KOEBERG NUCLEAR EMERGENCY PLAN: TRAFFIC EVACUATION MODEL

John Jones, Stef Naude, Gerhard van Wyngaardt and Antony Marks

HHO Africa Infrastructure Engineers, P O Box 6503, Roggebaai, 8012
Tel: 021 – 425 2870, Fax: 021 – 419 4689, E-mail: jrjones@hho.co.za

ABSTRACT

In terms of recent legislation regarding developments surrounding a nuclear installation, municipal and provincial authorities must perform assessments which demonstrate the adequacy of present and future disaster management infrastructure to ensure the effective implementation of any nuclear emergency plan.

While the City of Cape Town already has documented emergency procedures, a critical element is an appropriate traffic model for testing / estimating evacuation times for different incident, population, infrastructure and traffic management scenarios.

HHO Africa were recently appointed to formulate a Traffic Evacuation Model for the City of Cape Town for the area surrounding Koeberg Nuclear Power Station for the existing and future population. The study focused on testing the evacuation of the potentially at-risk population following an incident at Koeberg, and the traffic management actions required to do so.

A key component of the study was the use of a strategic traffic model to estimate evacuation times for the 5 km zone around Koeberg, and for the critical 67.5^{o} sectors within the 16 km zone.

A literature survey of emergency evacuation events, including those related to the recent natural disasters in the USA, was also undertaken to understand critical factors impacting on evacuation procedures and times.

This paper provides an overview of the findings of the study.

1. INTRODUCTION

This paper provides an overview of the methods and findings of the Koeberg Nuclear Emergency Plan Traffic Evacuation Model. The primary focus of the paper is on explaining the methodology used to develop the model. Of particular interest is the important role of international precedent in refining the model to ensure that it presents an accurate representation of real events.

The paper starts with a brief discussion of the background and regulatory context which gave rise to the need for a traffic modelling exercise to assess the evacuation planning for an emergency event at Koeberg Nuclear Power Station. The existing emergency procedures are discussed, as far as they relate to evacuation. The existing transport and land use planning proposals are identified and discussed as the primary informants of the modelling process. The international literature review is presented and its impact on the

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process described. Finally the modelling process and its results are elucidated, with a particular focus on the construction of the model and the choice of scenarios and sensitivity testing.

2. BACKGROUND

Recent legislation regarding developments surrounding a nuclear installation compels local and Provincial government to perform assessments of future and presents infrastructure to demonstrate that their Nuclear Emergency Plan can be effectively implemented (National Nuclear Regulator Act, 1999 and Government Notice No. 287, 2004).

In light of this legislation, the National Nuclear Regulator (NNR) requested the City of Cape Town to develop their procedures and processes in order to comply. The City already has documented emergency procedures; however, the further development of a model for the testing / estimation of evacuation times was required.

The aim of the model was to assess the performance of the existing and planned infrastructure to evacuate the population of the existing and planned development in the area. The assessment criteria were very specific: the area within 5km of the reactors (Precautionary Action Zone (PAZ)) must be capable of being evacuated within 4 hours and any 67.6º sector in the 5 – 16 km zone (Urgent Protective Action Zone (UPZ)) must be capable of evacuation within 16 hours (see Figure 1).

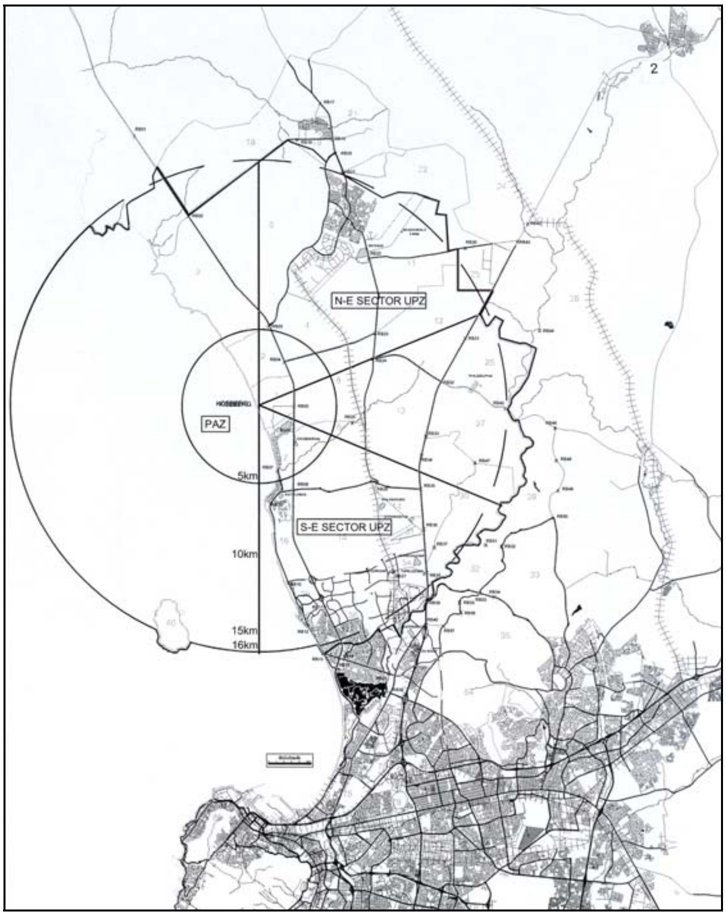

Figure 1: Locality Sketch

The new legislation places stringent restrictions on development within these zones. No development that will result in a population increase is permissible within the 0-5 km zone, while development can only occur in the 5 – 16 km zone if it can be demonstrated that the

16 hour evacuation time can be complied with. These restrictions resulted in a moratorium on development in parts of Blaauwberg North pending the outcome of the study.

3. REGULATORY CONTEXT AND LEGISLATION

The National Nuclear Regulator Act establishes the National Nuclear Regulator (NNR). In terms of Section 38(1) of the act the NNR must direct Eskom to enter into an agreement with the relevant municipality to establish an emergency plan.

Section 38(2) requires the NNR to ensure that the emergency plan is effective and Section 38(4) delegates power to the minister to make regulations regarding development surrounding Koeberg, in order to ensure that the emergency plan can be effectively implemented.

Government Notice No. 287 of 5 March 2005, section 3 requires the NNR to establish specific requirements for the control and monitoring of development within the formal emergency planning zones surrounding specific nuclear installations. Section 4 requires municipalities to have processes for the regular assessment of: current and planned population distribution, disaster management infrastructure and new developments to ensure that the emergency management plan can be implemented effectively at all times.

The NNR requirements outline the assessment criteria by which the effectiveness of disaster management plans are to be judged. Of particular relevance to this paper are the evacuation times for the Emergency Planning Zones and restrictions relating to these zones (see section 2: Background).

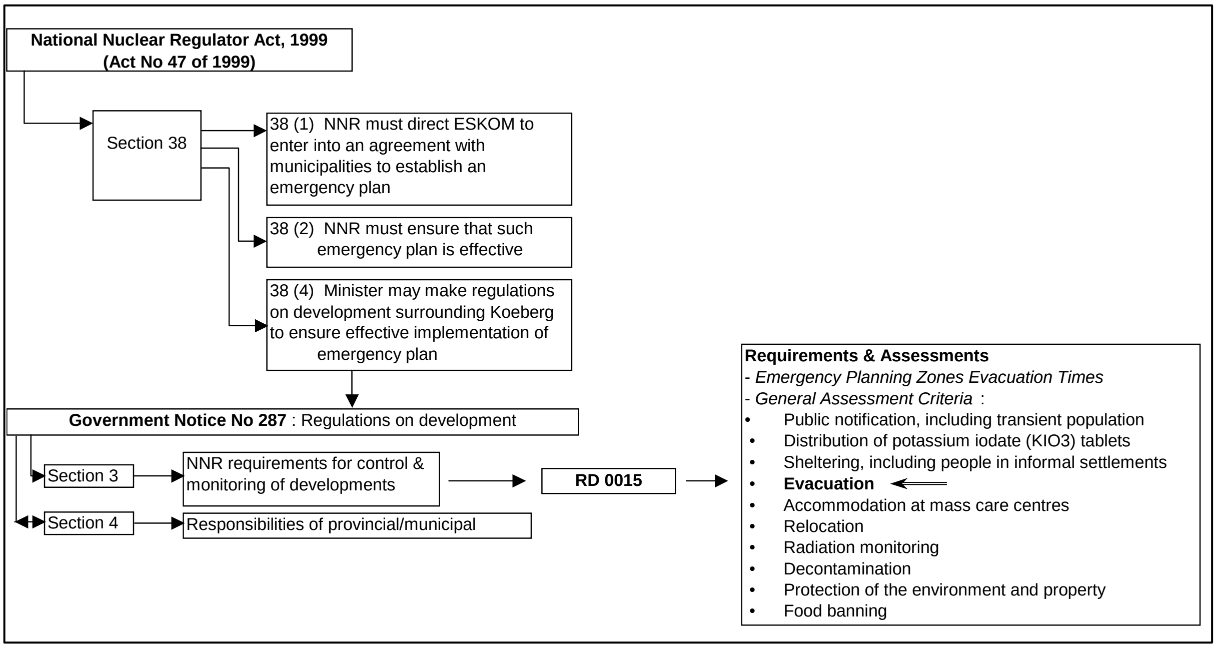

Figure 2: Schematic Representation of Relevant Legislation

4. EXISTING EMERGENCY PROCEDURES

There are two sets of inter-related plans for an emergency event at KNPS: Eskom's "Koeberg Nuclear Emergency Plan" (KNEP)(2005) and City of Cape Town Disaster Risk Management's "Koeberg Nuclear Emergency Procedures". Nuclear incidents are categorised using the following system, according to their level of severity:

- Unusual Event: unplanned deviation from normal operations - requires notification of Eskom Emergency Controller;
- Alert: situation exists that may develop into a site or general emergency - requires notification of all emergency personnel;
- Site Emergency: emergency conditions which pose a serious radiological hazard on site but no hazard beyond the public exclusion boundary; and
- General Emergency: emergency conditions exist which pose or potentially pose serious radiological hazards beyond the public exclusion boundary.

In the event of an alert, site emergency or general emergency the next phase of the Koeberg Nuclear Emergency Plan is implemented and this requires action by the City of Cape Town, in terms of their Koeberg Nuclear Emergency Procedures. Of particular importance in this context is the declaration of a General Emergency as this will result in an evacuation - the eventuality for which the traffic model is designed to test.

Once a general emergency has been declared, it is the responsibility of the City of Cape Town's Disaster Management Duty Co-ordinator (subject to the recommendations of the Eskom Emergency Controller) to inform the public in the PAZ and UPZ with the appropriate public announcement.

The next phase of emergency planning is termed "Protective Actions", these are measures designed to mitigate the radiological or psychological consequences of a nuclear incident. The Eskom Emergency Controller will recommend such actions, which are to be implemented by the City of Cape Town. Only those actions which will have a bearing on the transport plan are considered below:

- Notification of the public – warning the public in order to reduce the response time required to complete other protective actions.
- Sheltering – the use of buildings or other permanent structures to reduce the exposure to radioactivity.
- Thyroid protection – administration and ingestion of stable iodine tables in order to minimise the exposure of the thyroid to radioactive iodines.
- Evacuation – removal of the population from an area to avoid radiation exposure.

The following procedures have been drafted as part of the City of Cape Town's Koeberg Nuclear Emergency Procedures and are for the purpose of implementing "Protective Actions". Again, only those procedures which will impact on the transport system are identified.

Regardless of the level of the incident, the following actions are expected:

- Manager: Traffic Services to CoCT Joint Operations Centre to assist with planning
- Mobile traffic bus to establish traffic assembly point at corner of N7 and Morningstar turn off (or other location if this one is in the plume path due to prevailing wind).
- Traffic and law enforcement officers to proceed to traffic assembly point and report to their superintendents and principal inspectors. All cars must have a copy of Disaster Management planning map and public notification guidelines.

The Zone Co-ordinator: Traffic, acting on the instructions of the Disaster Management Duty Co-ordinator, is responsible for the following:

- Sheltering notification
- Evacuation
- Establishing of road blocks
- Traffic control on evacuation routes
- Traffic control at mass care centres

The following traffic control functions are expected of traffic and law enforcement services:

- Disaster Management Duty Co-ordinator to consult with Zone Co-ordinator: Traffic regarding the evacuation routes to be used.
- Where routes lie outside the City of Cape Town jurisdiction, the Disaster Management Duty Co-ordinator will arrange with the neighbouring authorities to patrol these areas.
- Patrols to ensure that all vehicles not performing emergency functions are evacuated.
- Traffic superintendents responsible for establishing road blocks at points marked on Disaster Management planning map. If road blocks are necessary for longer than 24 hours it is the responsibility of the Manager: Traffic Services to ensure that the appropriate equipment is delivered.

It is the responsibility of the Disaster Management Duty Co-ordinator to arrange necessary transportation, including ambulances, if required. Accordingly, it is the Duty Co-ordinators responsibility to inform the Golden Arrow Bus Services (GABS) Duty Operator of either a “site emergency” or a “general emergency” in order for GABS to prepare for the possibility of an evacuation. On receipt of evacuation notification, GABS are expected to arrange evacuation according to the following disaster management instructions:

- Area to be evacuated
- Priority populations, e.g. schools, hospitals
- Pick up points
- Estimated populations to be evacuated
- Routes for buses to take
- Destination of evacuees (Assembly points)

During the evacuation buses remain under the control of the GABS inspectors who are in contact with the GABS Duty Operator. The GABS Duty Operator will keep the Disaster Management Duty Coordinator appraised of the evacuation progress.

5. EXISTING TRANSPORT AND LAND USE PLANNING PROPOSALS WHICH INFORMED MODELLING

5.1 Transport Planning

The proposed transport network for the area has been established through a series of planning exercises which have taken place over the last 15 years. A major informant to the development of the transport plan has been the Macro Traffic Impact Assessment of the Table View North Area (2000). Subsequent to the Macro TIA for the area, a series of meetings between developers and the City of Cape Town have been held at which a bulk infrastructure plan has been developed for the period 2005 – 2030. This plan includes road development and public transport initiatives. For the purpose of the report and the model the capacity of the evacuation routes serving Atlantis / Mamre are assumed to remain static.

Public transport initiatives for the area were drawn from a document produced by the City in 2004 (CoCt 2004) identifying strategies necessary for the implementation of a transport network in the short to medium term (2015). Included in the modelling were the following proposals:

- Exclusive public transport lanes on Keoberg Road, Blaauwberg Road and Potsdam Road.
- Contra-flow peak period public transport lanes along the R27 and Marine Drive.
- Public transport priority measures along Parklands Main Road, Sandown Road and M12 link to Potsdam Road and the N7.
- Upgrading of existing public transport facilities, and the creation of new facilities within the study area.

The Atlantis railway line upgrade will only take place in the medium to long term and as such was not included in this study.

5.2 Population Forecasting

Population forecasting for the area was based on data from the 2000 traffic modelling process and data emanating from the forum involving the City of Cape Town and developers referred to above. The data was generalised to the specific zones identified above, namely the PAZ, UPZ – South East Sector and UPZ - North East Sector.

6. LITERATURE REVIEW

An international literature review made a significant contribution to the development of both the traffic model and the Traffic Evacuation Management Plan. The literature review identified important lessons from the international experience which were used to inform both the traffic modelling and the Traffic Evacuation Management Plan, ensuring that both accurately represented behaviour during an emergency event and evacuation. The most important aspects drawn from the literature and their impact on the modelling or management plan are discussed below.

Residents of areas that are to be evacuated, who are at work at the time of the evacuation will need to travel home first before they evacuate their homes. This adds additional time onto the evacuation process. Additionally, work to home travel takes longer in heavily populated suburban areas than it does in sparsely populated rural areas. This must be accounted for in the model. During the early phases of an evacuation there may be more people travelling towards an area than away from it. This has implications for the establishment of contra-flow systems and requires the cognisance of the agency tasked with access control to ensure that access to the evacuation area is not closed too early (Goldblatt and Weinisch 2005).

People who live in areas immediately surrounding the evacuation area may choose to evacuate voluntarily, even if they are not at risk. This must be considered when evacuation times are being modelled as the increased traffic flow in areas outside of the evacuation zone may have implications for evacuation times within the study area (Goldblatt and Weinisch 2005).

When modelling the population of the emergency planning zone it is possible to identify three categories, namely: permanent residents, employees and transients. Each of these categories will experience peaks at different times. Accordingly, it is necessary to consider various scenarios based on the specific land use of an area and to develop a worst case scenario time for each area (Goldblatt and Weinisch 2005).

Public transport has a very important role in an evacuation, as it is the only means of evacuation available to non-drivers. Accordingly, the level of public transport must be tailored to the specific circumstances of the area. Poorer areas will require more public transport provision to accommodate the increased number of non-drivers while more wealthy areas will require less public transport. Additionally, public transport is the only effective means of evacuating special facilities such as schools, nursing homes and prisons. Such facilities will often require very specific arrangements to cater for the needs of the users (Transport Research Board 2005).

Public transport provided for emergency evacuation should follow a predetermined route. It is important that people who are dependent on or choose to use public transport in the event of an evacuation know before hand where they can board public transport and where it is destined (Transport Research Board 2005).

If private carriers are to be used for an evacuation it is important that the contract between the public authority and the carrier provides for emergency eventualities and establishes the basis for remuneration in the event of emergency evacuation (Transport Research Board 2005).

Public transport operators need to be catered for and considered in evacuation planning. This includes the provision of rest areas, feeding schedules and regular rest breaks for operators if they are required to work for more than a few hours. Additionally, provision has to be made for public transport employees who refuse to work at the time of an emergency evacuation due to fear or other such factors. A percentage of such individuals must be factored in to the calculation of vehicles and operators available for the evacuation (Transport Research Board 2005).

It is important that maintenance support should be provided for emergency services, public transport and, if possible, private vehicles. Emergency response strains equipment and timeous technical or mechanical intervention can prevent down time. Such support includes spare tyres, fuel, tow trucks and mechanics (Transport Research Board 2005).

Measures to favour buses, HOVs and service vehicles must be instituted. This will ensure that the maximum number of people can be evacuated and service personnel are able to operate easily. The use of contra-flow lanes is a possibility in the later stages of an evacuation when there is little traffic entering the area and large numbers of people or vehicles have to be moved out of the area rapidly. Contra-flow systems require restrictions on the road system and may prevent route changes. Such a system needs to be carefully planned and an integral part of the emergency evacuation plan (Litman 2006).

The families of essential staff must be assisted with their evacuation to ensure that staff members can concentrate on the emergency response (Litman 2006).

It is important that instruction on disaster preparedness should be ongoing and start at an early age. It is recommended that such instruction should start at grade school and carry on through to the work place (Taylor Martin 2005).

7. TRAFFIC MODELLING

7.1 Spreadsheet Model

The City of Cape Town's Transport Directorate developed a new spreadsheet model to replace the old EMME/2 transport planning model which had previously been used to model the Koeberg Nuclear Emergency Plan. This simplified method is acceptable as most of the variables are either known or can be calculated leaving only the estimation of the time required as the function of the model.

In this study, the City's model was refined through the introduction of further variables, notably: contra-flow lanes, the inclusion of the population employed in the area and the testing of alternative scenarios which include different days and times resulting in different population and hence vehicle profiles.

The model makes use of the predicted residential, commercial and industrial developments and concurrent transport system improvements to estimate the time require for evacuation. From a transport demand perspective the model takes the following into account:

- Estimated number of households per zone;
- Income category of households (high, medium and low);
- Estimated household size (based on income category: 3 people / high income household, 4 people / medium and low income household);
- Estimation of cars per household (1,9 cars / high income household, 1,5 cars / medium income household and 0,2 cars / low income household);
- Estimated employment for commercial and industrial land uses (including at Koeberg itself);
- Average number of people per public transport vehicle;

This data was used to calculate the population of each zone, the number of cars per zone and the number of people who would require public transport due to lack of private transport for evacuation.

From a transport supply side the model takes the following into account:

- Existing and future transport links leading out of the area;
- Theoretical peak hour capacity per lane of each transport link;
- A risk reduction factor of 20% accounting for reduced capacity resulting from evacuation conditions, testing was also done with a factor of 40% to test for more restricted conditions;
- The number of lanes on each of the transport links; and
- The use of contra-flow lanes to increase the capacity of the road network for evacuations.

The supply side data is used to calculate the combined vehicle capacity per hour of all transport links leading from the area. Travel time can then be calculated by the model using demand (total number of vehicles to be evacuated) divided by capacity (number of vehicles per hour that can be accommodated on the network).

7.2 Traffic Modelling Assumptions

As indicated previously, the aim of the model is to test whether or not the National Nuclear Regulator's evacuation criteria, as discussed above, can be met. In this regard it is important to note that while the standard procedures specify the sequential evacuation of the PAZ and the UPZ, it is conceivable that the times between these evacuations could be so small as to present a worst case scenario of de facto simultaneous evacuation. This has been included as a sensitivity test.

The following assumptions have been included in the modelling exercise (many have been drawn from the literature review):

- Residents of the affected area who are outside the evacuation area at the time the order is given are assumed to behave differently based on the mode of transport that they use. Those who have access to a private vehicle will return to their homes prior to evacuating while those dependent on public transport will not.
- It is assumed that after the AM peak 70% of private vehicles will be outside of the area, either at places of work or on the road.
- Differential times are identified for communicating with and mobilisation of various groups based on their location and mode of transport:
  - Private vehicles users inside the area – 0.75 hour
  - Private vehicle users outside the area – 1 hour
  - Public transport operators outside the area – 1.5 hours
- All evacuation is assumed to take place towards the south to where all the designated Mass Care Centres are located. In the case of the North-East UPZ, evacuating the population northwards was tested due to the logistical advantage in doing so.
- It is assumed that all privately owned vehicles in the area will be used for evacuation purposes. This is clearly a very conservative assumption, particularly for high income households which are considered to consist of three people per household and own 1.9 vehicles per household.
- The impact of contra-flow lanes was also tested based on the following assumptions and constraints. Contra-flow lanes can only be introduced once all the external traffic returning home prior to evacuating has done so. Provision must be made throughout the entire period of evacuation for some two way road capacity to facilitate movement of emergency vehicles and public transport vehicles returning to collect additional passengers.

7.2.1 The Role of International Literature Review

The assumptions made above have been adapted and refined based on the information derived from the literature review and international precedent. The result is a more refined series of assumptions that more closely approximate the manner in which people actually behave during an emergency event. This results in a more accurate model which will indicate evacuation times similar to those that would be observed in the event of an emergency evacuation.

7.3 Scenario Development

Scenarios have been developed based on a selection of the variables which materially affect the result of modelling. These variables represent the land use, transport planning and activity patterns of the area.

The population scenarios presented are drawn from the population projection and represent the Base Situation (2005), Short Term Scenario (2010), Medium Term Scenario (2015) and the Long Term Scenario (2030).

Transport network scenarios as based on the phased bulk infrastructure provision plan, discussed above, and represent the Base Scenario, Short, Medium and Long Term Scenarios – coinciding with the population scenarios.

Time of day scenarios were developed in order to represent the differing numbers of people in the area and working out of the area at different times of day. Three scenarios are presented which accurately represents the situation:

- 09h00 Scenario – 70% of private vehicles owners will have arrived at the their external place of work or will be on the road there. They will need to return to their homes in the even of an evacuation. Additionally, there will be a number of people present who live outside the evacuation area but work in it. This scenario is considered to be the worst case scenario during the week.
- 12h00 Scenario – only considered for the weekend when the maximum number of recreational visitors will be in the area.
- 24h00 Scenario – Assumes whole population of the area is at home. Best case scenarios as all residents are in the area and there is little background traffic.

Day of week scenarios were developed to differentiate between the differing populations in the area during the working week and the weekend. The weekday scenario assumes a transient work population within the area and a large number of residents outside of the area during the daytime while the weekend scenario assumes a large transient recreational population inside the area during the day.

Wind direction scenarios were considered for South-Westerly, North-Westerly, Westerly and East winds. Of these only the South-Westerly and North-Westerly were modelled as they would result in the evacuation of the PAZ and north-east sector and south-east sections of the UPZ respectively. The other scenarios did not result the evacuation of a significant portion of the population and were therefore not tested.

Of the variables presented, combinations of scenarios were selected which represented the development of the area in terms of population, transport network and activity. These can be seen in Table 1.

7.4 Sensitivity tests for variations in conditions

Additional sensitivity tests were carried out in order to compensate for the wide range of alternative scenarios. These sensitivity tests are not required by the National Nuclear Regulator; however, they provide an insight into possible unexpected eventualities and their effect on the network. The sensitivity tests include:

- an extension of the PAZ; combined evacuation of the PAZ and South-East sector UPZ;
- inclusion of the evacuation of the 16-20km zone of the South-East and North East sectors of the UPS (5 – 20km);
- Evacuation of the North-East UPZ to the sound and north; and
- use of a more stringent risk reduction factor of 40% to reduce effective road way capacity, as a result of incidents and side friction and variations on the number of private vehicles to be evacuated.

7.5 Model Results

In all scenarios the PAZ can be evacuated in between 2.2 and 2.6 hours, even if the extended PAZ is used. The South-East or North-East UPZ can be evacuated in under 16 hours for all scenarios except for the North-East sector UPZ 2030 AM Peak Period evacuation to the south which can only be completed in 17 hours, however, with the use of contra-flow lanes this scenario can be evacuated in 14.3 hours. All scenarios benefit from the use of contra flow lanes and with the use of such almost all eventualities can be evacuated within 16 hours, even with the most severe of the sensitivity tests.

Table 1: Scenarios Analysed

Population Scenario	Time	Area	Transport Network: 2005 W-day	2005 W-end	2010 W-day	2010 W-end	2015 W-day	2015 W-end	2030 W-day	2030 W-end
2005	09h00	PAZ								
		UPZ - SE								
		UPZ - NE								
	12h00	PAZ								
		UPZ - SE								
		UPZ - NE								
	24h00	PAZ								
		UPZ - SE								
		UPZ - NE								
2010	09h00	PAZ								
		UPZ - SE								
		UPZ - NE								
	12h00	PAZ								
		UPZ - SE								
		UPZ - NE								
	24h00	PAZ								
		UPZ - SE								
		UPZ - NE								
2015	09h00	PAZ								
		UPZ - SE								
		UPZ - NE								
	12h00	PAZ								
		UPZ - SE								
		UPZ - NE								
	24h00	PAZ								
		UPZ - SE								
		UPZ - NE								
2030	09h00	PAZ								
		UPZ - SE								
		UPZ - NE								
	12h00	PAZ								
		UPZ - SE								
		UPZ - NE								
	24h00	PAZ								
		UPZ - SE								
		UPZ - NE								

8. TRAFFIC EVACUATION MANAGEMENT PLAN

A Traffic Evacuation Management Plan (TEMP) was produced as part of the modelling report. The plan is informed by the existing planning by the City of Cape Town, the traffic modelling and the international literature review. The TEMP should be seen as a complement to the existing City of Cape Town Emergency Procedures and read as an extension of these procedures. This paper will not discuss the details of the plan but rather the process through which it was developed.

The starting point for the development of the TEMP was the literature review, from which international precedent was identified. The existing emergency procedures were then compared to precedent and where found lacking, recommendations were made.

The final TEMP is in the form of a drawing which relates to the implementation of contra-flow lanes, intersection closures which are to be manned by traffic enforcement officials, the timing of the establishment of road blocks, identification of roads which are to remain open to two way traffic, necessary revision to the contract with Golden Arrow Bus Services, measures necessary to minimise disruptive effects of evacuation conditions and identification of locations requiring public transport to evacuate non-drivers.

9. CONCLUSION

Presented above is the background and methodology to the development of the Koeberg Nuclear Emergency Plan: Traffic Evacuation Model. The model and associated plan developed as part of this study demonstrated the use of multiple variables impacting on emergency event evacuation times, and the implementation of derived protective actions. By building in the capacity to conduct sensitivity tests to assess the relative impact of critical variables, a robust model to be used as a decision support tool by the responsible authorities, was created.

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