>
<td>Commission unanimously approved the application of probabilistic risk assessment</td>
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<tr>
<td>1998</td>
<td>Commission indefinitely suspended the &quot;Systematic Assessment of Licensee Performance&quot; program (created in the wake of the T.M.I. accident), efforts to promote the safe use of materials and the safe operation of nuclear power plants</td>
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According to the U.S.NRC, when an incident happens in a NPP, the proposed emergency response actions for protecting the population from any probable devastating implications depend upon the importance of that incident. Figure 1 below depicts the evaluation of seven emergency response measures that should be taken prior or subsequent to an incident in a NPP.
2.2. Evacuation Time Estimates for Nuclear Power Plants

Since the publication of NUREG-0654 / FEMA-REP-1, Rev. 1 (NRC, 1980), many licenses of local and state agencies have been developed. These licenses entail the detailed radiological emergency management program for every NPP. Taking into consideration the intention of these programs to be efficient and comprehensive, evacuation planning must be a part of the emergency planning. The evaluation of previous ETE reports has encouraged the authorities to develop a Protective Action Recommendation (PAR) plan in case of an emergency, which embraces actions such as sheltering, evacuating or use of prophylactics measures (masks or thyroid blocking agents). FNEP defines sheltering as: “The use of a structure for protection from an airborne plume and/or deposited materials. The structure can attenuate radiation from radioactive materials deposited on the ground and reduce exposure to airborne plumes” (FNEP, 2002). In the same report, evacuation is defined as: “The rapid removal of people from an area to avoid or reduce high-level, short-term exposure to a hazard”. Finally, the use of prophylactics measures such as masks or thyroid blocking agents is also defined as: “A substance that prevents or reduces the uptake of radioactive iodine by the thyroid. Usually stable potassium iodide (KI) is taken orally for this purpose” (FNEP, 2002).

Previous studies of large-scale evacuations identified that in the U.S., the evacuation cases concern areas with more than 1,000 people about three times a month (Witzig, et al, 1987; Weston, 1989; NRC, 2005a). Nowadays, the evacuation planning is a key element of emergency planning in NPP and after such an amount of incidents; its significance is beyond unquestionable.
ETE as defined by FNEP is the time required for the population to evacuate a residential area addressed as Emerging Planning Zone (EPZ) with a radius of about 10 miles (16 km) around a NPP (FNEP, 2002). According to the NRC, the emergency plan includes a plume exposure pathway of an EPZ around the nuclear facility. Subsequently, inside that EPZ, the detailed planning and preparation plans are included. In fact, these plans must be made in advance, in order to determine which appropriate protective measures can be applied to the entire population in a punctual and accurate manner. Preparations, such as sheltering, evacuation or use of prophylactics, stand for ingestion and plume exposure to the emergency planning zones (NRC, 2005a). In other words, ETE is a tool for preplanning, preventing and identifying any particular obstacles in order to achieve an efficient evacuation.

ETE aims to evaluate the controllable and uncontrollable variables of a traffic network such as traffic routing, signalization, weather conditions, accidents, population etc. To facilitate hazards, such as the variation in size of the population of the affected area and decrease of the capacity because of the weather conditions or effectiveness of TMS, data regarding the risk area population and the capacity of the area roadway network are necessary. In general terms, the three general objectives of an ETE analysis are considered below (Urbanik, 2000):

a. Provide data to emergency decision-planners in order to assess whether the evacuation of an area is mandatory for preventing the population from the radiation exposure;

b. Determine whether the evacuation process is considerably influenced by unexpected events such as adverse weather, and finally

c. Assess the effectiveness of the traffic management actions.

An ETE report is very important, process, yet ubiquitous. In fact, ETE is only one part of a complicated procedure that concerns events related to radiological release or events involved with response to that release. According to Urbanik, in such events, there are five factors that govern traffic flow conditions of the network (Urbanik, 2000):

- Number of distribution of evacuating vehicles is time and space dependent;
- Loading rate is controlled by the distribution of warning and preparation times;
- Capacity of the traffic system;
- Any unpredictable degradation to traffic capacity;
- Potential enhancements to improve evacuation process based on traffic management actions that influence demand or capacity.
Unlike traditional preplanning studies, the preparation plans of an area to evacuate include many complexities, such as: the density of the risk population area, the capacity of the roadway network, the actual demand, the implementation of any traffic management actions etc. The experienced sensitivity assessment of previous ETE studies showed that all these variables vary from case to case and therefore each case must be verified individually (Urbanik, 2000). Apart from that, an ETE report must be frequently updated due to the continuous advancements of technology and the evolution of various relevant scientific fields (NRC U.S., 2005).

### 2.2.1. Transportation Analysis

An evacuation transportation analysis embraces a certain number of methods for the acquisition of the desired data (maps, traffic and demographic characteristics), e.g. field surveys. These data will allow the planner to set up all evacuation scenarios needed, taking into account not only the fixed elements (roadway infrastructure, network topology and geometry), but also some other considerably important variable element (traffic loading, demand and determination of several traffic management actions). Still, there are also other issues that could be considered, such as the population groups with disabilities and their mode of transport as well as the potential effect of the evacuation of the shadow area.

As far as the demand is concerned, traffic data pertaining traffic volumes, traffic controls devices, pass-through traffic demand, traffic on the highway segments etc, should be provided. On the other hand, the roadway capacity estimation should entail a number of characteristics of the roadway topology and geometry: the number of lanes, the pavement width, the roadway constraints (such as guardrail locations and physical encroachments), shoulder type and width, bridge locations and widths, intersection lane channelization, intersection queuing capacities, posted speed limits, attainable speed, and surrounding land use should also be measured (TRB, HCM 2000, 2002).

Apart from conventional methods for the acquisition of traffic demand and roadway capacity data, a number of traffic field surveys, only when seriously needed, would play an important role to fill the missing information. These surveys will provide data that would eliminate any inaccuracies or deficiencies of the existing mapping or any other retrieved info. For instance, by conducting population surveys, the location of major traffic generators can be estimated. Hence, indicators such as population density, populations with special facilities, employees’ destinations, locations and demand of schools, hospitals, hotels etc. could enhance the data acquisition process.

Local and state transportation agencies from their side will provide planners with maps and information of the traffic control plans. In spite of that, data pertaining traffic signal control plans at the intersections will be provided by transport agencies.
Their acquisition must be elaborated very carefully due to the fact that the green
times or phases may differ during the day. In that stage and in order to enhance the
flexibility analysis as well as the data acquisition, municipalities could provide all data
electronically. Hence, the intersections that should be manually manned by the traffic
control officers would be indicated.

Nevertheless, ETEs should be regularly updated and the repetition of this procedure
must be performed in every time a new ETE study is conducted. Any potential
changes in the transport road network could result in different elapsed times (NRC

2.2.2. Emergency Planning Zone

Emergency Planning Zone (EPZ) is the area in which any exposure from plume
inhalation could exceed the environmental Agency’s Protective Action Guides (PAG).
According to the NUREG-036 and NUREG 0654/FEMA REP1, the standard planning
zone for an NPP emergency response plan embraces an area with a radius of 10
miles (16 km). In addition, there are two more areas: the voluntary and the shadow
region. The voluntary area is related to the voluntary evacuees that are living outside
the EPZ and they will evacuate using the designated routes for evacuation planning.
The shadow area concerns the vehicular traffic of the shadow evacuees, which is
being converged with the traffic from the population leaving the EPZ. In that case a
demand estimation of the shadow evacuees can be included in the total demand of
the traffic. Figure 2 shows the assumed evacuation response in respect to the three
different evacuating regions.

![Assumed Evacuation Response](image)

Figure 2: The assumed evacuation response
(Source: Goldblat, 2004)
The emergency-planning zone (EPZ) consists of two sites, the on-site and the off-site zone. As far as the on-site zone is concerned, it is determined as the area inside the boundary of the nuclear facility where the operators of the nuclear facility must be aware and ready to react in case an incident occurs. On the other hand, the off-site area concerns the area outside the boundary of the nuclear industry. In that area, the municipality, the province and the state authorities are responsible.

The EPZ is subdivided into sectors that are addressed as Emergency Response Protective Areas (ERPA) as well as to smaller concentric circles with radius of 2 and 5 miles (3.2 km and 8 km respectively). The ERPAs are located within the EPZ and they are generally defined by geographic or political boundaries. In these areas, the local authorities and agencies are in charge for the development of the emergency response plans and the notification for evacuation of the general public. As far as the 2 miles zone is concerned, it is the restricted area of each NPP site where only the employees and personnel are authorized to enter. On the other hand, the 5 miles zone stands for the area that is at higher risk and the first that tends to be evacuated.

Only seldom, EPZs cover very large and dense-populated areas. As quoted by FEMA, the population of the ten largest emergency planning zones concerning nuclear sites ranges from approximately 140,000 people to over 300,000 people (FEMA, 2005a). As shown in Figure 3 approximately 70% of the total sample population was reported to have 5,000 evacuees or less, while only six percent involved more than 100,000 (TRB, 2009). It is noteworthy that, even though only a small percentage of the evacuations (between 1990 and 2003) involved areas with more than 5,000 residents, ETE studies require a deep and thorough analysis whatever the case may be.

![Figure 3: Evacuation frequency based on evacuating population size (1990-2003)](source: TRB, 2009)
Some other aspects that should be also considered in the development of an ETE are the direction and the speed of the wind at the time of the incident. The role of these two factors is of great importance to understand the meteorological assessments capabilities within the EPZ in order to develop different scenarios regarding the configuration of the EPZ (circular or keyhole). Consequently, data can be obtained by various agencies, authorities or institutes of each ERPA and therefore the determination of different ETE scenarios of the affected area is necessary.

![Figure 4: The assumed evacuation response](Source: NRC, 2005)

Despite all NRC and FEMA regulatory actions, a study conducted after the Three Miles Island accident, proved that the 10-mile radius of the EPZ is not defined based on factors such as meteorology or other human behavior parameters (NRC, 2005). It is however, defined as a politically arbitrary distance. TMI accident showed that even though only pregnant women and pre-school children (approximately 3,400 evacuees) were advised to evacuate a 5-mile area around the nuclear site, up to as many 200,000 people (approximately 39% of the area’s total population) evacuated a 15-mile region (Zeigler & Johnson, 1984). It is also remarkable according to the same study that the average traveled distance by evacuees was approximately 85 miles. Consequently, after the experience gained from the TMI, the decision-makers and the planners may re-consider and rethink about the viability of executing a nuclear accident emergency plan with a fixed EPZ.

### 2.2.3. Scenario Development

ETE scenarios are defined as the planning assumptions of the planners before the emergency in an NPP occurs. The main objective of these scenarios is to identify the most important combinations of variables and events regarding regular and irregular conditions in order to provide the emergency planners with a realistic evacuation time.
estimation of the population. Broadly speaking, these potential combinations are associated with high demand conditions, which exceed the roadway capacity. Thus, the length of the delay is caused by the congestion, because of the high demand should be entailed in the ETE calculation. Frequently, these uncertain parameters concern scientific or professional opinions that are used to fit the data into a statistical distribution. To that extent, the sensitivity analysis is necessary in order to ascertain whether the estimated value or the statistical calculation reflects the correct value.

Planners do not consider that EPZ is either an area uniformly distributed in space and time or that its road network topology consists of straight radial roads directed out of the EPZ. Yet, in real planning procedures, the evacuation trips are generated in locations called zonal “centroids” within the EPZ and the trip generation is dependent upon time (mobility process) and space (population density and location of “centroid”). Scenarios may be defined according to: (a) seasons of the year (summer-winter), (b) weekdays (weekday, weekend), (c) times of the day (midday-evening), (d) weather conditions (good, rain, snow). It is noticeable that during the daytime, the majority of the population may be in transit, at work, at school, at home or at any recreational places, while at nighttime the biggest percentage stays at home. However, there are also other variables, such as special events, abnormal circumstances (large transients population within the EPZ as festivals and athletic events often take place due to temporarily reduce the roadway capacity), percentages of population dependent upon public transport, the presence of voluntarily or shadow evacuees etc.

![Congested highway in U.S.](source: TRB, 2009)

Regarding the influence of the weather to the roadway capacity and to the speed of the vehicle, previous studies have proved that weather phenomena such as rain, may reduce the speed and the highway capacity by 10% (Urbanik, 2000) However,
recent studies evidenced that the proportional range varies from 5-20% depending upon the speed of the wind and the precipitation rates (NRC, 2005a).

Since the aim of the analyst is to set up plausible evacuation scenarios that could generate the highest demand on a regular basis for each ERPA, the worst-case scenario should be avoided. A conservative ETE would not permit the activation of the appropriate measures by the decision makers when that may be the best decision to do.

2.2.4. Demand estimation

The estimation of the demand is the systematic approach that roughly calculates the total number of evacuees by taking into account population groups and the projected transportation modes. In order to elaborate such a complex calculation of the current number of vehicles that will evacuate the area, methods such as demographic data acquisition, assumptions of population groups and vehicle occupancy rates are needed. The first step is the determination of all different population groups through a systematic approach. Subsequently, people can be distinguished into categories such as: permanent residents, transients and special facility population. Secondly, the unit analysis, which is related to vehicles, should be determined and finally the number of vehicles per household should be estimated.

Although only numbers regarding vehicle occupancy are available, the evacuated vehicles will be less than the vehicle occupancy rates. It is proved that people evacuate using more than one vehicle but less than the number of vehicles registered to the household. For instance, according to the NRC, even if the U.S. average vehicle occupancy rate is roughly 2.7 veh/hsh (vehicles per household), residents will utilize only 1.3 vehicles (52% of the registered available vehicles) to evacuate (NRC, 2005c). Even though, in every evacuation event there is a percentage that denies evacuating, ETEs should include the entire population into the evacuation plan.

2.2.4.1. Permanent residents

The first category includes year round residents of the EPZ. In order to calculate the permanent residents of the area, Census Bureau data are used (decennial data regarding urban centers and data provided every five years for rural and small communities). It has to be mentioned, that for any estimation regarding the future number of the permanent residents, previous census data or data from any other reliable sources must be taken into consideration.
2.2.4.2. Temporal traffic

The second category consists of all temporal visitors, tourists and daily employees that do not reside in the EPZ. Primarily, it is of great importance to locate where the transients perform their activities (business, shopping centers, malls, parks, recreation facilities and special events). Secondly, the seasonal characteristics are fundamental factors that influence the transient populations. For instance, during the summer, many transients are driving to the beaches or to the parks for recreational reasons. During the daytime, motels tend to be empty, while during the nighttime they will be occupied by the tourists. However, the planners should avoid the double counting of the transient population vehicles. To estimate the employees who are occupied inside the EPZ but reside outside of it, statistical surveys combined with local and state statistical data are necessary. A convenient way for the planners to estimate the number of employee’s vehicles is to count the parking slots at all industrial zones, at all business centers or to acquire data from malls or large shopping centers regarding the employee’s occupation number. However, every attempt to estimate temporal traffic should be implemented carefully in order to keep away from counting the permanent resident’s vehicles.

2.2.4.3. Special facilities population

Special facilities populations are broadly associated with people who used to be at: large educational institutions such as schools, colleges, universities, day care centers, hospitals, nursing homes, correctional facilities such as prisons and infirmaries, large retail centers like malls and commercial centers, large transient population centers such as hotels, places for recreational activities such as parks or any other special event facilities.

At the most fundamental level, this population group should be examined individually in order to determine lists with everyone who is part of it. Attempts to start contacts with institutions such as the Chamber of Commerce, school boards, and local or regional municipal agencies will contribute significantly into the determination of this population group. Once all these facilities have been assessed by determining the number of patients or other vulnerable groups of people, the determination of the number and type of vehicles available and vehicles needed will be the next step. Furthermore, the planner must design a plan seeking to explain how it is possible to provide special facilities populations with transportation modes such as buses, mini vans, ambulances and automobiles in order to evacuate or to relocate them to other facilities (hospitals, prisons etc.) outside the EPZ. The planners should not underestimate the transportation needs of any population group and therefore they must provide alternative transportation modes for everyone.

According to NUREG/CR-6863, the ETE required information for preventing this population group from any hazardous situations are: the number of persons requiring
transportation, the special needs of these persons, the number and types of vehicles required, the number of trained drivers required, the time and means to notify, mobilize, and brief the drivers, the time to fuel the vehicles, the time for vehicles to travel from a transportation depot to the initiation of the route, the time for loading individuals, the time to drive to the EPZ limit and on to the congregate care center, the time to unload at a congregate care center and the return time against outbound traffic for repeat trips, if needed.

It has to be mentioned that the double counting regarding this population group is not considered as a hazard and therefore it has to be included into the calculation. For instance, in some scenarios (wintertime and weekdays) the school children may be counted both as permanent residents (home) and special facility population (school).

2.2.4.4. Pass through traffic

Regarding the pass through traffic at the time of the accident, the current traffic will continue to enter the EPZ during the first one or two hours. In order to control such complex situation and in particular to redirect all the vehicles traveling through the EPZ, the planners must develop and apply the appropriate TMS as well as all necessary control devices to eliminate the impact of the traffic. NRC suggests a ninety minutes time interval until the traffic control personal and the operation of any traffic management measures would be activated. However, this may not always be the case and the individual approach is recommended (NRC, 2005).

2.2.4.5. Returning vehicles

During an evacuation process, some people would drive opposite to the general direction of the evacuation flow, such as returning commuters who work inside or outside the EPZ (may return home as members of the family), residents who are not at home and prior evacuation will decide to return home or residents attending special events may return home too. According to NRC guidelines, these vehicles should be included into the demand calculation (NRC, 2005). However, Urbanik claims that the pass through traffic should not be considered into the demand, as vehicles that move counter to the direction of evacuation do not use the designated routes and therefore do not compete with the rest of the evacuees (Urbanik, 2000).

2.2.4.6. Voluntary evacuees

Voluntary evacuees are people who under such conditions will evacuate even if they are not forced to do so. This category consists of two different subcategories. The first stands for people who live within the EPZ but they are not advised to evacuate. Traffic demand is included in the ETE. The implementation of the appropriate TMS will force them to accommodate or shift from the designated routes. The second one, though, concerns people who live outside the EPZ but they will start evacuating once the notification for evacuation of the EPZ is published. It will not be included into the
demand calculation due to the fact that they do not interfere with other evacuees because they do not use the designated routes for evacuation (Urbanik, 2000).

2.2.4.7. Shadow evacuees

Shadow evacuees belong in a category that refers to residents who reside in the shadow area of the NPP. Shadow evacuations occur when people, who believe they are at risk, will evacuate even though they have not been officially advised to do so (Gunter, 2001). Shadow evacuees leave primarily because they concern about their safety, but could also leave for other reasons. Also in cases with extremely congested networks, TMS seem to be an efficient manner to minimize or to control such phenomena.

2.2.5. Capacity estimation

Highway Capacity Manual 2000 (HCM) defines road capacity as:

“The ability of the road network to service vehicle demand is a major factor in determining how rapidly an evacuation can be completed. The capacity of a road is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane of roadway during a given time period under prevailing roadway, traffic and control conditions” (TRB, HCM, 2000).

To proceed in qualitative measures of the operational conditions of the highways, the Level of Service (LOS) should be determined. According to the TRB, the range of LOS varies from A (free-flow and high speed conditions) to F (forced flow condition) and represents the level of congestion at particular time intervals during the evacuation (TRB, 2000). Once the LOS is determined, the planners will be able to investigate whether the implemented traffic actions are favoring the reduction of the congestion and the amelioration of the traffic flow or not (NRC, 2005).

As Urbanik states the most fundamental stage for estimating the roadway capacity is to design the hierarchy of the road network. Even though, while conducting an ETE analysis the roadway network can be thoroughly classified in many different road categories, such as locals, collectors, arterials, freeways etc., only the primary roadway system should be considered. The primary roadway system embraces roads where the highest volumes are being converged, such as the arterials and the freeways. Collectors and locals may be performed in specific cases in order to improve the evacuation capacity (Urbanik, 2000).

Basically, the estimation of the roadway capacity requires the broad and thorough investigation of the current road network characteristics and the traffic control measures. This can be achieved through data collection methods like field surveys,
existing data and interactive maps with field verification. Hence, the numbers of lanes, the lane width, the shoulder lane width, the grades the location, the operation of the traffic signals, the stop signs, the land use restrictions and the determination of one-way streets are needed.

As far as the highway capacity of sections is concerned, the variables that should be taken into account are the roadway geometrics, the traffic composition and the motorists' behavior. Figure 6 displays the relationship between the service volume and the traffic density.

![Diagram of traffic density and service volume relationship](Source: TRB, HCM 2000)

2.2.6. Capacity under adverse conditions

Roadway capacity may be reduced significantly due to capacity constraints, such as: (a) obstacles in flow such as accidents or constructions, (b) inefficient roadway designs such as disturbances in signal phasing, (c) adverse weather conditions and finally, (d) changes in driving behavior.

Even though accidents and breakdowns are rare, unpredictable and temporal events that most of the times take place only at limited sections, they should be considered in the ETE's calculation. A study conducted by Dotson and Jones has shown that traffic accidents concern only the 8% of 50 case studies; however, in case of an
accident, the impact to the existing capacity will still be significant (Dotson & Jones, 2004).

Limited accessibility of the roadway system might be provoked also by roadway construction activities. The planners should take into account only the long-term construction sites due to the long-standing disruption. In fact, HCM identifies methods to account the capacity reduction during short-term and long-term construction activities.

Adverse weather conditions, such as fog, ice, rain, heavy rain, snow and heavy snow can significantly reduce not only roadway capacity but also the operating speed of the vehicles, resulting in an increased ETE (TRB, HCM, 2000). It is remarkable that, the roadway capacity is affected more than the speed due to the drivers increasing the distance between the vehicles as the speed of the vehicle is decreased. As Urbanik quotes, in case of rain, while the speed drops by 10%, the roadway capacity decreases by 10-20% as well as the highest reduction of the capacity, circa 30%, is caused from heavy snowfall (Urbanik, 2000). However, in the HCM are included all the appropriate steps for calculating the reduction in capacity under adverse weather conditions are included.

Consequently, by acquiring comprehensive data from all potential regional and local agencies, the local traffic management center will be able to develop plans in order to reduce the impact of adverse conditions to the capacity. For instance, in frequently congested areas, surveillance might be an effective measure to alleviate road blockage phenomena. Another fundamental traffic management plan concerning the uniformity of the capacity under adverse conditions indicates the removal of the abandoned vehicles by staging of roadside service vehicles (e.g. tow trucks).

2.2.7. Traffic management strategies

Since technology is increasingly developed, TMS tend to be more efficient, as they are associated with real time traffic data acquisition methods (on-trip info). In addition, the evolution of the communication devices favors drivers to communicate with the infrastructure or with other drivers. In general, TMS aim to reduce the evacuation time by enhancing roadway capacity, reducing demand or eliminating any potential error of the drivers. The capacity enhancement would likely be achieved by permanent (construction of additional lanes of roadway) or expedient (attempts to minimize costs) interventions. Any permanent interventions to increase roadway capacity, apart from the fact that they are cost ineffective, they are also solely related to high traffic demand periods, which take part only specific time intervals during the day (Induced traffic). On the other hand, the expedient capacity enhancements such as the temporal reversing of specific lanes direction or the operation of adaptive
control plans in alliance with traffic personnel are considered as substantial tactics. Hence, another ETE’s study objective is to identify locations where the TMS are urgently needed. Some of the most frequent applied TMS are presented below:

2.2.7.1. Contra Flow

Contra-flow traffic operation is related to the temporal reverse of specific lanes direction in one-way direction. These lanes are originated from the NPP towards the EPZ borders in order to increase capacity. Generally speaking, contra-flow operation routes should be designated by taking into accounts all initiation and termination points. Indeed, traffic control equipment, such as barricades, cones, emergency vehicles and signs as well as experienced traffic control personnel should be available for contra-flow operations in case of emergency. In addition, the clarification of how many number of lanes and which type of vehicles (emergency vehicles, public transport vehicles, and returning commuters) will be allowed to use those routes should be included into the emergency plan. Thus, drivers will be adequately informed in order to avoid any disorientation or confusion. Despite the potential doubling of the roadway capacity, the access to emergency workers or to returning population will be limited. Therefore, the need for at least some inbound traffic lanes is of great importance. (Cuyahoga County, 2007)

![Figure 7: Temporal reverse of specific lanes direction in one-way direction](Source: Rita Houston Evacuation)

2.2.7.2. Diverting traffic from routes with excess demand to routes with excess capacity

The shift of the evacuation traffic from routes with excess demand to those with excess capacity will lead to traffic rerouting around the EPZ without affecting the flow...
of the evacuation traffic. Furthermore, by forcing vehicles to travel through minor streets like local or collectors, the capacity of the highway network (arterials, freeways) could be increased (NRC, 2005).

2.2.7.3. Traffic Control Personnel

At crucial traffic control points, such as at important intersections or at points where the roads are damaged, staffed personnel could be a fundamental manner to ensure safety and security as well as to prevent any accident.

2.2.7.4. I.T.S.

The installation of smart systems will: a) contribute to the monitoring of the roadway, b) provide instant response to adverse weather or traffic conditions, c) allow communication with infrastructure or among travelers through variable message signs (VMS), highway radio, car to car communication (C2C) etc. and finally d) permit the dynamic change of traffic control devices such as the adaptive traffic control signals. Table 2 depicts the most common ITS technologies.

<table>
<thead>
<tr>
<th>I.T.S.</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic message signs or VMS</td>
<td>Provide current traffic information (permanent signs, at key transportation points or may be transportable)</td>
</tr>
<tr>
<td>Video surveillance</td>
<td>Remote management of intersection signalization</td>
</tr>
<tr>
<td>Video surveillance at predetermined sites</td>
<td>Improve efficiency of detecting, responding, and clearing accidents</td>
</tr>
<tr>
<td>511 telephone</td>
<td>Traveler information system</td>
</tr>
<tr>
<td>Highway Advisory Radios</td>
<td>Traveler information system</td>
</tr>
<tr>
<td>Internet traveler information systems</td>
<td>Post evacuation routes, roadway conditions, and other transportation evacuation information</td>
</tr>
</tbody>
</table>

The cooperation of traffic control plans with real traffic data would likely favor the vehicles to flow in less congested conditions. Subsequently, by implementing adaptive control plans where the green times change dynamically according to the counts of vehicles, less congested roads and smoother traffic flow will arise. In general, the enhancement of the road equipment with ITS as well as their integration with standard traffic control practices will substantially contribute to speed-up the evacuation process and to improve traffic flow conditions.

2.2.7.5. Shoulder Lanes

Shoulder lanes allow the entrance of vehicles in the lateral lanes only in case of an emergency. The early activation of those lanes in the expressway or freeway might
prevent phenomena such as confusion of the drivers or stressful conditions. Apart from that, the capacity will be increased and subsequently the evacuation time will be reduced, as the number of lanes on each link is increasing by one.

2.2.8. Trip Generation Time (TGT)

Even though the ETE is an aggregate measure, the evacuation travel times concern only the times that the population needs to evacuate the affected area. According to NUREG/CR-6863/SAND2004-5900, Trip Generation Time is defined as: “the total time estimated for an individual or family unit to prepare to leave the EPZ” (NRC, 2005). The procedure regarding the calculation of TGT should rely on site specific information that they are possibly acquired via telephone, Internet, mail surveys, assumptions or even generalization methods but with all basis data provided. Under NRC policy guidelines, the total evacuation time consists of four different components (NRC, 2005):

1. **Notification time:** Once the decision for evacuation is made, all population must be informed to evacuate

2. **Mobilization time:** The time for preparing and packing necessary things

3. **Travel time:** The time that the drivers need to evacuate out of the EPZ

4. **Confirmation time:** The time required confirming that the population at risk has been evacuated

Aside from the evacuation travel time, there are more time categories to be considered. The notification time indicates the time required for the population to be informed, while the mobilization time stands for the preparation time of the evacuees for packing and preparing their stuff prior to evacuation. Total evacuation and mobilization times concern time and space processes as well as both are referenced to the advisory to evacuate (Goldblat, 2004).

TGT includes five different events, concerning four distinct activities. Each activity should entail a statistical distribution of all times for population to evacuate. As Urbanik quotes, the determination of the distribution over time of households that have completed each event is necessary (Urbanik, 2000). What concerns the definition of the statistical distribution, are these assumptions of average and marginal time values (minimum and maximum values) as well as retrieved data from previous studies. Table 3 displays these events and activities as well as their definition.
Table 3: The sequence of events and activities regarding TGT
(Source: NRC, 2005 & Urbanik, 2000)

<table>
<thead>
<tr>
<th>Events</th>
<th>Activities</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Warning initiation</td>
<td>1. Warning receipt</td>
<td>Length of time between first release and the info receipt from the evacuees</td>
</tr>
<tr>
<td>2. Warning receipt</td>
<td>2. Preparation to leave work</td>
<td>Time between receipt of notification by individuals until they leave workplace</td>
</tr>
<tr>
<td>3. Departure from work</td>
<td>3. Return from work</td>
<td>Time taken to reach home after leaving workplace (distance, direction, mode)</td>
</tr>
<tr>
<td>4. Arrival at home</td>
<td>4. Preparation to leave home</td>
<td>Time to pack and prepare home for an extended absence</td>
</tr>
<tr>
<td>5. Departure from home</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In simple words, TGT is the summary of the times required for each activity. Though, the aggregated TGT value regarding the entire EPZ population is a very complex procedure due to everyone has distinct requirements for each activity. Of course, some of these activities may last zero time. At the time of the evacuation, the workers, for instance, may be at home. Subsequently, the ‘preparation to leave work’ and the ‘return from work’ activities will not included into the TGT calculation. In order to estimate TGT, the requirements are: (a) identifying the sequence of events, (b) obtaining defensible data for each event, (c) developing statistical distribution for analysis and finally, (d) calculating the trip generation times.

Furthermore, transient and special facilities populations are recommended to evaluate individually. On the one hand, transient populations may not be notified on time due to the fact that they might be located in distant places. On the other hand, special facilities populations must include time concerning the mobilization of drivers’ vehicles, the preparation of the evacuees, the loading of vehicles and the time required to travel out of the EPZ. Indeed, more scenarios must be defined regarding to the residents that leave directly from home, to the car owners of the area, to the non-car owners of the area (mainly dependent upon public transport) and to different time intervals of the day. Figure 8 displays a comparison of different departure time curves from different case studies.
2.3. Computer and Simulation modeling in ETE studies

Since the power of personal computers and the search for traffic management solutions to transport problems is increasing, simulation models are becoming more and more important in traffic engineering. Simulation models in simple words are the experimental tools of a computer, which aim to draw valid conclusions as they are represented in the real world. Currently, there are many traffic simulation packages that tend to satisfy traffic-engineering requirements. These simulation models can evaluate alternative treatments, test new designs or conduct safety analysis through the recreation of traffic accidents.

The selection of the appropriate simulation model requires the thorough and concrete consideration of many distinct parameters, such as flexibility of the model, ease for data collection and coding, cost, training requirements, user friendliness, accuracy of estimation of measures of performance, as well as expandability and ability of the model to interact with other software. The importance of each dimension will depend on the nature of the activity, its objective, resources available, and user preferences. Indeed, the model selection is fundamental to the success of the experiment and this choice is usually a tradeoff between the accuracy and the precision of the model and the development costs, data needs, and the time required executing the simulation (Sisiopiku et al., 2004).

Broadly speaking, the user must specify a scenario configuration regarding the information inputs (capacity, demand and behavior) of the model. The results of the simulation process can be represented in two formats: statistical or graphical.
Nevertheless, it is the responsibility of the traffic engineer to interpret the information and the outcome provided by the model in order to gain an understanding of cause-and-effect relationships. There are many traffic simulation models mainly microscopic that have been developed and are currently being performed, such as CORSIM, VISSIM, INTRAS, AIMSUN, TRANS modeler and PARAMICS etc. Meanwhile, several studies are available comparing features, capabilities and limitations of available microscopic traffic simulation packages as they offer guidance on which model is the most appropriate (Sisiopiku et al., 2004).

Evacuation modeling can be applied in emergency situations such as nuclear accidents, earthquakes, floods, land fires etc. These simulation models are used to estimate the time that is required for the population in an area affected by a disaster to evacuate to safer and distant areas and furthermore to assess the traffic evacuation as a protective measure (Urbanik, 2000) Computer modeling may also integrate transportation and evacuation data with geo-spatial data through Geographical Information Systems (G.I.S.).

Nevertheless, all simulation models assist emergency managers and transportation officials in the decision-making process as well as program-developers in order to challenge with building costs of those models and all the data required. The deep and thorough knowledge of the planner over the analysis tools as well as the clear understanding of input’s parameters sensitivities, capabilities and limitations is necessary. Such parameters concern the transportation network (demand, supply) and the human behavior parameters, such as at-risk population response, travel characteristics, demand volumes, loading rates, origin-destination information (Pidd, 1996). Modeling in evacuation planning studies would definitely help the analyst to test the efficiency of traffic management and control strategies, to identify the optimum evacuation routes through the iterative processes, to identify the traffic control points and to validate other elements of the evacuation plans (ORNL, 2003).

The first step for the analyst is to structure the model. That is dependent upon the complexity of the EPZ and the input data. Next, the calibration and the validation of the model are very important procedures in respect of the credibility of the results. Afterward, the analyst will be able to develop various scenarios regarding alternative routes, different destinations, weather conditions, TMS or evacuation response rates and to assess them. All assumptions and input parameters as well as statistical and visual results should be documented, maintained and as well as to be available for review. According to Southworth, the following information is required (Southworth, 1991):

a. Description of the transportation infrastructure and in particular the highway network;

b. Description of the spatial distribution population by time of day and type of activity;
c. Representation of vehicle utilization during an emergency;
d. Representation of the timing of people’s response to the emergency and how this time varies by individual location and by current activity;
e. Representation of route and destination selection behavior of the evacuees;
f. Representation of any traffic management controls regarding the evacuation plan;
g. Representation of any non-evacuation based protective actions taken by significant population sub groups within the at risk area.

The generation of evacuation plans consists of five-step process (Southworth, 1991):

- A traffic generation sub-model;
- A traffic departure time sub-model;
- A destination selection sub-model;
- A traffic route selection sub-model;
- A user specified plan set-up, analysis and revision procedure.

2.3.1. Simulation Models in ETE studies

The last 30 years though, due to vigorous development of the computer technology, traffic simulation models tend to integrate real-time dataset into their input data. In general, there are three possible approaches pertaining traffic simulation models, such as microscopic (high fidelity), macroscopic (low fidelity) and recently mesoscopic (mixed fidelity). Microscopic simulation models provide a more detailed simulation in terms of computing speed, while macroscopic simulation models favor the simulation of large-scale areas operating under high traffic conditions very fast (Wang et al, 2010).

Microscopic models are based on the detailed movement of individual entities that are being simulated throughout the road network. The main idea is that entities of individuals or groups of people evacuating the affected zones seeking to find their way to safe destinations, either by their own route choice process or under police martial control. Microscopic simulators, due to the fact that they provide fine details of individuals, they favor the insertion of real-life factors such as congestion, police intervention and/or breakdowns of vehicles. Regarding the evacuation plans, microscopic models offer the greatest flexibility and more accurate results estimation of measures of performance (Sisiopiku et al., 2004). On the other hand, regional evacuations that are being performed with micro-simulators usually concern thousands of vehicles and therefore the computing process is quite time-demanding process. However, in macroscopic simulators, traffic flow is deemed as a cluster of platoons of vehicles in the roadway network and thus the traffic flows within the
network as fluid. One of the main macroscopic simulators disadvantages is that most of them can handle only steady state conditions, while the environment of an emergency evacuation is related to dynamic scenarios and in particular to chaotic conditions. Though, the macro-simulators are considerably less computationally demanding rather than the micro-simulators, as it is not necessary to keep information about all individual vehicles. Mesoscopic simulators concern models characterized of both micro and macroscopic simulators. In other words, a mesoscopic model generally represents most entities at high level of detail but describes their activities and interactions at lower level of detail than a microscopic model would do. Even though mesoscopic models are easier to develop, execute and maintain, their representation of the real world system may be less accurate, less valid and perhaps inadequate (Pidd, M., de Silva et al. 1996).

A recent evacuation study conducted for the Nine Mile Point Nuclear Station in New York State by KLD Associates Inc. proved that microscopic simulation process needed 300 times running time more than the macroscopic simulator to produce results. Thus, where large-scale networks and/or dense populated areas with high traffic volumes are involved for the evacuation scenarios, macroscopic modeling approaches provide more reasonable, accurate and efficient results (Goldblat, 2004). Meanwhile, several evacuation simulation packages have been recently developed. Table 4 depicts some of these efforts.

Table 4: Characteristics of Selected Evacuation Models
(Source: Southworth, 1991 & Wang, 2010)

<table>
<thead>
<tr>
<th>Simulation Models</th>
<th>Traffic Simulation</th>
<th>Route Assignment</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEAR</td>
<td>Micro</td>
<td>Simple</td>
<td>Moeller, Urbanik &amp; Desrosiers, 1981</td>
</tr>
<tr>
<td>NETSIM</td>
<td>Micro</td>
<td>Simple</td>
<td>Byrne, Courage &amp; Wallace, 1982</td>
</tr>
<tr>
<td>NETVAC</td>
<td>Macro</td>
<td>Dynamic</td>
<td>Sheffi, Mahmassani &amp; Powell, 1982</td>
</tr>
<tr>
<td>PC-IDYNEV</td>
<td>Macro</td>
<td>Static</td>
<td>FEMA, KLD, 1984</td>
</tr>
<tr>
<td>MASSVAC</td>
<td>Macro</td>
<td>Dynamic</td>
<td>Hobeica, Radwan, Jamei &amp; Sivasailam, 1985</td>
</tr>
<tr>
<td>OREMS</td>
<td>Micro</td>
<td>Static</td>
<td>Oak Ridge National Laboratory, 2001</td>
</tr>
<tr>
<td>DYNASMART-P</td>
<td>Meso</td>
<td>Dynamic</td>
<td>Brown, White, Slyke, Benson University of Texas at Austin, 2009</td>
</tr>
</tbody>
</table>

In past hearings, US Nuclear Regulatory Commission and Atomic Safety & Licensing Board (ASLB) recognized the model of the PC-IDYNEV System as state of the art model. This model was developed in an attempt to minimize the computations needed for a simulation with microscopic. This model proved to simulate successfully a certain number of NPP around the US due to the fact that it was able to run for various and successive loading rates resulting in different traffic route assignments. Route assignments that reflect better the dynamic interfaces of the network.
However, this process of matching static assignment results with the subsequent macroscopic simulation with DYNEV is not the most beneficial. The preferred traffic routing is dynamic traffic assignment. NETVAC (Sheffi, Mahmassani' and Powell, 1982); EVACD (Stone et al, 1986), and MASSVAC (Radwan, Hobek and Sivasailam, 1985; Hobeika and Jamei, 1985; Hobeika and Hwang, 1986) employ traffic assignment with stochastic route choice. By setting the route choice preferences and loading the links with the available information regarding traffic volumes (“downstream” of each intersection), the traffic assignment concerning evacuation can be done stochastically at each intersection of the network (Southworth, 1991). The Oak Ridge Evacuation Modeling System (OREMS) is a simulation model designed to analyze possible evacuation scenarios of large areas, where the road network involves major linkages like primary arterials and highways. MASSVAC is a simulation model designed for the analysis and evaluation of evacuation plans for urban areas threatened by natural disasters. It is capable of simulating the flow on highway networks and identifying the available efficient routes from a hazard area to the nearest shelters and calculating the evacuation time for the network. Hobeika and Changkyun (1998) have extended MASVAC by integrating a user equilibrium (UE) assignment algorithm into MASSVAC (Church & Sexton, 2002). Last but not least, DYNASMART-P is a mesoscopic simulation model, which includes demand-forecasting procedures for planning functions as well as traffic simulation models with dynamic traffic assignment and other operational applications. These applications seek to prove that phased evacuations in alliance with the contra-flow operations contribute significantly in the improvement of emerging preparedness plans. Subsequently, the current model overtakes many static limitations through its capability to model the evolution of traffic flows in a traffic network. This capability depends upon the individual’s decisions that usually seek for the best en-route paths over a given planning time-interval (Wang et al, 2010).

2.3.2. Traffic Assignment and User Equilibrium

One of the most important elements of traffic simulation modeling concerns the traffic assignment process. Traffic assignment is related to the process of determination of a traffic demand in an Origin-Destination (O-D) matrix. The basic inputs required for traffic assignment models are: a) a trip-matrix expressing estimated demand (different for peak and off-peak periods or a 24-hour matrix), b) a network with its links and its properties and principles or route selection rules. The fundamental hypothesis is that vehicles travel from origin to destination points through the available routes connecting them with many parameters included into a traffic assignment process defining how travelers will use these routes. The basic functions of each traffic assignment are: (a) the identification of the various routes that might be chosen by the drivers (tree-building stage), (b) the assignment of suitable
proportions of the trip matrix to these routes or trees (flows on the links in the network) and finally (c) the intention to achieve convergence (iterative patterns of successive approximations to an ideal solution). A possible classification of all traffic assignment methods is given in Table 5.

Table 5: Classification scheme for Traffic Assignment
(Source: Ortuzar, J. & Willumsen L., 2005)

<table>
<thead>
<tr>
<th>Capacity constrain/ Stochastic effects</th>
<th>Stochastic effects included</th>
<th>Stochastic effects not included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity constrain included</td>
<td>All or Nothing</td>
<td>Pure stochastic Dial’s, Burrell’s</td>
</tr>
<tr>
<td>Capacity constrain not included</td>
<td>Wardrop’s Equilibrium</td>
<td>Stochastic User Equilibrium</td>
</tr>
</tbody>
</table>

The main modeling hypothesis is that travelers try to minimize their individual travel times. Thus, the traveler prefers routes that he/she perceives as the shortest under the prevailing traffic conditions. This modeling hypothesis is based on the concept of User Equilibrium Models and in particular it is formulated in terms of Wardrop’s first principle: “The journey times on all the routes actually used are equal, and less than those which would be experienced by a single vehicle on any unused route.” (Ortuzar, J. & Willumsen, L., 2005)

Static traffic assignment models, widely used in strategic transportation analysis, are usually based on this formulation. In general terms, static models include processes such as trip generation, trip destination and travel mode selection model linked to static, user equilibrium route assignment mode. Static assignment models imply a steady state for traffic loading throughout the travel period. This means that if one-hour traffic volumes are loaded into the network, such a static assignment model assumes that such loadings represent conditions throughout the 15-minute period. Such methods of static traffic assignment models seek to balance the traffic demand with road capacity by ensuring the following Wardrop’s user equilibrium conditions on route selection, for any origin to destination specific trip.

As far as large-scale urban evacuations are concerned, recent findings proved that such static assignments tend to be unrealistic, as the rate of traffic loading and the route choice behavior are different between time intervals. In addition, as conclusively demonstrated by Janson, such static assignments do not seek to consider the true levels of congestion into the network (Janson, 1989, 1990a).

Since Intelligent Transportation Systems (I.T.S.) have dominated the sector of traffic engineering, the development of new models, far away from the static behavior, accounting for flow changes relevant to time have been emerged vigorously. These models, called as dynamic models, tend to describe the time dependencies of traffic
demand and the corresponding induced traffic flows using an analytic derivation of route selection based on mathematical simulation models of traffic route assignment.

The Dynamic Traffic Assignment (DTA) problem can be considered as a problem of determining time varying link or path flows. In fact, it concerns the capability of the model to describe how traffic flow patterns are evolved in time and space on the network (Mahmassani, 2001). The approaches proposed to solve the DTA problem can be broadly classified in two classes: mathematical formulations looking for analytical solutions and simulation looking for approximate heuristic solutions. General simulation based approaches explicit or implicitly split the process in two components: a route choice mechanism determining how the time dependent path flow rates are assigned onto the available paths at each time step and method to determine how these flows are being propagated in the network (Aimsun Manual, 2008).

In such cases, the route choice mechanism intends to optimize the route selection decisions based on the current available information. A variant, used in these simulation approaches to account for uncertainties on the information available to the travelers, is based on the use of choice functions based on discrete choice theory including the possibility of en-route rerouting mechanisms, based either on discrete choice theory or other probabilistic approaches (Mahmassani, 2001). These approaches can be considered Dynamic Traffic Assignment procedures but not Dynamic User Equilibrium (DUE).

In 1993 Friensz et al. firstly formulated the Dynamic User Equilibrium (DUE) problem, defined it as: “For every time instant, the experienced travel times of paths on used routes connecting an origin-destination (O-D) pair are equal and minimal” (Khoo, B.C., Lin, G.C., Peraire, J., Perakis, G., 2004). DUE principles rely on driver’s long-term and habitual behavior parameters to select the optimal routes. It is an iterative process that produces routes and percentages. Ran and Boyce 1996, formulate the dynamic version of Wardrop’s user equilibrium in the following terms: “If, for each OD pair at each instant of time, the actual travel times experienced by travelers departing at the same time are equal and minimal, the dynamic traffic flow over the network is in a travel-time-based dynamic user equilibrium (DUE) state.” (Aimsun Manual, 2008).
2.3.3. ETE methodology using simulation models

An ETE methodology using simulation systems, apart from the basic steps of the area identification, the demand and capacity estimation and the destination determination, involves an iterative process in order to identify the best evacuation routes as well as to estimate the time required to evacuate the area at risk. The steps that the traffic planner should follow are presented below (Goldblat, 2004):

1. Study area: The determination of the evacuation plan, as keyhole or circular. Regions usually are comprised of groups of emergency response planning areas (ERPA). Other factors as the wind direction and the speed play an important role in the emergency preparation.

2. Estimate all different demands in vehicles (over the area to be evacuated, the voluntary and the shadow evacuation areas). The population groups are: permanent residents, employees who work in the area a risk, and transients who are passing through the area or staying in the area temporarily. The distribution of this demand into zonal centroids is required in order to describe the changes in population density over the area. Also, the division of time into time periods is needed to represent the variation of demand over time.

3. The next step concerns the estimation of the highway link capacities based on field survey observations and on scenario based weather conditions.

4. The candidate destinations should be set on the periphery of the region for each origin centroid. These destinations represent the points where network links cross the outer boundaries of the region.

5. Since all input data have been introduced into the model, the traffic distribution and assignment model to compute the optimal routing of evacuation trips out of the region via the specified destination nodes can be applied. The traffic simulation model is then applied to simulate the movement of vehicles during the course of the evacuation. The model should explicitly describe traffic conditions in the saturated flow regime to account for congestion effects.

6. The Evacuation Time Estimates presents the elapsed time that the evacuating traffic originating within the evacuation region needs to leave that region. It has to be mentioned that the travel time that each vehicle needs to reach its destination (reception center, home of a relative, etc.) is not a component of the ETE.

7. Review simulation results to determine the need for traffic management to support the evacuation movements.

8. Introduce the traffic management tactics to the simulation and repeat the ETE analysis.

Figure 9 depicts a simplified model of evacuation.
Figure 9: A simplified model of evacuation

(Source: Lindell, 2008)
3. EVACUATION TIMES ESTIMATES: THE CASE OF AN NPP

It is the objective of this chapter to enlighten the reader with the appropriate information and knowledge regarding an area where an NPP is situated. It is moreover among the basic goals of this chapter to clarify the context within which, the general geographical, demographical and transportational characteristics of that wider area are influencing the capacity and the demand estimation process, as well as justify the choice of the current NPP for the illustration paradigm.

3.1. The study area

3.1.1. Nuclear Generating Stations

Nuclear Generating Station (NGS) A and B produce electricity, which is produced by nuclear fission that is using natural uranium fuel as an input. The two operating reactors of NGS A and the ones of NGS B produce a total output of 3.100 megawatts (MW) and therefore they are two out of the world's largest nuclear generating facilities. Figure 10 shows the current situation of the EPZ and the EPRZ of the actual NPP divided by PZ.

Figure 10: The EPZ and EPRZ of the actual NPP
During the construction of the current nuclear site, safety was seriously considered as a very important factor. This has happened because of the ability of the CANDU system, in accordance with the Nuclear Safety and Control Act, to entail many protective actions in order to prevent the reactors from any hazardous event. The protective actions concerned the installation of durable materials to protect health, safety, security and, finally the environment.

In 2006, the same owner and operator of these nuclear stations, OPG, were suggested to proceed to the refurbishment of the NGS B. Hence, OPG decided to undertake a deep and thorough environmental analysis considering, apart from the environmental effects, the safety and the economy impacts. Refurbishment for life extension could extend the service life of the NGS B reactors units to approximately 2060. As part of the Federal Environmental Assessment, an analysis was done including accidents, malfunctions and potential mitigation measures. This analysis determined that any release of radioactivity to the general public would not occur until at least 24 hours after the event was first initiated. Finally, in 2009, the National Nuclear Safety Commission (NSC) accepted the request, as the results of the environmental assessment proved to be encouraging.

### 3.1.2. Weather Conditions

According to online source “Theweathernetwork”, Figure 11 presents the annual average temperatures divided by month measured weather station (Latitude: 43.9° Longitude: -78.8° Altitude: 83.8 m).

![Figure 11: Temperature (°C)*](Source: www.Theweathernetwork.com)

Figure 12 depicts the rain and snow precipitation rates by month according to the national statistics for the environment.
EVACUATION TIMES ESTIMATES: THE CASE OF AN NPP

*The weather statistics displayed here represent the value of each meteorological parameter for each month of the year. The sampling period for this data covers 30 years. Record maximums and minimums are updated annually.

Figure 12: Rain and Snow Precipitation*

(Source: http://www.ec.gc.ca)

The weather statistics regarding the wind speed and direction regarding this station are not available to the public. It has to be mentioned that in the weather conditions were not taken into consideration in the new ETE study.

3.2. Previous study at the current NGS

3.2.1. Data and computational process

An ETE project regarding the current NGS was conducted by a specialized firm in ETE methods guided by the owner of the NPP and the emergency management personnel representing provincial and local governments in June 2008. Various elements such as previous ETE studies, GIS maps of the area in the vicinity of the NPP, data retrieved from field surveys of the highway network, demographic data concerning the population (residents and employees) of the EPZ and the Shadow area were available to the decision makers. The 2006 population is based upon statistics of 2006 Census data, consistent with the NGS B Environmental Assessment projections. As far as the forecast population for 2025 and 2060 were concerned, projections and extrapolation methods were used from local governments assuming all the future plans regarding the development of the road infrastructure improvements.

The various scenarios of the demand concern different time and weather circumstances, such as: (1) season (summer, winter); (2) day of week (midweek, weekend); (3) time of day (midday, evening); and (4) weather condition (good, rain or snow). The rain is assumed that begins at about the same time with the advisory’s notification to evacuate and therefore the transients are not affected. As about the snow that may occur only in winter scenarios, the roads are always passable due to
the fact that the appropriate agencies clean the roads as usual. These weather phenomena influence the capacity of the highways and the free flow conditions as well as the mobilization times. Table 6 represents the various scenarios of the demand data.

Table 6: Evacuation scenario definitions
(Source: Based on previous ETE report, 2008)

<table>
<thead>
<tr>
<th>id</th>
<th>Season</th>
<th>Day of Week</th>
<th>Time of Day</th>
<th>Weather</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Summer</td>
<td>Midweek</td>
<td>Midday</td>
<td>Good</td>
</tr>
<tr>
<td>2</td>
<td>Summer</td>
<td>Midweek</td>
<td>Midday</td>
<td>Rain</td>
</tr>
<tr>
<td>3</td>
<td>Summer</td>
<td>Weekend</td>
<td>Midday</td>
<td>Good</td>
</tr>
<tr>
<td>4</td>
<td>Summer</td>
<td>Weekend</td>
<td>Midday</td>
<td>Rain</td>
</tr>
<tr>
<td>5</td>
<td>Summer</td>
<td>Midweek, Weekend</td>
<td>Evening</td>
<td>Good</td>
</tr>
<tr>
<td>6</td>
<td>Winter</td>
<td>Midweek</td>
<td>Midday</td>
<td>Good</td>
</tr>
<tr>
<td>7</td>
<td>Winter</td>
<td>Midweek</td>
<td>Midday</td>
<td>Rain</td>
</tr>
<tr>
<td>8</td>
<td>Winter</td>
<td>Midweek</td>
<td>Midday</td>
<td>Snow</td>
</tr>
<tr>
<td>9</td>
<td>Winter</td>
<td>Weekend</td>
<td>Midday</td>
<td>Good</td>
</tr>
<tr>
<td>10</td>
<td>Winter</td>
<td>Weekend</td>
<td>Midday</td>
<td>Rain</td>
</tr>
<tr>
<td>11</td>
<td>Winter</td>
<td>Weekend</td>
<td>Midday</td>
<td>Snow</td>
</tr>
<tr>
<td>12</td>
<td>Winter</td>
<td>Midweek, Weekend</td>
<td>Evening</td>
<td>Good</td>
</tr>
</tbody>
</table>

Table 7 displays the factors assumed for the ETE study.

Table 7: Evacuation scenario definitions
(Source: Based on Agarwal, 2005)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Highway Capacity*</th>
<th>Free Flow Speed*</th>
<th>Mobilization Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain</td>
<td>90%</td>
<td>90%</td>
<td>No Effect</td>
</tr>
<tr>
<td>Snow</td>
<td>80%</td>
<td>80%</td>
<td>Clear driveway before leaving home</td>
</tr>
</tbody>
</table>

*Adverse weather capacity and speed values are given as a percentage of good weather conditions. Roads are assumed to be passable.

The ETE is defined as the elapsed time from the transmission of an Advisory to Evacuate issued to persons within a specific Evacuation Region of the EPZ, to the time that Region is clear of the indicated percentile of people. ETEs were computed for the evacuation of the general public. The Emergency Planning Zone was divided into 22 PZ in which there are two circles of 3 and 10km that define the evacuation regions. The general planning basis for this ETE study was that an accident at the NPP would immediately force the Advisory to activate the siren alert. It is assumed that 100 percent of the people within the impacted region will evacuate in response to this Advisory. The ETE computation assumes that a portion of the population within the EPZ, but outside the impacted region, will elect to “voluntarily” evacuate. In
addition, a portion of the population in the Shadow Region beyond the EPZ that extends to a distance of 15 km from the actual NGS will also elect to evacuate. The impedances that could be caused by voluntary and shadow evacuees are explicitly considered in the ETE computation for the impacted region.

All available evacuation routes are used in the analysis. It is assumed that everyone within the group of PZ forming a region that is issued an Advisory to Evacuate will, in fact, respond in general according to the planned routes. Population mobilization times are based on a statistical analysis of data collected at a suburban U.S. nuclear site with similar population demographics and will commence within 10 minutes of the Advisory to evacuate. No traffic management strategies were projected.

The computational procedure is outlined as follows:

- A link-node representation of the highway network is coded. Each link represents a unidirectional length of highway; each node usually represents an intersection or merges point. The capacity of each link is estimated based on the field survey observations and on established procedures. The network model was composed of a total of 530 nodes, 918 links and 22 Protective Zones.

- Evacuation trips are generated at locations called “zonal centroids” located within the EPZ. The trip generation rates vary over time reflecting the mobilization process, and from one location (centroid) to another depending on population density and on whether a centroid is within, or outside, the impacted area.

- The computer models compute the routing patterns for evacuating vehicles that are compliant with federal guidelines (outbound relative to the location of the plant) and then simulate the traffic flow movements over space and time. This simulation process estimates the rate that traffic flow exits the impacted region.

- ETE statistics provide the elapsed times for 50 percent, 90 percent, 95 percent and 100 percent of the population within the impacted region to evacuate from within the impacted region.

### 3.2.2. Demand Estimation

Although the estimation of the roadway capacity is based on field surveys, local traffic engineering insight and the application of Highway Capacity Manual 2000, the demand estimation is a more complex process. Subsequently, the traffic demand and the trip generation rates of the traffic evacuation were calculated based on a previous ETE study in NPP performed by the authors at a US nuclear site with similar demographic characteristics. The EPZ consisted of two population groups: (a) the
residents (people who are year-round residents of the EPZ) and (b) the employees (people who reside outside the EPZ and commute to business within the EPZ daily). Even if the double-counting of vehicles in some cases was inevitable, it didn’t influence the final results.

3.2.2.1. Permanent Residents

As it has been already mentioned, the population data for each population zone (PZ) was retrieved from the 2006 national Census. The relationship between resident population and evacuating vehicles that was developed from data collected at a suburban U.S. nuclear site is an average value of 1.24 evacuating vehicles per household. It is furthermore assumed that 62 percent of households in the EPZ have at least one commuter and 64 percent of these households will await the return of a commuter before beginning their evacuation trip. The following Table 7 shows the permanent resident population and the evacuation vehicle estimates for 2006 and 2025 as well as the population of the shadow region between 10 and 15 km from the NPP. Permanent resident population and vehicle data by PZ were obtained by regional transportation department for the years 2006 and 2025. Table 8 shows the total population data for 2006 and 2025.

Table 8: Permanent resident population, evacuation vehicle estimates for 2006 and 2025 and population of the shadow region between 10 and 15 km from the NPP.  
(Source: Regional Transportation Department)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>235.362</td>
<td>96.678</td>
<td>403.148</td>
<td>167.576</td>
</tr>
<tr>
<td>Shadow</td>
<td>167.400</td>
<td>68.762</td>
<td>286.618</td>
<td>119.138</td>
</tr>
</tbody>
</table>

3.2.2.2. Employees

The employees were divided into the ones that live and work within the EPZ and the ones that live outside the EPZ and commute to jobs within the EPZ. The first category was already counted as part of the permanent resident population since it was considered that prior to beginning evacuation they have had to return home in order to evacuate as a family. In order to avoid the double-counting, the planners focused on the employees who evacuated along with the permanent resident population. The majority of the employees were commuting to work in single-occupant automobiles with an average of 1.02 employees per vehicle. There were a total of 20,999 employees commuting into the EPZ on a daily basis. These employees used 20,588 vehicles. It is assumed that the existing commuter employee
estimates would also be valid for the 2025 analysis. Table 9 illustrates the number of the employees commuting into the EPZ by PZ for 2006 and 2025.

Table 9: Number of the employees commuting into the EPZ by PZ for 2006 and 2025
(Source: Regional Transportation Department, 2008)

<table>
<thead>
<tr>
<th></th>
<th>2006 Employees</th>
<th>2006 Employee Vehicles</th>
<th>2025 Employees</th>
<th>2025 Employee Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>20,999</td>
<td>20,588</td>
<td>20,999</td>
<td>20,588</td>
</tr>
</tbody>
</table>

### 3.2.2.3. Pass-Through Demand

The pass-through traffic and in particular trips from external origin to external destination will continue to be generated at the time of an accident. In the current study, these pass-through travelers are assumed to travel on the major routes in the EPZ which are: Route A (collector and express), Route B and Highway C. It is also noticeable the fact that the pass through trips (External-External) was permitted to run the EPZ for 90 minutes after the advisory notify the public to evacuate. After 90 min the pass-through traffic was redirected through the activation of the diversion plans. Table 10 displays the estimations of the number of the pass-through traffic (external-external trips). The major evacuation routes within the EPZ are presented in Figure 13.

![Figure 13: Evacuation Routes from the NPP](image)
Table 10: Pass-through traffic estimations (external-external trips)
(Source: Previous report, 2008)

<table>
<thead>
<tr>
<th>Direction</th>
<th>Route</th>
<th>Vehicle/lane</th>
<th>Lanes</th>
<th>Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastbound</td>
<td>Route A</td>
<td>800</td>
<td>6</td>
<td>4800</td>
</tr>
<tr>
<td>Westbound</td>
<td>Route A</td>
<td>1250</td>
<td>3</td>
<td>3750</td>
</tr>
<tr>
<td>Eastbound</td>
<td>Route B</td>
<td>900</td>
<td>2</td>
<td>1800</td>
</tr>
<tr>
<td>Westbound</td>
<td>Route B</td>
<td>900</td>
<td>1</td>
<td>900</td>
</tr>
<tr>
<td>Westbound</td>
<td>Highway C</td>
<td>900</td>
<td>1</td>
<td>900</td>
</tr>
<tr>
<td><strong>Total 2006</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>11250</strong></td>
</tr>
<tr>
<td>Westbound</td>
<td>Route B</td>
<td>+900</td>
<td>2</td>
<td>+1800</td>
</tr>
<tr>
<td><strong>Total 2025</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>13050</strong></td>
</tr>
</tbody>
</table>

3.2.3. Traffic Assignment Model

The models performed in the previous study were the PC-IDYNEV model and the TRAD model. The PC-IDYNEV consists of 3 different models: a macroscopic static simulation model, an intersection capacity model and a dynamic node centric routing model that recognized the congestion on the outbound links. TRAD is a User Equilibrium assignment model (based on User Optimization principle by Wardrop) including a trip distribution algorithm to compute Origin-Destination pairs and a minimizing travel time method to calculate the paths.

The trip assignment and distribution model, named as TRAD model, employed the equilibrium traffic assignment principles. It was included on the IDYNEV model system. In order to perform a simulation with a model, the user must specify all necessary info regarding the emergency area network such as the highway network, the geometry, the link capacity, the volume of traffic generated at all origin centroids, a set of accessible candidate destination nodes on the periphery of the EPZ for each origin and the capacity of each destination node. The model then calculates the optimal trip distribution and the optimal trip assignment (i.e. routing) of the traffic generated at each origin node, traveling to the associated set of candidate destination nodes, so as to minimize the travel time.

The major principle in which this model is based on is that people seek to travel out of the emergency area as rapidly as possible. Consequently, the model tends to distribute vehicles from the origins to the appropriate destinations and furthermore to route them over the highway network in a consistent and optimal way.

In detail, the model sought to route traffic along paths that will expedite their travel from their origins to points outside the EPZ. In other words, traffic moved out of the location of the NGS. Furthermore, restrictions were imposed regarding the movement
toward the NGS to the extent practicable, and disperse traffic demand so as to avoid focusing demand on a limited number of highways.

The main advantage of the TRAD model is that it includes a feature that expresses travel time on each network link in terms of traffic volume and link capacity. With that feature, the trip distribution and the trip assignment decision making process were processed. Hence, the TRAD model offers the opportunity to the user to select destination nodes and travel paths in order to minimize evacuation travel time. As such, this integrated model is classified as a behavioral model.

3.2.4. Evacuation Routes

According to the previous ETE report, the evacuation routes were starting the evacuation from a Protective Zone (PZ) to the boundary of the EPZ. In that sense, evacuees tend to minimize their exposure to risk. This was achieved by routing the traffic to move away from the location of the Pickering Nuclear Generating Station and by delineating evacuation routes that expedite the movement of evacuating vehicles.

In simple words, the main objective of evacuation routing was to achieve a balance between the traffic demand and the highway capacity. That was theoretically accomplished, when the user specified: (a) the total trips generated at each origin node, (b) the maximum number of trips that can be accommodated by each of the specified destination nodes and (c) the highway network attributes which include the traffic control tactics. Then, the TRAD model applied effectively.

Even though the highway network in 2025 is about to be extended (e.g. Route A) with the addition of new lanes and other highway capacity enhancements, the number of the available evacuation routes will not increase significantly. Though, the internal road construction was considered as an opportunity to enhance the development of new residential areas and therefore to increase the access to the existing evacuation routes.

It is also noteworthy that the routes are not strictly enforced. The model asserts that evacuees can alter their routing if significant congestion is encountered along their evacuation route. A decision to reroute is made based upon an imperfect knowledge of system-wide conditions (drivers are only aware of local congestion conditions). Drivers encountering congestion on their preferred route will only divert if the alternative route is uncongested within their knowledge horizon. They cannot look ahead to make an "optimal" routing selection.
3.2.5. Previous results

3.2.5.1. Results 2006

The ETE results for evacuating the entire 3 km zone range from 3:50 to 5:00 hours and for the entire 10 km zone the ETEs range from 3:50 to 6:30 hours. They are considerably below the first release time of 24 hours.

3.2.5.2. Results 2025

Table 11 shows the ETE results for evacuating the entire 3 km zone. The ETEs range from 5:40 to 7:10 hours and for the entire 10 km zone the ETEs range from 6:50 to 9:00 hours. They are well below the initial release time of 24 hours.

Table 11: Time to clear the indicated area of 100% of the evacuating population, 2025
(Source: Previous ETE report, 2008)

<table>
<thead>
<tr>
<th>Region ID</th>
<th>Protective Zone</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>midwek</td>
<td>midweek</td>
</tr>
<tr>
<td></td>
<td></td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td></td>
<td></td>
<td>rain</td>
<td>snow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5:00</td>
<td>6:50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5:00</td>
<td>6:50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7:10</td>
<td>9:00</td>
</tr>
</tbody>
</table>

3.2.5.3. Results 2060

Estimation of an evacuation time estimate for the 2060 timeframe is dependent upon the extrapolation of the EPZ population to that year. To be consistent with other population projections used in the NGS EA population growth to 2060 was obtained from the population data presented in the NGSB Human Health Technical Support Document (NK30-RE0-07701-00015). It is important to note that population growth within the EPZ will slow as the available land for development is used. Table 12 shows the elapsed times for the year 2060.

Table 12: ETE for the year 2060
(Source: Previous ETE report, 2008)

<table>
<thead>
<tr>
<th>Year</th>
<th>EPZ Pop</th>
<th>3 KM ETE</th>
<th>10 KM ETE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Good Weather</td>
<td>Snow</td>
</tr>
<tr>
<td>2060</td>
<td>426,127</td>
<td>5:50</td>
<td>7:30</td>
</tr>
</tbody>
</table>
3.3. Problem Identification

3.3.1. Introduction

The main objective of this ETE study was to evacuate the entire EPZ (100%) within 24 hours after the Advisory notification release. However, the current results concerning the various scenarios of this ETE report resulted in a very optimistic evacuation of the area in terms of time.

Generally speaking, a comparison among the evacuation scenarios proved that the various evacuation travel times did not present significant differences. At the following Table 12, which displays the time to clear the indicated area of 100 percent of the evacuating population in 2025, is displayed the minimum (6:50 hours) and the maximum (9:00 hours) ETE values among all evacuation scenarios regarding all population zone. This example shows that the minimum and the maximum ETE value have a difference of only 2:10 hours, even if the traffic and weather conditions are totally distinct each another. In particular, it is interesting the fact that the evacuation time regarding the scenario of Winter-Midweek-Weekend-Evening-Good Weather, in which a few vehicles circulate into the network, is 6:50 hours, while in the scenario “Winter-Midweek-Midday-Rain”, in which the traffic volumes should receive their maximum values, the evacuation time is 7:50 hours. Hence, comparing all results of the previous ETE study, it has been proven that they tend to be much very optimistic in relation to other ETE similar studies. Table 13 displays the ETE results concerning all different scenarios that were applied.

Table 13: Time to clear the indicated area of 100% of the evacuating population, 2025
(Source: Previous ETE report, 2008)

However, in the following ETE study, scenarios are not related to weather conditions. Therefore, as indicated in the Table 12 the elapsed times for the evacuating vehicles are 7:10 and 6:50 hours for the AM and the NIGHT demand scenario respectively. In summary, the ETE results proved to be well below the initial release time of 24 hours and therefore they are considered as very optimistic. Another disadvantage that may influence the quality of the results is that the link-node analysis of the model included a radial area of a 15 km radius away from the NPP. In evacuation studies, the planning area could entail a wider network including more sections, nodes and traffic volumes.
3.3.2. Destination points

Selection of specific destination points for accommodating the evacuees may limit the route choices of the evacuees and create congestion at the boundary points of the network. Instead, it is better if the planner allows the evacuees to opt for the shortest routes to get to the outside boundary area and afterwards seek the proper destination shelter. Such strategy may distribute the evacuees on a broader highway network area, minimize their evacuation time and allow them to get out of the danger zone in the best way possible. This can be easily applied by implementing a rerouting strategy for a certain percentage of vehicles (i.e. ~70 percent). Thus, evacuees just before they reach their destination points (it is preferable to only set one centroid) will be rerouted to secondary destination points, where the shelters, hospitals and other evacuation centers are located. As far as these points are concerned, it is suggested to set more “centroids” with different destination points.

3.3.3. Traffic distribution and assignment methods

To determine the probable reasons for this underestimation of the elapsed times, the trip distribution and traffic assignment methods applied have to be re-examined. As far as the current NGS is concerned, the function of the TRAD behavioral model, which drove the trip distribution and trip assignment decision making process, was expressing the travel time on each network link in terms of traffic volumes and link capacity. This proved that the elapsed times were a summary of travel times that were calculated in each link. Prior to the simulation of the model, the user had to specify the following data into the TRAD model: a) the total trips generated at each Origin, b) the maximum number of trips that can be accommodated by destinations, and finally c) the highway network attributes (e.g. traffic control tactics).

TRAD route choice behavior relied on evacuees that were starting from origin points to points outside the EPZ in direction outbound of the NGS including restrictions regarding movements towards the NGS. The routes were not strictly enforced and thus evacuees were allowed to shift route during the simulation, if congestion was encountered along their evacuation route or if the alternative route was less congested. However, this reroute decision was dependent on the drivers’ knowledge horizon, as the drivers were only aware for the local congestion conditions and couldn’t look ahead to make an optimal routing selection. In addition, as conclusively demonstrated by Janson, such static assignments do not usually consider the true levels of congestion into the network (Janson, 1989, 1990a).

The models applied in the current case study were based on the optimization of the route choice regarding the traffic conditions and the optimization of evacuation routes including some dynamic selection criteria for the selection of routes, such as the evacuees’ preference factors (final destination), limited traffic data available (local
congestion). However, other dynamic characteristics, such as risk factors (wind direction), travel costs (travel time or distance), traffic data (shortest paths, time-varying link), potential bottlenecks that would discourage free-flow of traffic and the assessment of the effectiveness of different traffic evacuation strategies were not considered. Thus, the user equilibrium assignment model that was applied performing static behavioral characteristics and limited dynamic re-routing pertaining congestion levels of the designated routes is not considered as the most efficient model that can express the dynamic behavior of the evacuees.

In general terms, dynamic models seek to describe how traffic flow patterns are evolved in time and space on the network and how the corresponding induced traffic flows using an analytic derivation of route selection based on mathematical simulation models of traffic route assignment (Mahmassani, 2001). In particular, the dynamic process can be split in two components: a route choice mechanism determining how the time dependent path flow rates are assigned onto the available paths at each time step and a method to determine how these flows are being propagated in the network (Aimsun Manual, 2008). Furthermore, dynamic mesoscopic traffic assignment could favor the simulation of queuing, estimating travel time delay and clearance time impacts within the evacuation period without requiring any network enhancement. This approach is proposed to solve the current assignment problem in the current study due to the fact that it includes a route choice mechanism that intends to optimize the route selection decisions based on the current available information. In such procedures, the use of choice functions are based on discrete choice theory including the possibility of en-route rerouting mechanisms, based either on discrete choice theory or other probabilistic approaches.

Moreover, prior to the model execution, the calibration of the network instead of the application of a macroscopic static model (previous study) is preferable to be done with a mesoscopic model performing a Dynamic User Equilibrium (DUE) traffic assignment. As it has already been mentioned above, DUE relies on driver’s long-term habitual behavior to select the usual routes as well as it is an iterative process that produces limited number of routes and traffic flow percentages. This method has been recently suggested due to the fact it is expected to give more comprehensive validation results. Indeed, prior to DUE application and due to the fact that DUE is time demanding process, the run of the simulation used Dynamic Traffic Assignment is considered as necessary in order to set the dynamic parameters of the software.
3.3.4. Traffic Management Strategies (TMS)

While in the previous study no Traffic Management Strategies (TMS) were considered, early studies of modeling and design for more effective emergency evacuation plans proved that the implementation of TMS under emergency conditions plays an important role concerning how the traffic flows in the network (Brown, White, Slyke & Benson, 2009). Such TMS paradigms, which were mentioned in the second chapter, are thoroughly examined especially for the current ETE study in the fourth chapter. Hence, the implementation of a concrete evacuation plan by the officials including various TMS is considered as necessary.
4. ETE METHODOLOGY USING DYNAMIC SIMULATION SYSTEMS

4.1. Introduction

In general terms, every methodological approach regarding evacuation time estimates seeks to determine whether the traffic demand of a roadway network is higher than the capacity. Urbanik states in his report that: “If the evacuation demand rate is lower than the roadway capacity, then the evacuation time is equal to the time required for the last evacuee to begin evacuating plus the evacuee’s driving time for leaving the area. On the other hand, in case of the demand exceeds the roadway capacity of the network, the delay due to the demand surplus must be added to the total evacuation time” (Urbanik, 2000). Such comparison though concerning an ETE study is a complex process due to the reason that evacuating vehicles may depart from different areas, in different times, to different destinations over different routes. That issue becomes more complicated if the planner takes into consideration the adverse weather conditions.

As far as the dynamic simulation methods regarding ETE studies are concerned, every planner intends to introduce as much parameters possible into a model. In that way, it will give him/her the opportunity to experiment simulations with the potential to retrieve more plausible results. During an evacuation traffic simulation process, all these different variables due to the fact that they can take abnormal and multiple values are strongly related with what the scientists use to address dynamic behavior of the evacuation models.

An ETE study should include various different scenarios related to different traffic conditions depending upon the demand, the capacity, the route choice and the weather conditions. Thus, an ETE could be more accurate, comprehensive and reliable as well as much close to the real traffic conditions. Such ETE studies encourage the planners to decide whether the residents of an area should wait long enough to avoid any costs caused by any attempt for unnecessary evacuation or to evacuate soon enough to avoid any fatalities (Lindell and Prater, 2007 & Lindell, 2008).

4.2. ETE Methodology

As in every ETE methodology using simulation systems, the basic steps concern processes such as the process of data collection methods, the insertion of the input data, the execution of the simulation model, the calibration of the network, the validation results, the development of the emergency scenarios, the execution of the
model, the assessment of the elapsed times and finally the repeat of the already mentioned process, though, introducing the Traffic Management Strategies (TMS). These basic methodological steps have been retrieved from an evacuation case study conducted by KLD Associates in the Indian Point Energy Center (IPEC), which is located on the eastern shore of the Hudson River, in Westchester County, New York (Goldblat, 2004).

To determine a new ETE methodology using dynamic simulation system, it is the first step to identify which parameters of the traffic assignment and thus the selection paths will be dynamically influenced during the simulation process of the model. In particular, dynamic route choice is related to parameters, such as the evacuees’ preference factors (final destination, type of vehicle), risk factors (wind direction), travel costs (travel time or distance), available traffic data (congestion, shortest paths), potential bottlenecks that would discourage free flow of traffic and the assessment of the effectiveness of different traffic evacuation strategies, dynamic rerouting, origin and destination centroids, capacity constraints, driving behavior of the evacuees and so forth (Georgiadou, 2007). It is the following Figure 14 that illustrates the basic steps of the Evacuation Times Estimates methodology.

![Figure 14: ETE methodology](image-url)
4.2.1. Data Collection Methods

Data concerning demographic and spatial information of the investigated area must be acquired. However, this data acquisition does not include only the EPZ but also the surrounding area. The identification of the EPZ area is necessary and one of the first steps in the evacuation emergency planning process. As NRC guidelines for NPP report, EPZ might be keyhole (wind direction) or circular (NRC, 2005). Then, the EPZ can be divided into various emergency response planning areas (ERPA) (Goldblat, 2004). In the second chapter is provided the detailed analysis of the parameters that should be taken into consideration.

Large scale maps in hard copy or GIS format of the EPZ and the surroundings with all necessary information could be obtained by transport agencies, institutes, organizations or any other services that provide statistics in a national, regional or local level. Though, if such data cannot be retrieved, additional surveys should be conducted. These surveys could estimate population density, categorize populations in different groups (residents, employees, transients, special facilities etc.) estimate employees’ destination, determine locations and demand data of schools, locate and obtain data from hospitals, hotels, prisons etc. Hence, the location of major traffic generators can be estimated.

The estimation of the highway link capacities is based on field survey observations and on scenario based weather conditions. For detailed information, see on the second chapter.

Generally speaking, as far as the traffic demand data in an ETE study are concerned, three different types are considered: a) “Evacuation demand data", b) “Background Origin-Destination (O-D) demand data” and c) “New Background demand data”. Regarding the evacuation demand data, the planner should set-up evacuation scenarios taking into account fixed elements such as the roadway infrastructure and other variable elements such as the traffic loading. Transport agencies may be able to provide the planners with hourly volumes at various major roadways on dates based on experienced evacuation events. Data related to evacuation demand can be also obtained by recording traffic volumes during peak hours of a day for a period of time (a week) since the accident in a NPP has taken place. Though, if data are not available and furthermore nor previous studies have been conducted, the potential to acquire data from another case with similar characteristics might be the case. “Background demand” can be easily retrieved from traffic surveys. These data concern 24-hour traffic data of the entire day and can be either obtained by related transport agencies or manually through traffic surveys. However, “Background demand data” are not likely to be equal when the evacuation starts. Therefore, the introduction of a certain number of assumptions should be also included in order to define the “New Background demand”. Such assumptions are also related with the demand estimation of voluntarily and shadow evacuees.
4.2.2. Input Data

The introduction of all necessary infrastructure and operational traffic inputs in the model such as the network geometric characteristics, traffic demand, traffic control plans, public transport and traffic management strategies are considered as the next step.

The geometric and operational characteristics are related to: a) the properties of the links, such as: name, category and number of lanes, b) the roadway constraints, such as: guardrail locations and physical encroachments, shoulder type and width, bridge locations, speed limits, channelization, c) nodes, d) public transport and e) traffic control plans. Several previous studies suggest that in case of traffic control data unavailability in real world, the signalized intersections of the model can be equipped with actuated signal controllers. Thus, the traffic lights into the model would adjust automatically the green times allocations for different approaches depending on their incoming time-varying traffic volumes. Although potential effects of the model such as the overestimation of the available capacity of major streets might emerge, this method offers a good approximation to the planners (Wang, 2010).

All models require demand data to run a simulation. In such models, the demand is usually separated into two different types: a) “New Background demand data (manually or automatically generated from the “Background demand data”) and b) “Evacuation demand data”. The first category will not include the same trips as the “Background demand data” due to the fact that a certain amount of movements or destinations would likely be excluded, rerouted or shift to different paths. In case of data unavailability, the traffic modeler should take into account a certain number of assumptions in order to generate the “New Background demand”. More detailed description of the demand estimation and introduction into the model is included in the sections below.

It has to be noticed that prior to the model execution, the model must be controlled for any potential pitfalls. The majority of all various software encloses a feature that performs diagnostic testing of the input stream. This feature assists the user in identifying and correcting potential errors or pitfalls in the input stream.

4.2.3. Model Calibration and Validation

Hereafter, the traffic planner is ready to proceed with the calibration of the model using traffic assignment models with static-dynamic and local-global parameters. The calibration of the network is necessary in order to evaluate the accuracy of the traffic assignment and to determine the input parameters for the evacuation demand data. More specifically, the calibration process tends to adjust computed traffic volumes in order to satisfy the predefined criteria under the specified “Background O-D demand data”.

Institute of Transportation, TU München
Dimitrios Triantafyllos, November 2010
Among the various alternatives of the traffic assignment models, the iterative process of Dynamic User Equilibrium (DUE) is considered as the most efficient in terms of accuracy compared to the existing static and dynamic simulation methods. Its objective is to achieve the optimal distribution of the vehicles in the network. This can be explained from the fact that, in an area that is dominated by residential traffic, traffic conditions are likely to be based on the habitual behavior of the drivers. Hence, residents of that area would select routes based on the optimal everyday paths that have been determined so far. However, this may not be the case in areas where the behavior of the drivers is not habitual (i.e. non-residential areas, tourist resorts).

Due to the fact that DUE is very time-consuming simulation process, the preliminary execution of the model performing a Dynamic Traffic Assignment (DTA one-shot) could be more time-efficient. Hence, all the various global and local parameters of the simulation model will be defined in less time and with less effort.

In general terms, the validation of the model emphasizes on the comparison between the output data of the calibrated model and the real data set. These computed traffic volumes and the real traffic volumes could be compared in various levels. Some examples of these comparisons are: (a) the total assigned traffic volumes of all links with the obtained volumes of all links, (b) the assigned traffic volumes of each road classification (i.e. freeways, arterials etc) with the observed total volume for that road category, (c) the specific link hourly volumes with observed volumes for specific highway locations etc. According to FHWA, the limits of these different comparison levels are ±5%, ±7%, ±12% respectively (Wang, 2010).

4.2.4. Development of emergency scenarios

The estimation of the evacuating vehicles number (demand) inside the EPZ is one of the most challenging parts of an ETE study. Demand population is comprised of: 1) permanent residents, 2) employees who work in the area at risk and 3) transients who are passing through the area or staying in the area temporarily (NRC, 1980a). Apart from residents, employees and transients, demand estimation must include the potential voluntarily and shadow evacuees. As far as the methods of acquisition and variables of demand data are concerned, the theoretical background is given thoroughly on the second chapter.

As it has been mentioned above, in recent evacuation studies the evacuation model simulates simultaneously two different types of traffic demand: a) the “Evacuation demand data” and b) the “New Background demand data”. The first have limited knowledge of alternatives concentrated on evacuation routes and freeways despite the existence of faster paths, while the “New Background traffic” follows normal daily travel patterns until the evacuation begins (Wang, 2010 & Lam, 2010). According to the current methodology, the everyday traffic demand data under normal conditions
is addressed as “Background demand data”. Into the model though, only the two following demand types are considered:

a) “New background demand data” (Model calibration and validation required),
b) The “Evacuation demand data” (calibration of the entire model is also required).

Figure 15 illustrates a random scenario of all different demand types regarding an NPP accident.

Figure 15: Random scenario of an accident in an NPP and all various daily traffic demands

4.2.4.1. Background demand

“Background demand” data in O-D matrices include all trips generated between traffic analysis zones due to normal travel needs but not related to evacuation activities. The “Background O-D demand data” should be obtained in matrices with the 24-hour traffic demand data of a normal day. Though, apart from the 24-hour “Background demand” of a representative day, different scenarios related to seasonal characteristics, days of the week, time intervals of the day, weather conditions and so forth are needed. However, in reality, this might be not possible due to the fact that such detailed data is difficult to be retrieved and only in rare cases are available. Therefore, in most of ETE studies, only O-D matrices regarding normal labor days are taken into consideration.
4.2.4.2. New background demand

Once the evacuation has begun, the “Background O-D demand data” will not be the same anymore. The purpose of the “New background demand” is to represent the traffic of the area inside and outside the EPZ during the evacuation process. These data concern vehicles that start their trip from centroids of the wider area of an NPP and finish to centroids of that area. Due to the fact that it is very difficult to obtain demand data of the NPP region, the current type of demand should be based on “Background demand” data in alliance with a certain amount of assumptions. The current methodology suggests that the “New Background demand data” should include the following types of trips.

1. Trips within centroids of the EPZ.
2. Trips from EPZ towards the shadow area.
3. Trips generated from centroids inside the EPZ and heading to centroids outside the shadow area.
4. Trips from centroids outside the shadow area towards centroids of the EPZ.
5. Trips started from centroids of the shadow area and ending to EPZ centroids.
6. Trips within centroids located in the shadow area.
7. Trips within centroids located in the outside area
8. Trips generated from centroids of the outside area towards centroids of the shadow area
9. Trips starting from centroids of the shadow area and ending to centroids of the outside area.

The main distinction between the “New Background demand” and the “Background demand” is that the first does not include the entire number of everyday O-D trips. In detail, since the evacuation process has begun, the following O-D pairs of the “New Background demand” matrices: 1, 2, 3, 4, 5 must be reduced according to various formulas. Once the evacuation demand has been distributed into the model, all these five trip categories should be excluded from the model.

According to NRC, the time interval required till every evacuee is being informed is approximately 90 min (NRC, 2005). Subsequently, trips that are generated from centroids outside the EPZ (outside and shadow area) towards destination points in the EPZ should included into the O-D matrices of the “New Background demand” till the “Evacuation demand” starts generating vehicles. Then, trips regarding vehicles leading towards the EPZ should be reduced proportionally. Reducing through a function the attraction of the destination points that are situated inside the EPZ and
shift to another destination points or minimizing the generation of these trips can perform such action. This reduction of the trips though, depends on the number of the drivers that will return home e.g. in most of the cases family evacuate as one unit. Recent empirical studies consider that within a time interval, the majority of the drivers would go back to their house in order to gather with household members and to secure their houses (Kang et al., 2007). Under no-notice for evacuation though and in particularly if the disaster is perceived as very severe and tremendous threat, as a NPP accident, individuals would intend to evacuate the impacted areas as soon as possible and select a secure and distant shelter. Figure 16 depicts all probable O/D trips that are included in O/D matrices of the model are considered below:

![Generated trips](image)

Figure 16: O/D Trips included in the "New Background demand" matrices

In addition, as far as the pass-through trips are concerned, those trips after the notification to evacuate release will be either reduced or shifted to another destination points.

1. Those trips start from origin points outside the EPZ towards destination points outside the EPZ but driving through the EPZ. It is expected that the people that would travel through the EPZ area will either shift their destination point in order to reach their relatives or select an alternative path in order to reach their primary destination outside the EPZ area.
2. A certain amount of drivers in order to reach their predefined destination point will select a more secure, safe path. A path that would provoke a long detour.

3. Many drivers will choose not to travel to the predefined destinations and they will either shift to another destination points by selecting either the same (till a point) or another path in order to avoid passing through the EPZ.

Subsequently, trips along routes around the EPZ may increase due to the fact that drivers will not choose to drive through the EPZ area, if it is not necessary. A certain percentage of the drivers will travel towards their predefined destination points as in situations of panic, reasons such as picking up children from school or any other family members play an important role into the route choice decision for evacuation. Nevertheless, these percentages of the drivers that used to travel through the EPZ vary from case to case and from scenario to scenario. Figure 17 displays several alternative routes and destination points of the pass-through traffic of the “New Background demand”.

![Diagram showing alternative routes and destination points]

Figure 17: Alternatives of the pass-through traffic of the “New background demand”

4.2.4.3. Evacuation demand

“Evacuation demand data” embrace O-D matrices with trips originated from centroids inside the EPZ towards a number of different destination points located at the boundary of the EPZ. Hereafter, by applying a traffic management strategy called as “rerouting”, it is possible to reroute vehicles to other destination points (shelters, hospitals, relatives etc.).
The estimation of the “Evacuation demand data” does not concern only one scenario. The determination of different scenarios is needed. Thus, the ETE study would be more thorough and comprehensive. As it has already been mentioned in the second chapter, the scenarios should consider different times of the day, days of the week, seasons, weather conditions, special events, public works etc. It can be also noted that most of the evacuation cases consider that the traffic circulates and the drivers seek to evacuate by mainly driving through the major road types. Figure 18 depicts a random scenario of “Evacuation demand”.

![Random scenario of Evacuation demand](image)

**Figure 18**: Random scenario of “Evacuation demand” including a route choice example

### 4.2.4.4. Destination points

The definition of the candidate destinations on the periphery of the EPZ plays a fundamental role in the implementation of an ETE study using dynamic simulation modeling. In simple words, these destinations represent the points where network links cross the outer boundaries of the region. As Southworth reports in his regional evacuation modeling review, the destination choice for people who are under threat to life or property tends to be modeled in one of four ways (Southworth, 1991):

- Evacuees are assumed to exit the at-risk area by heading for the closest destination (in terms of distance and/or expected travel time);
- Evacuees will display some degree of dispersion in their selection of area exit points, depending upon such factors as the location of friends and relatives and the speed of the hazard on-set;
- Evacuees will head for pre-specified destinations, according to an established evacuation plan;
• Evacuees will exit the area on the basis of traffic conditions on the network at the time they try to leave the area.

In detail, evacuations regarding small urban or rural systems are based on the first assumption. However, the second assumption that concerns a spatial dispersion in destinations is a phenomenon that could appear in cases where the hazard is not approaching rapidly but when evacuees may have relatives or simply better choice of overnight shelter elsewhere. The modeler to assess the system’s response to an experimental traffic routing plan can use the third assumption. Nowadays, in large cities and in particular in U.S, there are published evacuations routing plans that tend to direct drivers to fixed destination points. Supplementing such plans in alliance with the implementation of the highway restrictions of traffic flow, the third assumption may provide the best method for evacuation. Finally, the fourth assumption is related to the myopic evacuee behavior. Due to the fact that congestion and subsequently delay are mainly occurred at the major intersections, the channelization of flow may be considered as the most efficient option. Hence, once the evacuees will feel that the pre-selected path might be congested, they could make detours and shift their destination points to others other than the predefined ones (Southworth, 1991).

In particular, as far as the destination points of the “New background demand” are concerned, the percentage of trips originating outside the EPZ towards the EPZ, will be the same with the “Background demand”. On the other hand, due to the fact that new-built O-D matrices will be needed for the “Evacuation demand”, a certain amount of new destination points on the circular boundary area of the EPZ should be applied. As quoted by Hobeika, the selection of specific destination end points may limit the route choices and raise the congestion levels to the sections near to the boundaries of the EPZ. Instead, it is preferable to force evacuees to choose the shortest paths to evacuate the EPZ by establishing destination points (primary centroids) in the boundary of the EPZ area. Then, the majority of the vehicles should head to the proper destination points (secondary centroids). Such strategy aims to distribute the evacuees on a broader highway network area, minimizes their evacuation time and finally allows evacuees to get out of the danger zone using the best route (Hobeika, 1998). Subsequently, all trips originating from inside the EPZ should be routed towards the nearest exit of the EPZ boundary. Then, a certain percentage (i.e. ~70 percent) of these vehicles will be rerouted to the nearest designated shelters beyond the evacuation boundary of 10 miles. More specifically, the various entrances of the different centroids and destination point’s configuration are depicted below:

• A certain number of entrances (the number depends on the plans of the planners, highways or other important road types will be primarily chosen) connected with a number of Primary Centroids (PC) in a radial direction in about 10 miles far from the NPP.
A certain number of entrances connected to Secondary Centroids (SC) far away from the boundary zone of the NPP. These secondary destination points consider the evacuation refugees, shelters, hospitals, neighboring regions etc. Figure 19 illustrates the determination of the candidate PC and SC as well as the rerouting strategy.

Figure 19: Centroid configuration and “Rerouting traffic” strategy of the “Evacuation demand”

Although these destination points could be connected with one or more PC, this strategy is not recommended due to the fact that high number of the PC would make more complicated the distribution and assignment of the vehicles into the model. As soon as vehicles reach the last section prior to their destination points, a certain percentage of the traffic would be rerouted (in most software through the implementation of a TMS). Such action seems to be closer to reality as well as it tends to be the most plausible scenario for evacuating vehicles. In this manner, vehicles will seek to reach the destination points established in the boundary of the EPZ. Instead of removing all of them from the network at these points, some of them (circa 70%) will keep on travelling outside the EPZ seeking to find their secondary destination points (SC). Consequently, these destination points will be the final ones. The rest (i.e. 30%) will be either disappear in the PC or rerouted to other specific destination points.
4.2.5. Dynamic traffic distribution and assignment model

In general terms, route selection models aim to estimate motorists' behavior over a transportation network over time. Using dynamic simulation modeling, the most substantial concern is to determine the traffic distribution and assignment model. Dynamic route choice includes two different types of route choice behavior: Stochastic route choice and Dynamic User Equilibrium (DUE).

4.2.5.1. Stochastic models

Stochastic route choice consists of two steps: (a) the path calculation (i.e. Dijkstra algorithm, number of paths at the beginning of the simulation shortest path tree for each destination every cycle of the simulation) and (b) the path selection (distribution of new and guided vehicles among the alternative paths via discrete choice probabilities) processes. The steps of the stochastic route choice process are explained below (Manual Aimsun, 2008):

1. Initial shortest path calculation for each destination using initial cost function (free-flow conditions);
2. Simulate during an interval (route choice cycle);
3. Calculate shortest path tree for each destination using dynamic cost function;
4. Repeat steps 2, 3 till the end of the simulation period.

4.2.5.2. Dynamic User Equilibrium

Regarding the daily traffic operation of a road network and in particular the arterials and the freeways, the user equilibrium operation is likely to be the best assignment choice. It is expected that travelers (mostly residents and employees of the area) have already tested several alternative paths and they have finally decided to choose (as individuals) the shortest routes in terms of travel time or other capacity constraints. Hence, travellers will seek to minimize their individual travel times. According to Wardrop's principle the journey times on all the routes actually used are equal, and less than those, which would be experienced by a single vehicle on any unused route (Mahmassani, 2001). However, under certain conditions, drivers may prefer path with higher travel times rather than the shortest ones. This is explained from the fact that arterial routes provide better travel times on average compared to freeways routes with significant congestion. Though, according to previous studies, drivers will not always prefer these arterial paths due to the fact that they are more complex, with greater variability as well as the road user finds them unfamiliar and unsafe (Shah and Wunderlich, 2001) Hence, drivers will choose to remain on the congested lanes of the freeway rather than shifting to the arterial routes even though the travel time would be less (Chang Chiu, 2005). Figure 20 illustrates how the shortest path trees are performing during a multiple iteration traffic distribution and assignment model simulating with DUE.
4.2.5.3. Evacuation Route Choice Paths

In evacuation methods, the objective of the route choice is to compute the optimal routing of evacuation trips out of the region via the specified destination nodes as well as to determine which highways must be used. In such cases, the route selection is dependent upon a certain number of drivers’ and situations’ characteristics. Subsequently, the most important question for a modeler is: “Which level of myopia versus preplanning every driver concerns into the path selection process?”

In situations under rapidly developing and proximal risks, every experienced planner expects a higher degree of myopic decision making by the drivers. This may be balanced from the pre-considered assessments that define where the vehicles may head to as well as how to be distributed in the model under less stressful conditions.

Evacuation models are strongly related to the route choice behavior. The evacuation routes of the models are classified into three categories (Georgiadou, 2007):

(a) Pre-defined models where the route has been chosen before the evacuation simulation based on an existing evacuation plan or on calculation criteria such as reaching the closest destination;

(b) Models based on the optimization of the route choice regarding the traffic conditions (i.e. system optimal or user optimal route selection models). The majority is being performed based on the objective of the optimization of evacuation routes (reduce travel time or distance);

(c) Models that include dynamic selection of routes, associated with some of the following criteria:
- The evacuees’ destination, route or mode choice criteria (final destination, type of vehicle),
- Risk factors (wind direction, weather conditions),
- Travel costs for each destination (travel time or distance),
- Available traffic data contribute to shift routes (congestion, shortest paths),
- Potential bottlenecks that would discourage free flow of traffic
- Assessment of the effectiveness of different traffic evacuation strategies.

However, models nowadays favor the combination of different kind of routes during a simulation. Some paradigms of these combined route choices are considered below (Aimsun Manual, 2008):

- Pre-trip vs. on-trip vs. no information
- Scheduled vs. unexpected events
- Short-term vs. long-term
- Essential for large networks

In an ideal case, it is assumed that all drivers would follow the directions of the emergency management personnel. As it was proved from a 2004 study, conducted by Dotson and Jones, evacuees would comply with the protective actions of emergency guidelines of the responders and traffic control barricades and signs (Dotson & Jones, 2005a) More specifically, according to the same study, it was concluded that the majority of the drivers would follow some specific designated evacuation routes. In practice though, the ETE results may underestimate the evacuation times in order to move all the individuals to safe areas. Therefore, the behavior of the drivers in an evacuation route choice model must entail real-traffic evacuation management system to calculate the deviations of the drivers from pre-defined routes (Chang Chiu, 2005). As Srinivas P. quotes in his report, the modeling of evacuation behavior and the route selection accommodates the following considerations (Srinivas & Yu-Ting, 2010):

- Perception of risk related to the subjectivity rather than objectivity that the assessments and the observations results prove.
- During the evacuation process, information about traffic conditions under such hazardous situations should be published rather than numerical measurements.
The model must take into account the heterogeneity of the individuals in each PZ.

Although the proposed evacuation route choice model adopts discrete choice theory, fuzzy and heterogeneous behavior of the individuals plays a crucial role into the process. In addition, route choice for vehicles in an evacuation model should be determined individually including the potential for en-routing as well as those who just made the decision to evacuate and need to choose an evacuation route from the zone where they are located. Therefore, in case of an area evacuation, route choice behavior can be a combination of predefined, optimized and dynamic selection path types.

Among the various discrete probability choices (binomial, proportional, Logit, C-Logit, etc.) for the distribution of new and guided vehicles throughout the alternative paths available, the most adequate for emergency cases is considered the C-Logit one. Cascetta in his study proved that traditional multinomial logit models do not consider the overlapping effect between different paths among the various alternatives (Cascetta et al, 1996). For instance, if the model defines three different paths of the same length, each one will receive a probability of one-third (path utility is solely based on the path length). Thus, Cascetta in his study proposed a model addressed as C-logit model. This model can adjust the path utilities according to the degree of overlap, by means of a Commonality Factor (CF) incorporated into the traditional form of the multinominal logit model (Cascetta et al, 1996). Figure 21 depicts an example to illustrate the use of C-Logit route choice model, comparing it with four alternative paths starting from the same origin point (O) towards the same destination point (D).

Figure 21: Various paths with costs in each link from an Origin to a Destination.
(Source: Based on Aimsun Manual, 2008)
Table 14 displays the costs in terms of travel time regarding the various paths and Table 15 represents the resulting choice probabilities of both models.

<table>
<thead>
<tr>
<th>Travel Times</th>
<th>Path 1</th>
<th>Path 2</th>
<th>Path 3</th>
<th>Path 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seconds</td>
<td>540</td>
<td>600</td>
<td>720</td>
<td>900</td>
</tr>
<tr>
<td>minutes</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>hours</td>
<td>0.15</td>
<td>0.1667</td>
<td>0.2</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Table 14: Costs in terms of travel time.
(Source: Aimsun Manual, 2008)

In situations of emergency, the C-logit route choice model is able to calculate the percentages of the route selection paths taking also into account the congestion effects on the overlapping section among the various paths, while the logit model is not able to recognize the overlapping sections of the various paths and subsequently their effects on the calculation of the dynamic costs. In addition, values of the scale factor lower than 20 is expected to give better model results due to the fact that the traffic would be better distributed throughout the network of the model. During an evacuation, the majority of the traffic is concentrated in the major road categories in order to evacuate rapidly. In case of a small value of a scale factor with a logit model (i.e. scale factor: 10), for instance, the overlapping section (including Route 1, Route2 and Route 3) tends to attract much more traffic (i.e. 87%) rather than the Route 4 (i.e. 13%). With the introduction of the C-logit model, it is considered that more drivers will be eager to shift to the Route 4 (i.e. 26%), even though it is the route with the higher aggregated initial cost.

<table>
<thead>
<tr>
<th>Scale Factor</th>
<th>P(1)</th>
<th>P(2)</th>
<th>P(3)</th>
<th>P(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.26045</td>
<td>0.25614</td>
<td>0.24775</td>
<td>0.235663</td>
</tr>
<tr>
<td>10</td>
<td>0.3545</td>
<td>0.30008</td>
<td>0.21501</td>
<td>0.130412</td>
</tr>
<tr>
<td>50</td>
<td>0.65642</td>
<td>0.28528</td>
<td>0.05388</td>
<td>0.004423</td>
</tr>
<tr>
<td>100</td>
<td>0.83636</td>
<td>0.15797</td>
<td>0.00564</td>
<td>0.000038</td>
</tr>
<tr>
<td>1000</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 15: Comparison between Logit and C-Logit route choice models.
(Source: Aimsun Manual, 2008)

4.2.5.4. Traffic simulation model

The application of a traffic simulation model is necessary to simulate the movement of vehicles during the process of evacuation. The model should explicitly describe traffic conditions in the saturated flow regime to account for congestion effects. As it has been mentioned in the second chapter, to evaluate such studies related to evacuations, there are various different static and dynamic micro, meso or macro
simulation models available. It is responsibility of the planner to assess each case study individually and furthermore to select the optimum simulation model for each evacuation study.

4.2.6. ETE results

The final results of each ETE study are the elapsed times of the evacuating traffic originating from the centroids within the evacuation region (EPZ) till they evacuate utterly the EPZ. It has to be mentioned that once all evacuating traffic has been moved out of the EPZ, the travel time that the vehicles would need to reach their final destination point (reception center, home of a relative, etc.) would not be considered as a component of the ETE study. The ETE results can be presented either with graphical diagrams or numerical tables.

4.2.7. Implementation of Traffic Management Strategies

The last step of the ETE study concerns the assessment of the traffic simulation results in order to determine whether there is a need for implementation of traffic management strategies or not. TMS can contribute to find the most effective ways of managing traffic and impose valid measures in time to reduce congestion and therefore travel times. Hence, the implementation of such strategies could support the evacuation movements, resolve some of the congestion problems and ameliorate the traffic flow. In fact, by introducing the traffic management tactics to the simulation and repeat the entire process of the ETE analysis have been proved that it will contribute to the avoidance of the underestimation of evacuation time (Goldblat, 2004). Previous studies identified that the most successfully operated strategies to improve the total efficiency of transportation infrastructure under evacuation conditions were:

1. Contra-flow operation (Theodoulou & Wolshon, 2004a,b; Tuydes & Ziliaskopoulos, 2006; Wolshon, 2001);
2. Coordinated evacuation operation (Dixit & Radwan, 2009b; Liu, Lai & Chang, 2006; Sbayti & Mahmassani, 2006); and

However, the development of traffic control plans could also be applied in order to contribute to the alleviation of the congestion levels. Previous studies proposed some operational alternatives, such as: resetting stop lights to continuous green, stop operation of traffic control and starting controlling intersections manually,
establishment of exclusive special traffic control points. Actually, there are a several TMS that could contribute to more efficient and fast evacuation of the EPZ, such as: closure of specific turnings prohibition of the on, off-ramps and several other that have been applied and proved to be successful in many case studies (Wang, 2010).

4.2.8. Basic assumptions

Each ETE study is different and unique and it has its own site-specific assumptions. These assumptions should be evaluated in respect to their level of credibility. Some of these assumptions are considered below:

- The evacuation procedure concerns the entire population of EPZ;
- The effective evacuation of all population groups with the minimal risk of injury or death is possible (EPA, 1992);
- All evacuees will be notified from the advisory;
- All evacuees will comply with the protective actions of emergency responders guidelines and traffic control barricades and signs (Dotson & Jones, 2004);
- Some of the population who relies on public transport will share a car with relatives, friends or neighbors;
- Urbanik reported that people do not panic in an emergency and drivers will act in a manner that promotes good traffic flow, obeying the rules of the road and acting in an orderly manner(Urbanik, 2000). However, recent studies have proved that the behavior of the drivers during an evacuation is expected to be abnormal and unpredictable due to the fact that each case study is distinct and depends on many different individual characteristics (Wang, 2010);
- The best driver of the family will drive during the evacuation of a family group (Urbanik, 2000);
- Evacuees will try to escape in a radial direction away from the NPP. Only in extreme cases evacuees will move laterally or even towards the NPP for some part of their trip (Urbanik, 2000);
- Double-counting phenomena will appear with school children who are included in the special facility population and permanent residents (NRC, 1992);
- Emergency responders will be available while an incident occurs (NRC, 1980);
- Pre-planned traffic control will be installed by law enforcement at key intersections to ameliorate the guidance of the drivers.
- It has been observed that parents seek to go to their children’s locations first before leaving the evacuation areas (Stern, 1989).
Each individual’s awareness of the hazard is related to: (i) his/her prior experience with disasters and/or evacuations, (ii) education and training that he/she has received related to the disaster preparedness, and (iii) influence of information or news reports about disasters (Lindell & Prater, 2007)

As it has been noted in the second chapter, the aggregation of conservative assumptions in one scenario may result in conclusions far from reality and therefore should be avoided.
4.3. Description of case study: ETE in an NPP using AIMSUN

4.3.1. Introduction

The third chapter, apart from the previous ETE study results, included also the roadway capacity and the demand data estimation process of the current ETE case study. It is the objective of this chapter to explain the simulation steps of the current ETE study in an NPP performing dynamic simulation systems.

The mesoscopic simulator of Aimsun was selected to perform such process due to the complexity and the size of the area. Mesoscopic simulator proved to be the most efficient in terms of time and results credibility simulator. Figure 22 depicts the network characteristics of the EPZs and the wider areas of the NPP as well as the centroids' configuration in the environment of Aimsun.

Figure 22: The EPZs of the actual NGS in the environment of Aimsun.

The introduction of the network's geometrical characteristics, the insertion of all necessary elements (section and intersection attributes, demand O/D matrices, traffic management strategies) in the model in order to execute the simulation process and the calibration as well as the validation of the model were done by transport engineers of TSS SL. The configuration of all various demand scenarios as well as the implementation and the introduction of all the TMS in Aimsun was defined by the author of this project.
In this stage, the activities to compute the elapsed times with Aimsun software regarding the ETE study are described below:

**Step 1:** The simulation process started with the execution of a Dynamic Traffic Assignment (DTA) -“One shot” in Aimsun in order to determine roughly all various model parameters. To perform a DUE simulation is a time-demanding process. Demand data included only the “New Background demand” (generated from the “Background demand” with assumptions). It is used to verify the model.

**Step 2:** After obtaining the model parameters estimations (from previous DTA), a DUE traffic assignment simulated in order to execute an “.apa” file. By performing an iterative simulation process, the different route selection paths concerning the “New Background demand” were executed.

**Step 3:** Subsequently, a DTA-”one shot” simulation was performed with the “New Background demand” and the “Evacuation demand” O/D matrices. In the actual DTA, the previous “.apa” file was uploaded. A file that includes a certain percentage of the available paths retrieved from the DUE before. The first scenario, addressed as “DO-NOTHING” did not take into account any traffic measures. However, the implementation of a TMS (rerouting) was considered as necessary in order to reroute traffic from PC to SC.

**Step 4:** The next step concerns the evaluation of the model results. This was achieved by obtaining and assessing various Aimsun simulation outputs, such as the elapsed time (through a script), speed levels, vehicle density, traffic flow, queue length, virtual queue length etc. Or else, the adequate elapsed times were given through a script. By the time the simulation outputs were considered as inadequate, the planner has had to reconsider the demand data and/or the static, dynamic, local or global parameters of the model.

**Step 5:** The simulation process was performed with respect to all the predetermined various demand scenarios. Two different demand scenarios were defined: a) Morning peak-hour, b) Evening.

**Step 6:** Once the first ETE results regarding the two demand scenarios were acquired, apart from the “DO-NOTHING scenario - No TMS” two more scenarios were applied.

- Firstly, a numerous road closures (mainly on-ramps and off-ramps) in specific points on the highways were implemented.

- Secondly, the “Full advanced TMS in emergency situations”, aside from the TMS applied above, also included the Contra-Flow operation.

Each individual step of this effort is represented as a flow diagram in Figure 23.
1. Dynamic Traffic Assignment (DTA)  
   only New Background demand (“one shot”)

2. Dynamic User Equilibrium (DUE)  
   (.apa file with routes of “New Background”)

3. Dynamic Traffic Assignment (DTA)  
   New Background demand + Evacuation demand  
   (with .apa file from previous DUE)

4. Evaluation results (flow, density, av. speed, av. virtual queue length)

   Re-consider: Demand data, dynamic or static, local and global parameters

   Repeat from step 2

5. Various Scenarios  
   A. Morning peak-hour,  
   B. Night scenario

   Repeat from step 2

6. TMS  
   - Road closures,  
   - Contra Flow

   Repeat from step 2

Figure 23: Flow diagram of simulation activities with Aimsun
4.3.2. Development of emergency scenarios

The current study was based on the evacuation scenario, in which a large amount of traffic would evacuate from the evacuation and shadow area due to an accident in an NPP. The objective was to simulate the evacuation traffic that entered or passed by the EPZ and furthermore to analyze the effectiveness of TMS for the possible congestions caused by the evacuation traffic on the highway network of the area in proximity to the NPP. In the actual case study, two different evacuation scenarios related to two different times of the day were developed. Each scenario was evaluated with respect to various TMS. Subsequently, all these scenarios resulted in six different elapsed time results. Table 16 displays the development of the various scenarios.

Table 16: Scenarios development

<table>
<thead>
<tr>
<th>Scenario Demand/ Scenario TMS</th>
<th>Scenario 1: &quot;AM peak-hour&quot;</th>
<th>Scenario 2: &quot;Night scenario&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. &quot;DO NOTHING&quot;</td>
<td>1A</td>
<td>2A</td>
</tr>
<tr>
<td>B. &quot;MANUAL OPERATION&quot; (RC)**</td>
<td>1B</td>
<td>2B</td>
</tr>
<tr>
<td>C. &quot;ADVANCED TMS for EMERGENCY PURPOSES&quot; (RC &amp; CF)**</td>
<td>1C</td>
<td>2C</td>
</tr>
</tbody>
</table>

*Re-routing strategy regarding primary centroids and secondary centroids is included in all scenarios

** RC=Road Closures, CF= Contra-Flow

- Although “Background demand” data were not available in any of the following demand scenarios, the rest of the demand data regarding the AM demand scenario were provided by the previous ETE report.

- In every demand scenario, the simulation process lasted thirteen hours.

- In every scenario the “New Background demand” was included from the beginning of the simulation process, while the “Evacuation demand” was introduced after the first hour of simulation.

- As far as the TMS are concerned, they were activated 1:30 hour after the evacuation demand was introduced into the model. For example, in the 1C scenario, the simulation started at 07:00, the evacuation demand started simulating at 08:00 and therefore the road closures and the contra-flow TMS were both activated at 9:30. The duration of the simulation with the TMS lasted in total 10:30 hours.
4.3.2.1. Scenario demand 1: Morning peak-hour (AM)

Regarding the first demand scenario (AM), emergency evacuation simulated from 07:00 a.m. to 20:00 p.m. Evacuation demand generated traffic from 08:00 a.m. till 12:00 a.m. As far as the “New Background demand” is concerned, the O/D matrices embraced nine different trip categories (see Figure 20 in previous sub-chapter 4.2.4.2 pp. 52). “Evacuation demand” data were generated into the EPZ and the vehicles headed towards the PC. Both demand data were obtained by the previous ETE report (official document is confidential). Figure 24 depicts the “New Background demand” and the “Evacuation demand” concerning the first demand scenario.

![Evacuation scenario 1: Morning peak-hour](image)

Figure 24: “New Background” and the “Evacuation” demand concerning the AM demand scenario.

4.3.2.2. Scenario demand 2: Evening (Night)

In the Night demand scenario, the “New Background demand” was determined by the existing traffic demand data taking into account the night traffic conditions in the wider area of the existing NPP. In particular, thirty percent of the previous O/D matrices (afternoon peak-hour) were taken into account. As a result, an approximate “flat” demand was created. It is also noticeable that during the evacuation some O/D trips were reduced proportionally till the moment that the evacuation traffic was not generated any more. After this moment, these trips were not considered anymore. Figure 25 depicts the configuration of the “New Background demand” and the “Evacuation demand” of the third demand scenario.
4.3.3. Destination points

After the introduction of the demand into the model, the next step concerns the determination of the destination points. Since vehicles were generated from the origin points, they were searching their destination points. The determination of the destination points is described in the methodology above. In simple words, the various entrances of the different centroids and destination point’s configuration are depicted below:

- A certain number of entrances connected with a number of Primary Centroids (PC) in a radial direction in approximately 10 miles far from the EPZ.
- A certain number of entrances connected to Secondary Centroids (SC) far away from the boundary zone of the NPP. These secondary destination points with some other individual points consider the evacuation refugees, shelters, hospitals, neighboring regions etc.

Traffic distribution is considered below:

- 60 percent rerouted to SC where they ended their trips;
- 25 percent finished their trip (attracted) at the PC destination points;
- 15 percent are rerouted to specific destination points (shelters, hospitals etc).
Figure 26 depicts the centroids’ configuration of the EPZ, the primary, the secondary centroids and their connectors (Entrances, Exits).

Figure 26: Representation of PC and SC in the environment of Aimsun.

4.3.4. Dynamic traffic distribution and assignment model

The mesoscopic simulator of Aimsun was selected into the actual ETE study due to the fact that on the one hand the macroscopic traffic assignment that was executed in the previous study was not able to model the dynamic behavior (selection paths based on travel costs, capacity constraints, en-routing etc.) nor to give outputs, such as queuing, virtual queuing, vehicles waiting-out etc. On the other hand, Aimsun microscopic traffic assignment was considered as time consuming process and inappropriate concerning that large and complex study area. Consequently, a bridge connecting macroscopic and microscopic assignments addressed as dynamic mesoscopic traffic assignment was finally proved to be the most efficient alternative.

According to Lam, the dynamic traffic assignment with mesoscopic simulator could better estimate the travel time delays because of the queue and the clearance time impacts during the evacuation regardless any enhancement in the network (Lam, 2010). Furthermore, the Aimsun mesoscopic simulator is a flow-based algorithm that calculates travel time by volume delay functions and queuing algorithm. Hence, when traffic demand is lower than the road capacity, the travel time is defined only by a function that is determined by volume and delay. On the other hand, when demand is greater than the capacity, vehicles will be blocked at the upstream links and wait until the downstream vehicles have been dispatched. Consequently, dynamic traffic assignment with mesoscopic simulator calculates more realistically the travel times, the time delay, the density, the volumes, the queue length and the virtual queue length compared to static traffic assignment. Finally, the Aimsun mesoscopic simulator permits the implementation of a certain amount of TMS, such as: a)
changing of the control plan operation during the simulation process by applying a strategy, b) road closures by applying a strategy relevant to speed or time and c) contra-flow operation by changing the infrastructure of the model.

4.3.4.1. Evacuation Route Choice Paths

In order to obtain different paths regarding the background traffic, it was firstly performed three different macroscopic simulation processes with one-hour demand data: a) AM peak-hour, b) Night one-hour demand. This process generated static route paths. Then, the model was tested in accordance with these static paths.

However, the dynamic behavior of the model through a DUE simulation process was needed. Therefore, a DUE traffic assignment with all the “New Background demand” matrices of second scenario was simulated. In both cases, the result was an “.apa” file with the various route choices. The first one was based on static traffic assignment, while the second in the dynamically selection of routes. Hereafter, this “.apa” file was uploaded to the DTA “one-shot” in order to define the routes available for the background traffic (car). Figure 27 displays the percentage of the assigned routes (70%) that vehicles will follow according to the .apa file.

![Figure 27: Route choice models parameters window in Aimsun.](image)

Table 17 considers all values of the DTA route choice parameters:
Table 17: Scenario development

<table>
<thead>
<tr>
<th>Route Choice parameters</th>
<th>Final values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle</td>
<td>0:05:00</td>
</tr>
<tr>
<td>Interval</td>
<td>1</td>
</tr>
<tr>
<td>Attractiveness weight</td>
<td>5</td>
</tr>
<tr>
<td>Route choice model</td>
<td>C-Logit</td>
</tr>
<tr>
<td>Initial K-Paths</td>
<td>5</td>
</tr>
<tr>
<td>Max Nu. To keep</td>
<td>10</td>
</tr>
<tr>
<td>Max Nu of Paths</td>
<td>10</td>
</tr>
<tr>
<td>Scale factor</td>
<td>2</td>
</tr>
<tr>
<td>Beta</td>
<td>0.15</td>
</tr>
<tr>
<td>Gamma</td>
<td>1</td>
</tr>
<tr>
<td>En-routed</td>
<td>checked</td>
</tr>
<tr>
<td>Virtual en-routed</td>
<td>checked</td>
</tr>
</tbody>
</table>

4.3.5. Implementation of Traffic Management Strategies

In the current study, operational traffic management methods such as: a) Manual operation of the traffic (RC) and b) reverse flow of traffic (CF) were considered and modeled in Aimsun using the TMS and incident tool available in the program.

In the beginning, none of the demand scenarios (AM and Night) included any traffic management plans. That was addressed as the “DO-NOTHING” (A) scenario. However, it is one of this project’s objectives to investigate the efficiency of various TMS in emergency situations. Therefore, the second TMS scenario (B) addressed as “Manual Operation” scenario embraced the implementation of Road Closures (on and off ramps). Finally, the third scenario (C) called as “Advanced TMS for Emergency Situations” suggested both the Road Closures and the implementation of the Contra-Flow operation. However, an inbound lane was always available for vehicles willing to enter in the EPZ.

4.3.5.1. Road closures

The “Road closures” strategy considered some of the major evacuating routes of the NPP wider area (Route A, Route B and Highway C and few arterial streets). This strategy was activated in Aimsun 90 minutes after the evacuation process had started. Figure 28 displays the intersections with the TMS “Road closure” (on and off ramps) implemented.
4.3.5.2. Full advanced TMS regarding emergency situations

Besides the Road Closures, the third scenario was included Contra-Flow (CF) operation. In detail, it was implemented in the west part of the Route 401 originating from the NPP until outside the EPZ. Ninety minutes after the evacuation of the vehicles started. Aimsun 6.1 favored the implementation of a pair of strategies. Apart from one (in some cases two) inbound lane(s) available for vehicles willing to enter the EPZ, traffic was not allowed to enter. Figure 29 displays the part of Route 401 that the CF operation was implemented.

In order to implement CF operation in Aimsun, the extension of the road network was required. These additional lanes were applied in the sections where the CF operation took place. Then, two lane-closure strategies were applied with the first one (1) lasting the first 90 minutes of the simulation, while the second (2) was activated from...
the end of the first until the end of the simulation. Figure 30 displays the CF implementation in a random section in Aimsun.

Figure 30: Example section implementing Contra-Flow operation in Aimsun.

4.3.6. ETE results

The simulation results concerning every scenario demand (AM, NIGHT) are expressed for both “New Background demand” (car) and “Evacuation demand” (car P) in terms of traffic indicators such as traffic density, traffic flow, virtual queue length and speed. A script needed to be manually created in Aimsun, for the ETE results to be obtained regarding each of the nine scenarios. According to the script, the ETE results were obtained when the following indicators: a) “traffic density” and b) “vehicles inside the area” took zero values. Table 18 depicts the ETE results retrieved from the script, which was created manually in Aimsun, after the simulation process with the mesoscopic simulator of Aimsun.

Table 18: ETE Results

<table>
<thead>
<tr>
<th>Scenario Demand/Scenario TMS</th>
<th>Scenario 1: &quot;AM peak-hour&quot;</th>
<th>Scenario 2: &quot;Night scenario&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. “DO NOTHING”</td>
<td>09:20</td>
<td>08:40</td>
</tr>
<tr>
<td>B. “MANUAL OPERATION” (RC &amp; ETCP)</td>
<td>08:50</td>
<td>07:50</td>
</tr>
<tr>
<td>C. “ADVANCED TMS for EMERGENCY PURPOSES” (RC &amp; ETCP &amp; CF)</td>
<td>08:20</td>
<td>07:25</td>
</tr>
</tbody>
</table>
5. SIMULATION RESULTS AND ANALYSIS

5.1 ETE results and analysis

In the current study, emergency evacuation was simulated for the morning peak-hour (AM) from 07:00 a.m. to 20:00 p.m. and for the night hours (NIGHT) from 00:00 a.m. to 13:00 p.m. with a total of 780 minutes duration of each simulation. To come out with more plausible results and to distribute the “New Background demand” smoother into the model, the evacuation traffic was not added until the second hour of the simulation period. Hence, in the first hour of the simulation there was only the “New Background traffic” and in the next four hours, the “Evacuation demand” was loaded as well. As has been already mentioned in the fourth chapter three distinct TMS scenarios of two different hours of the day were considered. Table 19 shows the “New Background demand” (car), the “Evacuation demand” (car P) and the totaled demand (Total) concerning the entire area during all thirteen hours of simulation.

Table 19: Average background, evacuation and totaled traffic of four simulations with different seed
(Source: Based on Aimsun v6.1 outputs)

<table>
<thead>
<tr>
<th>TOTAL TRAFFIC VOLUMES</th>
<th>Scenario 1: &quot;AM peak-hour&quot;</th>
<th>Scenario 2: &quot;Night scenario&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. “DO NOTHING”</td>
<td>- car: 2,327,570</td>
<td>- car: 820,863</td>
</tr>
<tr>
<td></td>
<td>- car P: 161,397*</td>
<td>- car P: 161,998*</td>
</tr>
<tr>
<td></td>
<td>- Total: 2,588,967</td>
<td>- Total: 982,861</td>
</tr>
<tr>
<td>B. “MANUAL OPERATION” (RC)</td>
<td>- car: 2,467,960</td>
<td>- car: 877,478</td>
</tr>
<tr>
<td></td>
<td>- car P: 161,986*</td>
<td>- car P: 162,621*</td>
</tr>
<tr>
<td></td>
<td>- Total: 2,629,946</td>
<td>- Total: 1,040,099</td>
</tr>
<tr>
<td>C. “ADVANCED TMS for EMERGENCY PURPOSES” (RC &amp; CF)</td>
<td>- car: 2,513,870</td>
<td>- car: 975,560</td>
</tr>
<tr>
<td></td>
<td>- car P: 161,456*</td>
<td>- car P: 161,790*</td>
</tr>
<tr>
<td></td>
<td>- Total: 2,675,236</td>
<td>- Total: 1,137,350</td>
</tr>
</tbody>
</table>

* The variability in evacuation traffic volumes is due to the distinct random seeds

As indicated in Table 19, the average total traffic volumes under the three different TMS scenarios increased in the order of A, B, and C. The increasing tendency due to TMS was apparent at both AM scenario and NIGHT scenario even though in the last one the traffic demand was considerably low. The simulation results suggest that “Manual Operation” (1.B, 2.B) strategy could add more than 1,56% and 5,82% capacity to the existing highway network for demand scenario 1 and 2 respectively, while the Advanced TMS (1.C, 2.C) could increase evacuation capacity significantly by 3,22% and 15,72% respectively.
Another significant output that was also evaluated is the total simulation time of each simulation test performing the mesoscopic simulator of Aimsun v6.1. Table 20 presents the average total simulation times of the various TMS and demand scenarios.

Table 20: Average total simulation time of four simulations tests with different random seed
(Source: Based on Aimsun v6.1 outputs)

<table>
<thead>
<tr>
<th>Scenarios/Av. Simulation Time</th>
<th>AM (sec)</th>
<th>NIGHT. (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do Nothing</td>
<td>4206</td>
<td>1481</td>
</tr>
<tr>
<td>Manual Operation</td>
<td>4263</td>
<td>1356</td>
</tr>
<tr>
<td>Advanced TMS</td>
<td>4869</td>
<td>1362</td>
</tr>
</tbody>
</table>

The evacuation time was estimated through a script that was manually created by the author of that project. Through this script, by counting the number of vehicles in each individual section and turning off the network inside the EPZ area, the number of vehicles that were circulating inside the EPZ was calculated. Figure 31 and Figure 32 depict the curves of the number of vehicles inside the EPZ of all six scenarios regarding “Evacuation demand” (car P) and the “New Background demand (car).
The analysis consists of several distinct comparisons of the previous ETE results and the outcomes of Aimsun v6.1. More specifically, the ETE outcomes of Aimsun v6.1 were compared among them: 1.A-1.B-1.C and 2.A-2.B-2.C (red color). Furthermore, the ETE results of the previous report are compared with the 1.A (Do Nothing) and the 2.A (Do Nothing) scenarios respectively (green color). Table 21 below apart from the elapsed times that were obtained through that script, it also displays these comparisons.

Table 21: ETE Results
(Source: Based on Aimsun v6.1 outputs)

<table>
<thead>
<tr>
<th>Scenario Demand</th>
<th>Scenario 1: &quot;AM peak-hour&quot;</th>
<th>Scenario 2: &quot;Night scenario&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETE results - Previous Report, 2008</td>
<td>7:10</td>
<td>x</td>
</tr>
<tr>
<td>ETE results - AIMSUN v6.1, 2010</td>
<td>9:20</td>
<td>8:50</td>
</tr>
</tbody>
</table>
5.2 Aimsun v6.1: Simulation Outputs

Aimsun provides as outputs, statistical measures, such as Flow, Speed, Density, Virtual Queue Length, Travel and Delay Time. Prior to a simulation experiment, the user may select which statistics are required, how they are to be gathered and also how and where to store the results via the Output folder in the Scenario editor. The most important simulation outputs of the simulation tests performed with mesoscopic simulator of Aimsun in the current ETE study were considered the density, the traffic flow, the average virtual queue length and the speed. These attributes were obtained and analyzed for each demand scenario and TMS. All these variables were used to identify the most congested freeway and arterial links in the network for each individual simulation. In addition, to avoid the randomness effect of individual simulations, a total amount of four simulation tests using different random seed numbers were tested for each scenario. Therefore, for each scenario 16 output records including density, flow, average speed and mean virtual queue length were obtained.

5.2.1. Density

Density concerns the average number of vehicles per kilometre in the section or in the whole network. However, in the simulation software of Aimsun, density measure is not provided for turnings. Density was one of the most fundamental outputs due to the fact that it helped the planner to estimate the elapsed times for each scenario. After each simulation test, the output of density in a global (network) or local (sections, “centroids”) scale forced the user of Aimsun to identify in terms of space and time any potential traffic problems that were caused in the model by any possible constraints (grid lock, congestion in local of global level etc.) and to intervene in order to ameliorate the traffic conditions of the model.

5.2.1.1. Demand Scenario 1: AM

As indicated in Figure 33 and Figure 34, the three densities regarding the three TMS scenarios of the “Evacuation demand” (car P) and the Background demand (car) of the AM demand decreased in the order of 1.A, 1.B, and 1.C. The decreasing tendency due to TMS was apparent due to the fact that the traffic capacity of the model was increased significantly after the activation of the TMS operation. Figure 33 depicts the comparison of the three different densities (vehicles/km) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “Evacuation demand” (car P) of the AM demand scenario.
Figure 33: AM scenario – Density (car P) inside the EPZ
(Source: Based on Aimsun v6.1 outputs)

Figure 34 depicts the comparison of the three distinct densities (vehicles/km) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “New Background demand” (car) of the AM demand scenario.

Figure 34: AM scenario – Density (car) inside the EPZ
(Source: Based on Aimsun v6.1 outputs)
5.2.1.2. Demand Scenario 2: Night

As displayed in Figure 35 and in Figure 36, the various density curves of the “Evacuation demand” (car P) and the Background demand (car) under the three different TMS scenarios of the NIGHT demand decreased in the order of 2.A, 2.B, and 2.C. More specifically, as far as the “Evacuation demand” is concerned, although the 2.B curve decreased in a smoother grade than the 2.A curve, the 2.C curve appeared to be more congested in the beginning. Though, from 4.30 a.m. and on, the 2.C curve dropped significantly compared to 2.A and 2.B curves. That decreasing tendency due to TMS was apparent due to the fact that the traffic capacity of the model was considerably increased after the activation of TMS operation. Figure 35 depicts the comparison of the three different densities (vehicles/km) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “Evacuation demand” (car P) of the NIGHT demand scenario.

![Figure 35: Night scenario – Density (car P) inside the EPZ](Source: Based on Aimsun v6.1 outputs)

As far as the “New background demand is concerned, even though in the first hours of the simulations the densities of all three TMS scenarios do not show any particular differences, from 05:00 a.m. the density of the 2.C scenario was higher than the 2.A and the 2.B scenario respectively. Figure 36 depicts the comparison of the three distinct densities (vehicles/km) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “New Background demand” (car) of the NIGHT demand scenario.
5.2.2. Traffic Flow

Flow is the average number of vehicles per hour that have crossed the section or have passed through the network during the simulation period. Concerning the mean flow, vehicles are counted when leaving the network via an exit section. Traffic flow was also an essential output of Aimsun due to the fact that in combination with the density gave the opportunity to the modeler to estimate the source of the traffic congestion in each simulation test individually, in either global or local scale. When density was very high or taken the maximum value and the traffic flow was very low or received zero value, the result of the simulation was indicating that the levels of traffic congestion were significantly high. After each simulation test, the output of traffic flow and density in either global or local scale forced the user of Aimsun to identify in terms of space and time the potential traffic problems that were caused in the model by any possible traffic constraints (grid lock, congestion in local of global level etc.) and to intervene (calibration of the model) in order to represent the traffic conditions into the model as it is in the real world.

Although the curves of all various traffic flows did not demonstrate any particular differences in accumulated numerical terms, when the TMS were being introduced into the model, the distribution of the traffic into the model was achieved faster. That increase due to TMS operation was apparent due to the fact that the traffic capacity of the model was considerably increased and the traffic was introduced needed less time to wait outside. That fact was also proved by the decreasing tendency of
another output, called as mean virtual queue length (vehicles). By introducing the TMS, fewer vehicles were waiting outside of the sections in order to enter the model.

5.2.2.1. Demand Scenario 1: AM

As it is shown in Figure 37 and Figure 38, the traffic flow value of the “Evacuation demand” (car P) and the Background demand (car) under the three different TMS scenarios increased in the order of 1.A, 1.B, and 1.C. In detail, during the first simulating hours, the traffic flow curves of all three TMS scenarios did not demonstrate any particular differences. However, from 9.30 a.m. the curve of 1.C scenario increased compared to the curves of 1.B and 1.B scenarios. According to Figure C, traffic flow curves decreased in an order of 1.C, 1.B and 1.A. Figure 37 depicts the comparison of traffic flow curves (vehicles/h) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “Evacuation demand” (car P) of the AM demand scenario.

![AM Evacuation Demand (car P) - Traffic Flow EPZ (vehicles-h)](image)

Figure 37: AM scenario – Traffic flow (car P) inside the EPZ
(Source: Based on Aimsun v6.1 outputs)

According to the Figure 38, the curves of traffic flow (vehicles/h) of all three scenarios of “New Background demand” did not present any particular differences among them. Figure C depicts the comparison of the three distinct traffic flow outputs of Aimsun (vehicles/hour) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “New Background demand” (car) of the AM demand scenario.
5.2.2.2. Demand Scenario 2: Night

As it is presented in Figure 39 and Figure 40, the traffic flow of the “Evacuation demand” (car P) and the Background demand (car) under the three different TMS scenarios raised also in the order of 2.A, 2.B, and 2.C. Regarding the “Evacuation demand” of the NIGHT scenario, the traffic flow curves showed the same behavior as in the AM scenario. Figure 39 depicts the comparison of the three distinct traffic flow curves (vehicles/h) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “Evacuation demand” (car P) of the AM demand scenario.
According to the Figure 40, even though the curves of traffic flow of all three scenarios of “New Background demand” did not present any special variations among those, from 03:00 a.m. and afterward they declined in an order of 2.C, 2.B and 2.A. Vehicles were reaching easier their destination points without shifting to alternative paths during the simulation. Figure 40 depicts the comparison of the three distinct traffic flow outputs of Aimsun (vehicles/hour) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “New Background demand” (car) of the AM demand scenario.
5.2.3. Mean Speed

Speed, as an output of a simulation in Aimsun, is the average speed for all vehicles that have traversed the section or left the system. This is calculated using the mean speed (for the section) journey for each vehicle. Speed is an attribute that shows the quality of the traffic flow in the network. It is directly shows to the modeler whether there is a congestion problem in the model. In cooperation with the outputs mentioned above, it forces the modeler to identify any potential local or global constraints of the model. Especially, when vehicles were not equally distributed throughout the lanes of a section, it favored the user to check the output “speed by lane” and to calibrate the model.

Although the curves of the mean speed of the “Evacuation demand” did not present any special differences in the first simulating hours, when the TMS were being activated the variations then were significant as well as the tendency was declining in an order of 1.C, 1.B 1.A and 2.C, 2.B and 2.A respectively. This is also explained from the fact that the capacity of the network with the activation of the TMS was increased significantly. As far as the “New Background demand” is concerned, the differences of the mean speed curves did not present any particular variations.

5.2.3.1. Demand Scenario 1: AM

Figure 41 depicts the comparison of the three distinct mean speed outputs of Aimsun (vehicles/hour) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “Evacuation demand” (car P) of the AM demand scenario.
Figure 42 depicts the comparison of the three distinct mean speed outputs of Aimsun (vehicles/hour) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “New Background demand” (car) of the AM demand scenario.

![AM Background Demand (car) - Speed EPZ (km-h)](image)

Figure 42: AM scenario – Speed (car) inside the EPZ

(Source: Based on Aimsun v6.1 outputs)

5.2.3.2. Demand Scenario 2: Night

Figure 43 depicts the comparison of the three distinct mean speed outputs of Aimsun (vehicles/hour) inside the EPZ of the three different TMS scenarios (2.A Do Nothing, 2.B Manual Operation, 2.C Advanced TMS) concerning the “Evacuation demand” (car P) of the NIGHT demand scenario.
Figure 43: Night scenario – Speed (car P) inside the EPZ
(Source: Based on Aimsun v6.1 outputs)

Figure 44 depicts the comparison of the three distinct mean speed outputs of Aimsun (vehicles/hour) inside the EPZ of the three different TMS scenarios (2.A Do Nothing, 2.B Manual Operation, 2.C Advanced TMS) concerning the “New Background demand” (car) of the NIGHT demand scenario.

Figure 44: Night scenario – Speed (car) inside the EPZ
(Source: Based on Aimsun v6.1 outputs)
5.2.4. Mean Virtual Queue Length

The average virtual queue length is strongly related to the dynamic behavior of the model. In simple words, virtual queue length determine the theoretical arrival time for each vehicle. It is then necessary to check whether the arrival is physically feasible or not. The Vehicle Entrance Process is defined by the following procedure (Manual Aimsun, 2008):

If (IsThereSpace) then

Enter a new vehicle

Else

Add Vehicle in the Virtual queue

Endif

In detail, the traffic generation process determines the headways time for each vehicle. These headways times are used to generate the vehicles that are going to enter into the Dynamic Network Loading. Vehicles are entered into the network using the origin “centroids” where an origin “centroid” can be connected either to a section or to a node. The network structure for both situations is depicted in Figure 45.

In both cases, the vehicles are entered to virtual sections/queues and then these vehicles enter to the real network when the node server considers that can enter the network. The vehicle enters into the model always through a virtual section. It is considered that a vehicle is in the system when it goes into a real section. As it can be seen there are virtual sections, virtual turnings and virtual nodes (Manual Aimsun, 2008).

<table>
<thead>
<tr>
<th>Aimsun Representation</th>
<th>Mesoscopic Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Aimsun Representation" /></td>
<td><img src="image2.png" alt="Mesoscopic Model" /></td>
</tr>
</tbody>
</table>

Figure 45: Night scenario – Speed (car) inside the EPZ
(Source: Manual Aimsun, 2008)
5.2.4.1. Demand Scenario: AM

In Figure 46 and Figure 47, the mean virtual queue length of the “New Background demands” (car) under the three different TMS scenarios decreased in an order of 1.C, 1.B, 1.A and 2.C, 2.B, 2.A respectively. However, as far as the “Evacuation demands” (car P) of AM and NIGHT demand scenarios are concerned, the variations are very small. In detail, regarding the “New Background demand” of both AM and NIGHT demand scenarios, in the beginning of the simulation the number of vehicles waiting outside the sections that are connected to the “centroids” is almost equal to all distinct TMS scenarios. In continue though, and in particular from 10.00 a.m. and then, the number of vehicles waiting outside is decreased in an order of 1.C, 1.B, 1.A and 2.C, 2.B, 2.A. This can be easily explained from the fact that after the activation of TMS for the 1.B, 1.C and 2.B, 2.C TMS scenarios the traffic congestion is far less than the 1.A and 2.A scenario and therefore vehicles are faster inserted into the model. Figure 46 depicts the comparison of the three distinct mean speed outputs of Aimsun (vehicles/hour) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “Evacuation demand” (car P) of the AM demand scenario.

![Figure 46: AM scenario – Mean virtual queue length (car P)](Source: Based on Aimsun v6.1 outputs)

Figure 47 depicts the comparison of the three distinct mean virtual queue length outputs of Aimsun (vehicles/hour) inside the EPZ of the three different TMS scenarios (1.A Do Nothing, 1.B Manual Operation, 1.C Advanced TMS) concerning the “New Background demand” (car) of the AM demand scenario.
5.2.4.2. Demand Scenario: Night

Figure 48 depicts the comparison of the three distinct mean virtual queue length outputs of Aimsun (vehicles/hour) inside the EPZ of the three different TMS scenarios (2.A Do Nothing, 2.B Manual Operation, 2.C Advanced TMS) concerning the “Evacuation demand” (car P) of the NIGHT demand scenario.
Figure 49 depicts the comparison of the three distinct mean virtual queue length outputs of Aimsun (vehicles/hour) inside the EPZ of the three different TMS scenarios (2.A Do Nothing, 2.B Manual Operation, 2.C Advanced TMS) concerning the “New Background demand” (car) of the NIGHT demand scenario.

![NIGHT Background Demand (car) - Virtual Queue Length (vehicles)](image)

Figure 49: Night scenario - Mean virtual queue length (car)
(Source: Based on Aimsun v6.1 outputs)

5.3 Comparison with previous ETE study results

The major factor contributing to the differences between the ETE values obtained in this study and those of the previous ETE study can be summarized as follows.

- Dynamic route choice parameters (percentage of vehicles en-routed, virtual queue en-routed, route choice model: C-Logit and the scale factor)
- The highway representation is far more detailed and the link-node analysis network extends out to 20 kilometers from the plant
- Rerouting vehicles from PC to SC
- Implementation of various TMS

Table 22 represents a comparison of the present ETE study with a previous ETE study carried out for the same case in 2008.

Table 22: Comparison with previous ETE report
(Source: Based on Aimsun v6.1 outputs & Previous ETE report, 2008)
## Indicators

<table>
<thead>
<tr>
<th>Total Evacuation vehicles</th>
<th>Previous ETE study</th>
<th>Current ETE study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>167,576 vehicles for 2025</td>
<td>161,828 vehicles for 2025</td>
</tr>
</tbody>
</table>

**Voluntary evacuation from within EPZ in areas outside region to be evacuated**

<table>
<thead>
<tr>
<th></th>
<th>Previous ETE study</th>
<th>Current ETE study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35% of total vehicles between 3 km and 10 km, for a 3 km evacuation.</td>
<td>Traffic is reduced according to time. The reduction is based on mathematical formulas. For the NIGHT scenario, a flat demand was considered. Special feature of Aimsun for instant operations. See Appendix B</td>
</tr>
</tbody>
</table>

**Shadow Evacuation**

<table>
<thead>
<tr>
<th></th>
<th>Previous ETE study</th>
<th>Current ETE study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30% of people outside of the EPZ within the area between the outer Emergency Planning Zone boundary at 10 km and a 15 km radius from PNGS.</td>
<td>Traffic is reduced according to time. The reduction is based on mathematical formulas. For the NIGHT scenario, a flat demand was considered. Special feature of Aimsun for instant operations. See Appendix B</td>
</tr>
</tbody>
</table>

**Network Size**

<table>
<thead>
<tr>
<th></th>
<th>Previous ETE study</th>
<th>Current ETE study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>918 Links; 530 Nodes.</td>
<td>Total section length in Km: 2558, Total lanes length: 4964, Sections: 5121, Intersections: 2338, Centroids: 413 (in 5 Centroids Configurations)</td>
</tr>
</tbody>
</table>

**Traffic and Access Control**

<table>
<thead>
<tr>
<th></th>
<th>Previous ETE study</th>
<th>Current ETE study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No special traffic control tactics applied.</td>
<td>Traffic control were applied (Road Closures, Contra Flow)</td>
</tr>
</tbody>
</table>

**Weather**

<table>
<thead>
<tr>
<th></th>
<th>Previous ETE study</th>
<th>Current ETE study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal, Rain, and Snow conditions considered. The capacity and free flow speed of all links in the network are reduced by 10% in the event of rain and 20% for snow. Additional snow clearance time for household mobilization activities</td>
<td>Weather adverse conditions were not considered into the ETE study</td>
</tr>
</tbody>
</table>

**Ambient Traffic Conditions**

<table>
<thead>
<tr>
<th></th>
<th>Previous ETE study</th>
<th>Current ETE study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal traffic prior to evacuation advisory; External-External trips on Route A diverted 90 minutes after the evacuation advisory. Discretionary trips in the region are assumed to be reduced during the emergency. Voluntary and shadow evacuation trips present in all scenarios.</td>
<td>Same as previous report. In addition, trips 1, 2,3,4,5 (sub section 4.2.4.2, Figure 20) were reduced according to mathematical formulas.</td>
</tr>
</tbody>
</table>
IDYNEV System: TRAD and PC-DYNEV. The PC-IDYNEV consists of 3 different models: a macroscopic static simulation model, an intersection capacity model and a dynamic node centric routing model that recognized the congestion on the outbound links. TRAD is a User Equilibrium assignment model (based on User Optimization principle by Wardrop) including a trip distribution algorithm to compute Origin-Destination pairs and a minimizing travel time method to calculate the paths. A flow-density-speed paradigm is used to determine roadway speeds, throughputs, and congestion levels based upon dynamic routing of traffic. The influence of traffic control devices at intersections are explicitly represented and modeled. The model then calculates the optimal trip distribution and the optimal trip assignment (i.e. routing) of the traffic generated at each origin node, traveling to the associated set of candidate destination nodes, so as to minimize the travel time.

Evacuation Time Estimates Reporting

ETE reported for 50, 90, 95, and 100th percentile population. Results presented by Region, Protective Zone and Evacuation Scenario. No estimate of time to Reception Center.

Package Aimsun v6.1: Integration of three level models Micro- Meso- Macro. The Mesoscopic simulator was performed. Dynamic User Equilibrium (DUE) with only the Background demand uploaded was performed in order to calculate the apa file with the paths of the area based on the habitual driving conditions. Dynamic Traffic Assignment (DTA) -one shot with all demand data and with the apa file with the paths calculated was performed to calculate the elapsed times 70% of the background demand were following the same route paths. The rerouting strategy was applied at the last section of each PC entrance to reroute 70% of the drivers to the SC and 15% to shelters. After the Contra Flow implementation, a new DUE was performed due to the changes in the geometry of the model.
| Route Choice | Balance between the traffic demand and the highway capacity was theoretically accomplished, when the user specified: (a) the total trips generated at each origin node, (b) the maximum number of trips that can be accommodated by each destination nodes and (c) the highway network attributes which include the traffic control tactics. | Evacuation demand: 100% dynamically routing, Background demand: 70% routes from apa file, 30% dynamically routing. In every subsequent simulation cycle, 50% of the background demands are able to shift from the predefined path. The calculation of the cost entails the following attributes: Travel Time, capacity attractiveness and user defined cost. |
| En-routing | Routes are not strictly enforced. The model asserts that evacuees can alter their routing if significant congestion is encountered. A decision to reroute is based upon an imperfect knowledge of system-wide conditions (drivers are only aware of local congestion conditions). Drivers encountering congestion on their preferred route will only divert if the alternative route is uncongested within their knowledge horizon. They cannot look ahead to make an “optimal” routing selection. | After every simulation cycle, 50% of vehicles of the background demand were able to en-route and en-route after Virtual Queue dynamically. |
| Route Choice parameters | None | See subsection 4.3.4.1 Table 15 |
| Global Parameters | Unknown | See Appendix C |
| Local Parameters | Unknown | See Appendix C |
| Outputs | **Measure Units**: PC-DYNEV
Travel: Vehicle-Miles (Veh-Km) and Vehicle-Trips
Moving Time: Vehicle-Minutes
Delay Time: Vehicle-Minutes
Total Travel Time: Vehicle-Mins
Efficiency: Moving Time/Total Travel Time: Percent
Mean Travel Time per Vehicle: Sec
Mean Delay per Vehicle: Seconds
Mean Delay per Vehicle-Mile: Seconds/Mile (Sec/Km)
Mean Speed: Miles/Hour (Km/Hr)
Mean Occupancy: Vehicles
Mean Saturation: Percent
Vehicle Stops: Percent | **Measure Units: Outputs**
Delay Time: (Sec-Km)
Density of entire area: (Veh-km)
Traffic Flow: (Veh-h)
Harmonic Speed: (Km-h)
Max Virtual Queue Length: (Vehs)
Mean Queue Length: (Vehs)
Mean Queue Length: (Vehs)
Mean Queue Length: (Vehs)
Speed: (Km-h)
Travel Time: (Sec -Km)
Number of vehicles in: (Vehs)
Number of vehicles out: (Vehs)
Number of vehicles waiting out: (Vehs) |
| Simulation Time | Unknown | 780 min |
5.4 Further Research in ETE Studies with Aimsun Dynamic Simulation Methods

The calibration of the model was necessary for every scenario in order to obtain plausible results. The calibration process was a time consuming process due to the fact that a certain number of constraints were detected performing the simulation tests in mesoscopic simulator of Aimsun v6.1. These constraints were related to the path calculation process and the dynamic en-routing behavior of vehicles.

As far as the 1.B - 1C and 2.B – 2.C scenarios are concerned, it was proved that, while calculating the dynamic costs to result in the optimum paths, the capacity constraint of Aimsun v6.1, which is called as attractiveness weight, was not taken properly into consideration. In detail, in order to implement the contra-flow strategy in Aimsun v6.1, the extension of the infrastructure network and in particular the addition of a certain amount of lanes into the existing infrastructure is required (see subsection 4.3.5.2 pp. 75). Hereafter, the “Lane Closure” TMS in Aimsun v6.1 was required in order to activate the contra-flow operation 90 min after the notification for evacuation. Thus, even though the calculation of dynamic costs is based on a formula that includes parameters such as travel time, attractiveness weight and user defined costs (see more details in Appendix A), when additional infrastructure was introduced into the model, it was observed that vehicles were being attracted from this additional infrastructure, even if the additional lanes were not yet activated. Hence, a significant percentage of vehicles were attracted from the extra infrastructure that was appeared in the model, even if it was not passable till that moment.

Furthermore, in case of an evacuation, drivers are not expected to be explicitly informed about the presence of contra-flow operation. Due to the fact that evacuations are considered as panic and chaotic situations, a certain percentage of drivers would not be explicitly informed about the initial points of the highway that the contra-flow would be implemented. Therefore, the additional capacity prior to and after the activation of the contra flow operation should not be taken into account from the drivers equally in the calculation of the optimum paths as it is taken for the permanent infrastructure. Consequently, in the calculation of the dynamic paths in Aimsun v6.1 an additional feature should be included in order to reduce the importance of the extra infrastructure when it is either not yet activated or it is not fair to be taken equally into account into the path calculation process.

It was also found that in case of an traffic incident, the dynamic en-routing behavior of the vehicles should not always be applied from the beginning of the simulation but it should rather be activated during the simulation and in particular when the evacuation has already been announced and it is about to start (distinction by time). In addition, there are some cases that the dynamic en-routing of vehicles could take
place only at specific areas of the model (distinction by space), where the drivers are about to evacuate. Therefore, an extra feature that could offer the option to the user to define in terms of time and space the dynamic en-routing and the virtual queue en-routing should be also added to Aimsun v6.1.

Aside from the TMS that were tested in the current study, recent studies using various simulation packages that are available suggest the determination of more TMS. Regarding TMS of Aimsun v6.1, there are many more than the tested ones that could be also tested regarding the current case study. Firstly, the determination of an emergency traffic control plan where a new control plan for emergency cases would be activated by time (from-to), by a trigger (activation depends on the speed, density or flow conditions) or any other relevant attribute (i.e. police manned control at intersections). Secondly, an effective TMS strategy suggests the addition of more road lanes and in particular shoulder lanes at all off-ramps and on-ramps of the freeway segments. These lanes could be activated in case of an emergency where the highways tend to be more congested than in regular conditions. Finally, the change of drivers’ behavior during the simulation could also be tested in Aimsun v6.1. This TMS could take place in a specific section or in a specific segment of the network. The values that could be changed concern the jam density, the look-ahead distance and the reaction time factor (in each section).

It could be also interesting to test the evacuation of the entire EPZ area not by private car but by providing alternative modes of transport to the public, such as public transport, mini vans or taxis, mainly to areas with scattered demand. The results though are not expected to be encouraging in areas where the model share includes small percentages of public transport usage (i.e. U.S., Canada and developing countries). Furthermore, some recent evacuation studies proved that walking results in less congestion than driving and thus it could decrease the total egress time (Zhou et al, 2010). Based on that fact, it could be also extraordinary to compare walking evacuation with traffic evacuation or other means of transport evacuation results.
6. CONCLUSIONS

This report has used a case study in order to apply an ETE methodology using dynamic traffic simulation systems concerning evacuations in areas with NPPs. The Dynamic Traffic Assignment (DTA) and Dynamic User Equilibrium (DUE) of mesoscopic simulator of Aimsun v6.1 were used to simulate the evacuation traffic conditions in case of a nuclear incident. The findings presented throughout this report suggest that every ETE study is not ideal and optimum for every area with a nuclear reactor, but it largely depends on the local demographical, geographical, weather and transportational characteristics of it.

As every methodological approach regarding ETE study seeks to determine whether the traffic demand of a roadway network is higher than the capacity, all data sources available must be examined carefully. Such comparison though, was proved to be something more than a simple process due to the fact that evacuating vehicles may depart from different areas, in different times, to different destinations over different routes. Subsequently, data about density of the risk population area, capacity of the roadway network, actual demand, implementation of any traffic management actions etc. are considered as necessary in order to conduct a thorough and comprehensive ETE study.

What concerns the traffic demand; this is without doubt an important tool to have. For the current study, demand data were divided into three different categories: a) “Background”, b) “New Background” and c) “Evacuation” demand. Despite its unquestionable necessity though, this paper has concluded that to conduct an ETE study, it is not only the traffic demand and the capacity calculation that can be investigated, studied and included into the model, but also other dynamic processes and parameters such as the model calibration and validation, the emergency scenarios development, the dynamic route choice, the selection of destination points, the selection of dynamic traffic distribution and assignment model, the selection of traffic simulation model and finally the implementation of TMS. These parameters could reduce or alleviate phenomena that could cause unexpected congestion problems into the model.

In summary, the ETE results of the previous report proved to be well below the initial release time of 24 hours and therefore they were considered as very optimistic. To determine the probable reasons for this underestimation of the elapsed times, the applied trip distribution and traffic assignment methods were re-examined. Even though routes in the previous ETE study were not strictly enforced and furthermore evacuees were allowed to shift route during the simulation if congestion was encountered along their evacuation route, this reroute decision was only dependent on the drivers’ knowledge horizon (only local congestion conditions). The dynamic
route selection criteria for the route selection considered only evacuees’ preference factors (final destination) and limited traffic data available (local congestion). Such static assignments proved that they don’t consider the true levels of congestion into the model. On the other hand, according to the current study performing dynamic models, these models can describe more realistically how traffic flow patterns are evolved in time and space on the network and how the corresponding induced traffic flows, using an analytic derivation of route selection based on mathematical simulation models of traffic route assignment. In addition, the dynamic mesoscopic traffic assignment favored the simulation of virtual queuing, estimating travel time delay and clearance time impacts within the evacuation period without requiring any network enhancement. Thus, the optimization of route selection based on the current available information was successfully achieved. Compared to the user equilibrium assignment model that was applied in the previous ETE study, the current study performed a simulation with a DUE (driver’s long-term habitual behavior) and the results proved that the representation of the behavior of the habitual traffic into the model was perceived as more real.

Unlike the previous ETE study, the current one suggests the introduction of primary and secondary destination centroids regarding the evacuation traffic. Such strategy, favored vehicles to reach firstly the boundary area and then to reroute (via a traffic management strategy of Aimsun v6.1, 60% of the totaled traffic) to the secondary destination centroids where the shelters, hospitals or any other final destination points were located. Consequently, evacuees were better distributed on the broader highway network area, minimized their evacuation time as well as, such strategy allowed them to get out of the danger zone in the best way possible.

Furthermore, this study analyzed the potential impacts of the evacuation traffic and evaluated the effects of various TMS including “Manual Operation” (Road Closures), “Advanced TMS” (Road Closures and Contra-Flow) operations under two different demand scenarios: a) Morning peak-hour (AM) and b) Evening (NIGHT) evacuation. The simulation results suggest that the “Manual Operation” could add more, 1.56% and 5.82% for the AM and NIGHT demand scenario, extra capacity to the existing highway network when a certain amount of off, on-ramps or other road types were being closed 90 min after the notification for evacuation. The “Advanced TMS” could increase evacuation capacity by 3.22% for the AM and 15.72% for the NIGHT demand scenario due to the fact that it could reverse traffic in the direction of low demand to the opposite direction of high demand. In general terms, according to this study, it was also proved that TMS can significantly increase traffic flow, speed and reduce density and mean virtual queue length of the evacuation traffic.

On the other hand, contra-flow operation in Aimsun v6.1 may cause significant disturbances to the routing of the traffic into the model. In Aimsun v6.1, dynamic costs, which are calculated in every simulation cycle, take into account apart from
travel times and user defined costs, the capacity of the road network to define the optimum evacuation routes. Subsequently, when the capacity of this corridor was doubled, vehicles were being attracted, even if the extra lanes were not yet activated. The dynamic en-routing of the vehicles in Aimsun v6.1 expanded these traffic disturbances. Analysis of the effect of different TMS shows that the contra-flow operation could be extensively implemented in the major routes (Route A, Route B, highway C) of the current network, if a new feature added in Aimsun v6.1, that would offer the option to the user to define in terms of time and space the percentages of dynamic en-routing and the virtual queue en-routing.

The main objective of this study was to represent more realistically the behavior of the evacuation traffic from the current EPZ by proposing a new methodology using dynamic simulation systems. Through the application of this methodology to the actual case study, the ETE results proved to be more plausible than the ones in the previous ETE report. Finally, the elapsed times compared to the previous study were increased from 7:10 to 9:20 hours and from 6:50 to 8:40 hours regarding the AM and the NIGHT scenario, respectively. By implementing the “Manual Operation”, the elapsed times were reduced by 5.35% (8:50) and 9.61% (7:50) for the AM and the NIGHT demand scenario, while by implementing “Advanced TMS”, the elapsed times were dropped by 10.71% (8:20) and 14.42% (7:25).

To sum up, this report can offer the initial steps both on the way, the approach and the aspects of an ETE study using dynamic simulation systems. However, as the nuclear regulations obligate each NPP to frequently update its ETE study due to the continuous advancements of technology and the evolution of various relevant scientific fields; this study suggests that the models regarding these studies nowadays, apart from the TMS implementation, they must be performed with dynamic simulation systems.
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Institute of Transportation, TU München          Dimitrios Triantafyllos, November 2010


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APPENDIX A:
Dynamic Traffic Assignment with Aimsun v6.1
Dynamic Traffic Assignment with Aimsun

A myopic implementation of a heuristic stochastic Dynamic Traffic Assignment (DTA) in Aimsun, based on the above considerations, is the following:

A. Calculate Initial Shortest Paths (ISP) for each O-D pair using defined initial costs. The procedure entails the following three steps:

- a) Evaluate Initial cost function per each link: \[ \text{Cost}_j = \text{InitialCost}_j \]
- b) Apply shortest path for each destination. Calculate the shortest path tree
- Identify the shortest path from shortest path tree for each O-D pair i. Add K-Paths.

During the first seconds of the simulation, these initial costs are calculated as functions of the travel time in free flow conditions, the capacity and other attributes. In general, travel time in free flow conditions is defined as the time for a vehicle to cross the link and the turn assuming that the vehicle has a maximum speed along the section and maximum speed during the turning movement. In detail the initial cost function can be divided into two different types. The first one does not consider the vehicle type while the second function calculates the initial costs per vehicle type (in case of reverse lanes existence, the cost is also included). The two different formulas are given below:

\[ \text{IniCost}_j = \text{TT}_j + \phi(1 - \frac{C_j}{C_{\text{max}}}) + \tau \ast \text{UserDefCost}_j \]
\[ \text{IniCost}_{j, \text{veh}} = \text{TT}_{j, \text{veh}} + \phi(1 - \frac{C_{j, \text{veh}}}{C_{\text{max}}}) + \tau \ast \text{UserDefCost}_{j, \text{veh}} \]

B. Simulate for predefined time interval \( \Delta t \) (cycle) assigning to the available path \( K_i \) the fraction of the trips between each O-D pair i for that \( \Delta t \) according to the selected route choice model.

- Assignment of path probabilities for each O-D pairs i.
- Calculate probability \( P_k \) using route choice models where \( KEK_i \) of vehicles between O-D for \( \Delta t \) selecting randomly the path according to probabilities \( P_k, KEK_i \).

C. Recalculate shortest path taking into account the experienced average link travel times.

- Update link cost functions; evaluate Dynamic Cost Function per each link j. For each link j, \( \text{Cost}_j = \text{Dynamic Cost}_j \).
- Apply shortest path routine for each destination centroid d. Calculate the shortest path tree (SPTd) using Cost_j.
- Identify shortest path from SPT for each O-D pair \( i \) (from origin to destination). Add to Path(s) K-Shortest Paths.

Dynamic Cost Function uses travel time data during the simulation process. The default current cost for each section equals to the mean travel time (in seconds) for all vehicles that have crossed the link (section+turning). The Dynamic Cost Function is also divided into two different types: In the first, vehicle type attribute is not considered, while the second function calculates the initial costs per vehicle type:

\[
\text{DynCost}_j = \text{estimated TT}_j + \varphi*(1 - \text{CL}_j/\text{Cmax}) + \tau*\text{UserDefCost}_j \\
\text{DynCost}_{j, \text{veh}} = \text{estimated TT}_{j, \text{veh}} + \varphi*(1 - \text{C}_j, \text{veh}/\text{Cmax}) + \tau*\text{UserDefCost}_{j, \text{veh}}
\]

The Shortest Path Algorithm is calculated in every route choice cycle (\( \Delta t \)). It performs the Dijkstra algorithm, which provides the shortest path tree for each destination centroid and thus the shortest path is obtained.

D. If there are guided vehicles or any VMS that suggest rerouting, provide the information in step C to the drivers. The drivers will be able to reroute on-trip dynamically.

E. Go to step B.
APPENDIX B:
Demand Estimation
Evacuation demand estimation

The demand data regarding the “Evacuation demand” were retrieved from the previous report of the current case study. Hence, static and dynamic simulation systems have been assessed in an equal basis. It has to be mentioned that the “Evacuation demand data” do not differentiate in any of the two distinct demand scenarios. Table 1 displays the hourly “Evacuation demand” statistics.

Table 1: Hourly statistics of the “Evacuation demand”

<table>
<thead>
<tr>
<th>Time Intervals</th>
<th>Evacuation Demand</th>
<th>Cumulated</th>
<th>Cumulated %</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00:00</td>
<td>0</td>
<td>0</td>
<td>0,00%</td>
</tr>
<tr>
<td>8:00:00</td>
<td>0</td>
<td>0</td>
<td>0,00%</td>
</tr>
<tr>
<td>9:00:00</td>
<td>65281</td>
<td>65281</td>
<td>40,34%</td>
</tr>
<tr>
<td>10:00:00</td>
<td>72091</td>
<td>137372</td>
<td>84,89%</td>
</tr>
<tr>
<td>11:00:00</td>
<td>20325</td>
<td>157697</td>
<td>97,45%</td>
</tr>
<tr>
<td>12:00:00</td>
<td>4.131</td>
<td>161828</td>
<td>100%</td>
</tr>
<tr>
<td>13:00:00</td>
<td>0</td>
<td>161828</td>
<td>100%</td>
</tr>
<tr>
<td>14:00:00</td>
<td>0</td>
<td>161828</td>
<td>100%</td>
</tr>
<tr>
<td>15:00:00</td>
<td>0</td>
<td>161828</td>
<td>100%</td>
</tr>
<tr>
<td>16:00:00</td>
<td>0</td>
<td>161828</td>
<td>100%</td>
</tr>
<tr>
<td>17:00:00</td>
<td>0</td>
<td>161828</td>
<td>100%</td>
</tr>
<tr>
<td>18:00:00</td>
<td>0</td>
<td>161828</td>
<td>100%</td>
</tr>
<tr>
<td>19:00:00</td>
<td>0</td>
<td>161828</td>
<td>100%</td>
</tr>
<tr>
<td>20:00:00</td>
<td>0</td>
<td>161828</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>161828</strong></td>
<td><strong>161828</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Figure 1 and Figure 2 depict the “Evacuation volume response” and the “Evacuation response rates” respectively, calculated from the “Evacuation demand” statistics above.

Figure 1: Evacuation volume response (veh/ hour)  Figure 2: Evacuation response rates
New Background demand: Reduced trips

The “New Background” O/D demands data concerning all scenarios were included 9 different trip categories. Figure 3 depicts all possible different types of trips.

All trips mentioned above were included in the “Background demand” and subsequently into the “New background demand” O/D matrices. Even though the “New background demand” data regarding the AM scenario were available from the authorities, the determination of the NIGHT scenario was done manually based on a certain amount of assumptions. The O/D matrices of the NIGHT scenario were included these 9 different types of trips derived from 1-hour O/D demand data given also by the authorities. However, concerning that demand scenario, only the trips with the numbers: 1, 2, 3, 4, 5, were reduced in accordance with the formulas (curves) above and only for the first hour of the simulation.

\[
F(x) = 100 - (5.536 \times x^2 / 3600) \\
F(x) = 100 / e^{(x/60)} \\
F(x) = 100 \times e^{-(x/100)^2}
\]

(Source: Original work)
In this stage, it has to be mentioned that the availability of an Aimsun feature was very useful and furthermore it contributed to reduce the time for the calculation process. The online feature of Aimsun allow the users to apply all basic arithmetic formulas either in some particular O/D pairs or in the entire O/D matrix. Figure 4 shows an O/D matrix and the feature of Aimsun above.

Figure 4: Feature of direct formulas’ applications on the O/D matrix data in the environment of Aimsun
(Source: Aimsun v6.1)
Scenario demand AM: New Background demand

Table 2: Statistics of the "New Background demand"

<table>
<thead>
<tr>
<th>New Background Demand (O/D matrices)</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00:00-7:15:00</td>
<td>59,540,40</td>
</tr>
<tr>
<td>7:15:00-7:30:00</td>
<td>62,246,70</td>
</tr>
<tr>
<td>7:30:00-7:45:00</td>
<td>67,659,50</td>
</tr>
<tr>
<td>7:45:00-8:00:00</td>
<td>68,640</td>
</tr>
<tr>
<td>8:00:00-8:15:00</td>
<td>68,640</td>
</tr>
<tr>
<td>8:15:00-8:30:00</td>
<td>68,640</td>
</tr>
<tr>
<td>8:30:00-8:45:00</td>
<td>68,640</td>
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Scenario demand PM: New Background demand

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Table 3: Statistics of the “New Background demand”

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Scenario demand NIGHT: New Background demand

### Table 3: Statistics of the "New Background demand"

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APPENDIX C:
Global & Local Parameters of Aimsun v6.1
In this chapter, the majority of the Aimsun v6.1 functions are provided. That description of these parameters is obligatory due to the fact that it is required for the preparation and running of dynamic simulation experiments. It aims to explain briefly the operation of the commands that are available in the menu bar in order to give a deep understanding to the users. The explanation of the main parameters is presented below:

**Global parameters**

- **Warm-Up**: In order to start the replication with predefined shortest paths and flow and not an empty network, the introduction of a warm-up period is considered as necessary. When congestion problems are depicted in the network, warm-up is considered as a very useful parameter due to its contribution to identify the source of the problem. In practice, when the user seeks to find the source of the congestion, he could set as warm-up period equal to zero.

- **Look-Ahead Distance**: It defines the distance that the car driver who tends to change lane in order to turn right or left will keep before the turning. It is a parameter that strongly interacts with the existence of nodes and in particular the roundabouts. The Look-Ahead distance is referred to a global level (all sections or defined by Road Types) and local level (defined by sections).

- **Reaction Time**: Reaction Time is not the real time but an empirical time defined by Gipps that takes the driver to react to speed changes of the preceding vehicle, when accelerates or decelerates. It can be either Fixed or Variable. The reaction time influences the capacity of the section and the On-Ramp capacity. Besides, in case of Variable, there is the possibility to define different reaction times. The sum of the reaction times for each vehicle due to it is associated with a probability must be equal to 100.

- **Reaction Time in Traffic Light**: It is the time defined by Gipps that the driver of a vehicle needs in order to react in any change of the traffic light. It has to be mentioned that only the first vehicle is influenced by this reaction time in traffic light, while the rest are influenced by the reaction time. Usually, it is higher or equal to the reaction time and it can be either Fixed or Variable.

- **Global Arrivals**: The user of Aimsun v7.0 is able to choose among different headway models such as the exponential, the uniform, the normal, the constant, the external or the ASAP distribution. In fact, the current distributions define the time interval between two consecutive vehicle arrivals when the user has already loaded the traffic demand either as a set of traffic states or as a set of O/D matrices. Additionally, the generation model may be ignored for some specific centroids or sections.
Route Choice parameters

- **Cycle**: It is the time interval used to the dynamic traffic assignment algorithm. It defines the time that a calculation of the shortest path will be repeated.

- **Number of Intervals**: The cycle parameter determines the length of the interval. The observed data that have been retrieved during the calculation of the dynamic cost of each link is taken from the last number of intervals.

- **Attractiveness weight**: This is a user-defined attractivity weight parameter that allows the user to control the influence that the link attractivity has on the cost in relation to the travel time.

- **Route Choice Model**: The several route choice models with the all the related parameters are: **Binomial**: probability, **Proportional**: alpha factor, **Logit**: scale factor, **C-logit**: scale factor, beta and gamma.

- **K-Initial Paths**: The number of the shortest paths per destination centroid calculated in the beginning of the simulation takes into account not only the initial cost function but also the algorithm of the model until the moment that will gain the desirable number.

- **Max. Number of Paths to keep**: It defines the maximum number of the shortest path trees per destination that can be saved in the memory during the simulation. By saving more Paths in the memory during the simulation, the performance is improved.
• **Max Number of routes:** This parameter defines the maximum number of different paths used in the path selection process

• **Scale factor:** It is used to define the routes based on differences between utilities independent of measurements units and furthermore it influences the standard error of the distribution of expected travel times. It can be defined through the route choice parameters window but not for all the distributions.

• **Local Parameters**

Even though in the Mesoscopic simulator the most important parameters concern the global level, there is a cluster of parameters that may affect the vehicle behavior through the change of some parameters of the sections. These parameters are applied when a vehicle enters into a section but they change when the vehicles leave the section. Hence, there are also parameters that during the simulation they locally influence the vehicles.

• **Section Speed Limit:** It defines the maximum allowed speed (in km/h) for all the vehicles that travel through a section. Depending on the characteristics of the drivers, they may or may not follow speed limit recommendations.

• **Turning Speed:** It defines the maximum speed (km/h) at which a vehicle will travel when making the turn. It depends on the behavior of the driver and in particular whether they will use a higher or lower speed. A vehicle driving through a section will start to decelerate while approaching the turning in order to reach its turning speed at the end of the section. The turning speed is maintained during the turn and, when entering the next section, the vehicle will start to accelerate again according to its desired speed for this section.

• **Jam Density:** By this parameter the capacity of the link is denoted. Each lane allows only a certain number of vehicles to enter. That number is defined by the Jam Density. When a lane reaches this Jam Density it is considered that the lane is full so no more vehicles can enter the lane until the first vehicle in the lane leaves it.

• **Reaction Time Factor:** It is located on the menu of each Section and each Road type. The default value is equal to one. This factor gives flexibility in the calibration process by helping the user to define different reaction times for each Section or Road Type. It is noticeable though the fact that the ultimate outcome of the reaction time in a section will be the result of the multiplication between reaction time (i.e. RT=1,2 sec) and reaction time factor (i.e. RTF=0,7 sec)\(\rightarrow\) (i.e. total RT= RT*RTF=1,2 *0,7=0,84 sec).
Table C depicts an example of all the global parameters that have to be considered in a calibration process with Mesoscopic simulator in Aimsun v6.1.

### Table C: Parameters in Aimsun v6.1.

<table>
<thead>
<tr>
<th>Experiment Attributes</th>
<th>Parameters</th>
<th>Sub-parameters</th>
<th>Values (Example of Vitoria)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main</strong></td>
<td>Warm-Up</td>
<td></td>
<td>0:20:00</td>
</tr>
<tr>
<td><strong>Behaviour</strong></td>
<td>Look Ahead</td>
<td></td>
<td>300 m</td>
</tr>
<tr>
<td><strong>Reaction Time</strong></td>
<td>Reaction Time (RT)</td>
<td></td>
<td>1,3 sec</td>
</tr>
<tr>
<td></td>
<td>Reaction Time at Traffic Light (RTTL)</td>
<td></td>
<td>1,6 sec</td>
</tr>
<tr>
<td><strong>Arrivals</strong></td>
<td>Global Arrivals</td>
<td></td>
<td>Uniform</td>
</tr>
<tr>
<td><strong>Route Choice (RC)</strong></td>
<td>Cycle</td>
<td></td>
<td>0:10:00</td>
</tr>
<tr>
<td></td>
<td>No. Intervals</td>
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<tr>
<td></td>
<td>Attractiveness weight (φ)</td>
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<tr>
<td></td>
<td>Route Choice model: C-Logit</td>
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<td></td>
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<tr>
<td></td>
<td>Initial K-Ps</td>
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<tr>
<td></td>
<td>Max No. To keep</td>
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<td></td>
<td>Max No. Paths</td>
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</tr>
<tr>
<td></td>
<td>Scale factor</td>
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<td>1</td>
</tr>
</tbody>
</table>
Statement of degree thesis

I hereby declare that the following master thesis “(Evacuation Times Estimation with Dynamic Simulation Systems: The case of a Nuclear Power Plant)” has been written only by the undersigned and without any assistance from third parties.

Furthermore, I confirm that no sources have been used in the preparation of this thesis other than those indicated in the thesis itself.

To date, my master's thesis has not been submitted to any other board of examiners in the same or similar format and has not been published yet.

Munich, November 2010.

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Declaration of Consent

I agree that the Institute of Transportation keeps my master's thesis on file for university purposes and makes a copy available in the library of the Chair of Traffic and Engineering.

Munich, November 2010

Dimitrios Triantafyllos