EMERGENCY EVACUATION MODELLING FOR THE KOEBERG NUCLEAR POWER STATION

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1. INTRODUCTION

The Koeberg nuclear power station is situated about 26km north of the Cape Town central business district. Development in the metropolitan area has spread northwards since the power station was constructed. The present population living in the area around the power station, as well as high expected future growth, have given rise to concerns relating to the evacuation times of the area in the event of a nuclear emergency.

This paper presents the evaluation results of the existing evacuation plan in terms of transportation impacts, highlights the use of EMME/2, and lists the recommendations made to the National Nuclear Regulatory Board.

2. BACKGROUND

Nuclear facilities are obliged to put evaluation plans in place and to ensure that they are operational. There are a number of physical elements in a nuclear evacuation that need to be complied with, in order to reduce exposure to radiation. These range from notification of an emergency to sheltering, administration of stable iodine, evacuation of the population, the caring and repatriation of evacuees, amongst others.

Legally, the nuclear operating authority must provide detailed safety and emergency procedures able to cope with emergencies. Such procedures have been developed in line with stringent South African and international standards. These have well defined spatial elements but there are no strong time elements relating to the evacuation of affected areas. In terms of the South African Nuclear Regulator Act of 1999 there are no specific requirements with regard to maximum evacuation times of affected areas in the event of an emergency.

3. APPROPRIATE TOOL

The accident at the Three Mile Island Nuclear Power Station in 1979 resulted in the adoption of emergency evacuation planning based on traffic simulation software packages. This dynamic simulation approach produces turning movements on each link which are then introduced to the simulation data set to model delays and congestion. The resultant evacuation time estimates are obtained when the network is cleared. In terms of this investigation, which focuses on the broad transport evacuation issues and also the expected future performance of the transport system in the event of an emergency, it was decided to use the existing EMME/2 model calibrated for the Cape Metropolitan area. EMME/2 does not give the same level of detail as a simulation model but in this study it did assist the process by quickly defining the traffic demand flows for a number of scenarios that needed to be tested.

4. ZONING SYSTEM

International practice is to subdivide the area around a nuclear facility into a number of zones as follows :

- the Public Exclusion Boundary (PEB) : an area of approximately 2km radius from the nuclear facility which is not accessible to the public;
- the Inner Emergency Protection Zone (Inner EPZ) is an area radiating 5km from the reactor;

- the Intermediate Emergency Protection Zone (Intermediate EPZ) extends 5km to 16km (10 miles) from the reactor; and
- the Outer EPZ extends from 16km to 80km from the reactor.

Detailed planning is not required in the outer EPZ, which includes almost the entire Cape Metropolitan Area, although certain protective actions such as control of contamination, may be necessary. As far as the transportation evacuation plan is concerned, the Inner and Intermediate EPZs were addressed.

5. POPULATION AND EMPLOYMENT PROJECTIONS

Demographic and employment projections were undertaken for the Inner and Intermediate Emergency Protection Zones (the "Study Area") on a traffic zone basis (43 zones) as an input to EMME/2.

The area around the power station is under extreme development pressure. The current development framework predicts very high growth in residential developments, that will be completed within the next 15 to 20 years. Table 1 shows the current and expected population and employment figures for the area.

Table 1 : Population and Employment Projections

	Year		
	2000	**2015**	**Full Development**
Population	108 300	283 800	419 300
Employment	24 650	91 800	153 700

The population in the study area was categorised into 3 income groups according to a sub-area basis as shown in Table 2.

Table 2 : Income Distribution for Study Area

Sub-area	**Income Category**		
	Low	**Middle**	**High**
Coastal	5%	35%	60%
Table View	20%	60%	20%
Corridor	75%	20%	5%
Melkbosrand	10%	30%	60%
Atlantis	35%	60%	5%

6. TRAVEL DEMAND

The evacuation scenarios need to be evaluated in terms of travel demand. This requires the estimation of the number of trips (person and vehicle) and their origins and destinations. These trips can then be assigned onto the transport system to obtain travel demand (trips) on each element of the system.

The number of persons that may need to be evacuated during an emergency is significant and equates to about 15% of the current total population of the metropolitan area (± 3 million persons). The majority of the households are low income households with low car ownership levels which means that vehicular transport will have to be provided by external parties in the event of an evacuation.

The modelling procedure adopted for each evacuation scenario evaluated is described below.

The population in the study area has been categorised into 3 **income groups**. Each income group in the study area (16km EPZ) is assumed to have the following household (HH) car ownership and size properties

Low income:	0.2 cars per HH	4.0 persons per HH
Middle income:	0.6 cars per HH	3.5 persons per HH
High income:	1.7 cars per HH	3.0 persons per HH

The **income distribution** per traffic zone is as per the local area development frameworks.

The **vehicle occupancy** assumptions and usage are as follows:

Private cars :	all cars in the low and middle income groups will be used to evacuate all persons in the household owning the car, and all cars per household in the high income group (more than 1 car per household) will be used to evacuate the high income group (i.e. all cars in the study area will be used for the evacuation).
Public transport : (where applicable)	Rail : 2000 persons per train set Minibus-taxi : 15 passengers per vehicle Bus : 60 passengers per vehicle
Trip generation :	Calculate number of cars in study area (per traffic zone) = HH x cars per household. Calculate number of persons evacuated in cars = Cars x vehicle occupancy. Allocate balance of people to public transport = Total persons – persons in cars. Select public transport vehicle supply scenario. Calculate public transport vehicles (including return trips – shuttle service) = Public transport persons / public transport occupancy. Do the above for each income group and add to get the total.
Evacuation destinations :	Car users will travel to all CMC high income residential zones. Public transport users will be sent to the *Koeberg Emergency Procedure* reporting points allocated to each protective action zone.
Trip distribution :	Car users are sent from the study area to high income residential areas outside the study area throughout the CMC area. Public transport vehicles are sent from the study area to reporting points (plus return trips reversed). Add cars and public transport vehicles to get total evacuation traffic (vehicles).
Trip assignment :	Background traffic (non-evacuation traffic) is assigned onto the transport network (selected network scenario) prior to the evacuation traffic, on the basis of the evacuation demand scenario being tested. Assign evacuation traffic “on top” of background traffic.
Evaluation :	Demand traffic flows on each link. Travel speeds (or times) on each link. Clearing times (based on link capacities) are calculated by dividing the total traffic demand by the hourly capacity of each link. Identify clearing bottlenecks as being those links with the longest clearing times.

7. EVACUATION DEMAND SCENARIO DEVELOPMENT

There are many possible evacuation scenarios that can be developed. These depend upon the area to be evacuated, the time of day, the presence of background traffic, emergency vehicles, etc.

The initial scenario was one of the anticipated worst case demand scenarios – the full evacuation of all persons living in the intermediate EPZ 16km zone (the study area). It represents the greatest number of persons leaving the area (excluding emergency and support traffic). This scenario would typically occur at night (everyone at home) or after an emergency has been declared for some time (i.e. non-resident traffic has been banned from entering the area, residents have been allowed to return prior to evacuating). In the second case an additional lag time will need to be estimated and added to the expected evacuation time. This scenario included the following assumptions :

Scenario 0 : Full residential (population) development in Inner and Intermediate EPZs (± year 2025).
Public transport supply : 50% of the public transport users will be evacuated by buses and the other 50% by minibus-taxis.
All residents are at home and need to be evacuated at the same time (e.g. at midnight). This represents the highest evacuation demand from within the Intermediate EPZ.
There is no background traffic (e.g. at midnight), so this represents the lowest background traffic demand.

In addition to the initial Scenario 0 above, the scenarios listed in Table 3 below were identified for evaluation (using the same basic assumptions but varying the road network, area of evacuation, wind direction and time).

Table 3 : Evacuation Demand Scenarios

Koeberg Scenario	Road Network	Evacuation			Time	Back-ground	Private	Public	Public To
		0 – 5km	6 – 16km	Direction*					
0	2015	Full	Full	360°	Midnight	None	High, Resid.	50% bus 50% taxi	Report points
1	2000	2000	2000	360°	Midnight	None	High, Resid.	50% bus 50% taxi	Report points
2	2000	2000	Shelter	360°	Midnight	None	High, Resid.	50% bus 50% taxi	Report points
3	2000	2000	2000	67.5° South-east	Midnight	None	High, Resid.	50% bus 50% taxi	Report points
4	2000	2000	2000	67.5° North-east	Midnight	None	High, Resid.	50% bus 50% taxi	Report points
5	2015	Full	Shelter	360°	Midnight	None	High, Resid.	50% bus 50% taxi	Report points
6	2015	Full	Full	67.5° South-east	Midnight	None	High, Resid.	50% bus 50% taxi	Report points
7	2015	Full	Full	67.5° North-east	Midnight	None	High, Resid.	50% bus 50% taxi	Report points
8	2015	Full	Full	360°	Weekday AM	Off-peak	High, Resid.	50% bus 50% taxi	Report points
9	2015+	Full	Full	360°	Midnight	None	High, Resid.	50% bus 50% taxi	Report points
10	2000	1995+ Approved	1995+ Approved	360°	Midnight	None	High, Resid.	50% bus 50% taxi	Report points

Note: * Either all residents would evacuate (360°) or only those living in a specific cone area extending away from the power station would be evacuated (67° SE or NE, depending on the wind direction).

8. EVACUATION DEMAND MODELLING RESULTS

The demand scenarios were assigned onto the CMC's EMME/2 transport network, either the current (2000), future (2015) road network or the 2015 plus local improvements / upgradings as currently planned depending on the scenario being evaluated. The following information was extracted for the purposes of the scenario modelling evaluation:

(a) traffic flows (vehicles),
(b) link travel times and speeds,
(c) travel time contours, and
(d) link clearing times.

The modelling assignment is based on the existing CMC model and no additional calibration or sub-model development has been undertaken. The assignment is based on the EMME/2 equilibrium assignment algorithm which means that trips will be distributed in a balanced manner throughout the network, rather than taking the shortest, free flow route. It is felt that this assignment method is acceptable as there are in any event only a limited number of routes from the Koeberg study area towards the south, and a large proportion of the vehicle trips (car trips) will be dispersed all over the CMC area and thus use a number of routes.

The initial evacuation demand scenario, Scenario 0, was tested on both the current and 2015 route networks. This gives an indication of the expected evacuation clearing times. The current network required the addition of links to connect traffic zones that are "empty" at present but have trips in the full development scenario. Link flows within the study area in the scenarios which include the full development and the current network are thus not realistic. However, as one moves away from these zones the modelled link flows should become more acceptable.

The results of the EMME/2 assignments of each evacuation demand scenario are summarised in Table 4. Total trip demand (vehicles) varies from a low of 2 500 vehicles (Scenario 2) to a high of 96 000 vehicles (Scenario 0). The expected clearing times vary from 0.7 hours to 19.2 hours respectively. The clearing times represent those links that will take the longest time to clear all the traffic that is expected to use the link.

Table 4: EMME/2 Assignment Results

Scenario	Evacuation	Demand	Network	Private Cars	Public Persons	Public Vehicles	Total Vehicles	Max. Clear Time
0 : Full	360°	Full	Current	77 617	225 771	18 877	96 494	19.2 hrs
0 : Full	360°	Full	2015	77 617	225 771	18 877	96 494	15.7 hrs
1 : 2000	360°	2000	Current	20 751	52 572	4 376	25 127	4.5 hrs
2 : 2000	0-5km	2000	Current	2 408	1 104	92	2 500	0.7 hrs
3 : 2000	67.5° SE	2000	Current	15 236	19 072	1 589	16 825	4.2 hrs
4 : 2000	67.5° NE	2000	Current	7 923	34 556	2 879	10 802	3.9 hrs
5 : Full	0-5km	Full	2015	4 154	2 294	191	4 345	1.3 hrs
6 : Full	67.5° SE	Full	2015	66 463	175 291	14 607	81 070	14.2 hrs
7 : Full	67.5° NE	Full	2015	15 308	53 536	4 461	19 797	4.0 hrs
8 : Full	360°	Full	2015	77 617	225 771	18 877	96 494	16.0 hrs
9 : Full	360°	Full	2015+	77 617	225 771	18 877	96 494	15.2 hrs
10 : 2000	360°	1995+ Approved	Current	28 321	69 517	5 793	34 114	7.3 hrs

Due to the nature of the CMC's EMME/2 demand model, the link clearing times are not explicitly modelled. They are derived from link capacities and associated vehicle demand. The model is a peak hour model and has been developed to model a single hour of traffic demand. As seen in Table 4, the expected clearing times in nearly all the scenarios exceed 1 hour. This situation could not be accommodated within the one-hour model without developing sub-models to incorporate the effect of long clearing times. This was beyond the scope of this study. The evacuation demand scenarios were thus evacuated within the limitations of the one-hour EMME/2 model.

The decision on whether to accept the longest (or any other) bottleneck as the current evacuation time is not simple as there are a number of issues that are not reflected in the one-hour EMME/2 model. The following are possible options :

- the traffic will divert from the longer link bottleneck points to parallel links with shorter bottleneck times, i.e. tend to balance between parallel routes; or
- the traffic will not have the chance to self-balance as it will be impractical to change routes. This would also “create” more trips which would lead to more congestion.

Some of the minor links with long clearing times tend to skew overall results. This should be borne in mind when evaluating scenarios and selecting the most appropriate evacuation clearing time. Such links should be upgraded and the long clearing times would then reduce.

The selection of routes in the EMME/2 model is based on expected link travel times (or speeds) and does not allow for bottleneck delays. Although it may take 3 hours of travel to complete a trip from the study area to the trip destination it may take a greater number of hours to get all vehicles through a particular link (the link clearing time).

9. NETWORK IMPROVEMENTS

The network improvements (bottleneck locations) identified during the evaluation of scenarios were added to the 2015 EMME/2 network and evaluated using Scenario 0 (full development, full evacuation). The improvements are aimed at producing a more balanced situation in terms of overall basic link clearing times as well as a reduction in maximum link clearing times. The following improvements were incorporated :

- increasing the capacity of the Plattekloof Road link between Blaauwberg Road and N7 (assuming concurrent N7 interchange improvements);
- adding a lane to the R27, Wood, Gie and Koeberg Extension Roads north of Blaauwberg Road;
- adding a lane on the East-west Road to the N7 (and interchange improvements); and
- adding a lane from Atlantis to N7 on the R304.

The main changes in network clearing times relative to the Scenario 0, 2015 network are given in Table 5. As can be seen from Table 5, a number of links need to be upgraded to achieve more balanced clearing times in the study area. The longest clearing times are on the access roads (R27, Wood, Gie, Koeberg) north of Blaauwberg Road. When upgraded, the result is an apparent large improvement in the clearing times, but it is only the worst links that are reflected in Table 5. The overall effect of the improvements in the 2015 network listed in Table 5 result in a more balanced evacuation scenario with a reduction in maximum link clearing times from 19 to 12 hours.

Table 5 : Network Clearing Time

Network	Max. Clearing Time
2015 Base	15.7 hours
Upgrade Koeberg – Plattekloof – N7	19.6 hours #
Upgrade R27, Wood, Gie, Koeberg extension north	13.1 hours
Upgrade East-west Road to N7	12.4 hours
Upgrade R304 from Atlantis to N7	12.4 hours

Note: # The increase in maximum clearing time is due to the increase in traffic demand on the approaches to the improved links – revert to 2015 base situation.

10. OTHER ISSUES

During this investigation a number of other issues that influence the travel times of the evacuation process were identified. Briefly these are :

- location of reporting points as it affects the turnaround time of public transport evacuation vehicles;
- access to reporting points is also critical in terms of traffic congestion in the vicinity;
- availability of public transport vehicles for the segment of population not owning cars;
- willingness of public transport vehicle drivers to enter zone that needs to be evacuated;
- road space for emergency services will reduce the available road capacity for evacuation;
- walking as a means of transport to evacuate 16km radius could be a feasible alternative (3 hours). However once they are out of the Intermediate EPZ they will need to be transported to reporting points;
- the lag in time between the time that a decision is taken to evacuate up until the time the actual evacuation begins is difficult to estimate.

11. EMME/2 NOTES

The use of an hourly model to evaluate up to 19 hours of travel raises some modelling issues as listed above. Initial runs incorporating the link clearing times (saved in a node user field) in the travel time functions to include bottleneck congestion effects were positive. However, the clearing times had to be damped between iterations. It is thus possible to "improve" EMME/2 but this needs to be done within the assumed behaviour assumptions of evacuation traffic. The bottleneck balancing of the assignment may not be valid as evacuees may have no chance to change their routing, no knowledge of bottlenecks or system changes over time, a notification system to manage re-routing would need to be put in place, panic elements, etc.

12. CONCLUSIONS

The traffic modelling of the evacuation of the population living in the Inner and Intermediate EPZs was carried out to estimate the evacuation duration and identify problems related to the road network. The modelling was based on the development of an evacuation demand scenario that allows for the evacuation of all residents at once, i.e. the maximum demand from the study area. Such a scenario would manifest, for example, at midnight when all residents would be in the study area and there would be no other traffic. Various other scenarios, sub-groups of the base scenario, were also tested to estimate likely evacuation times.

The full development of the study area will include a population of 419 000 and have an employment base of 170 000 jobs; up from 80 000 and 21 000 in 1995 respectively. The full evacuation scenario is expected to generate a demand of 77 600 private car trips and 18 800 public transport vehicle trips, a total of 96 400 vehicle trips.

The CMC's EMME/2 transportation demand model was used to model the expected traffic link flows resulting from the various evacuation demand scenarios tested. The basic link clearing times were defined as the traffic demand flows divided by the hourly link capacity which yielded the basic time (hours) required to clear the link of traffic. Provided that all of the assumptions in this study are met (i.e. availability of public transport vehicles, orderly evacuation, etc.) the main results of the scenario evaluation are :

- the Year 2000 demand scenario (current) traffic can be accommodated and cleared from the 16km EPZ in a period of 4.5 hours on the current road network; and
- the full development of the area will create traffic demand that will clear in a period of about 19 hours. This will reduce to about 16 hours on the expected Year 2015 road network (which includes a number of new roads in the study area).

EMME/2 proved to be a valuable tool for the quick assessment as the many possible scenarios that manifest from a myriad of variables such as, wind speed, time of evacuation, different location of reporting points, availability of public transport vehicles, etc.

The procedure followed in this study does not substitute the traffic simulation process required for preparing detail traffic management plans in a case of evacuation. The process gave a good estimate of overall travel demands and travel times and highlighted issues that need to be investigated further.

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