WRITTEN REPRESENTATION FOR
SPR EA1N and EA2 PROJECTS (DEADLINE 1)

SAFETY

Interested Party: SASES **PINS Refs:** 20024106 & 20024110

Date: 2 November 2020 **Issue:** 1

Summary

The written representation on safety comprises written representations on:

1. Safety - Sizewell Emergency Evacuation

2. Safety - Construction & Operational

WRITTEN REPRESENTATION FOR
SPR EA1N and EA2 PROJECTS (DEADLINE 1)

SAFETY - SIZEWELL EMERGENCY EVACUATION

Interested Party: SASES **PINS Refs:** 20024106 & 20024110

Date: 21 October 2020 **Issue:** 2

1. Introduction. The proposed projects cannot be Consented if they would place at risk the well-established public safety Evacuation Plans for the Nuclear Power Station complex at Sizewell. This is a very likely outcome of approval of the EA1N and EA2 projects for the reasons described below.

2. A serious equipment failure or other event (e.g. terrorism) at the Sizewell nuclear complex could lead to a likelihood of the release of radioactive contamination which would be threat to health. In these circumstances an evacuation of the population in the vicinity could be required and detailed Suffolk County Council plans exist for such a requirement.

3. The Outline Emergency Planning Zone (Fig. 1 taken from Ref.1) within which evacuation might be required in the event of serious radioactive release is in the process of being extended to 30km from Sizewell. Such an evacuation, especially from the Detailed Emergency Planning Zone (Fig. 1), would inevitably rely on the road infrastructure which has a number of bottlenecks in the Leiston Saxmundham area leading to the A12, including the congested signal controlled junctions in both towns.

4. Current Government policy supports the construction of a new dual reactor nuclear power station called Sizewell C, adjacent to the existing nuclear plants, and a DCO application has already been made for this. This project would be based mainly to the North of Sizewell/Leiston area and involve a very wide range of civil engineering activities, including multiple heavy lorry movements over as many as ten years.

5. It follows, therefore, that any required evacuation from the Sizewell/Leiston area would need to make most use of routes to the West and South, with the routes to the West being constrained by the congested traffic light controlled crossroads in Saxmundham centre, and the alternative narrow country roads leading to the A12. Routes to the South would inevitably pass through areas in the Leiston/Friston area proposed for use by the SPR and National Grid projects, as well as any other follow-on projects planning to connect at the Friston substation. These will therefore be highly constrained both by increased traffic movements and by cable route crossings with associated traffic lights. Fig. 2 taken from Ref. 2 refers and clearly shows the importance of the A1094 road as an evacuation route to the South, which road is also critical to the traffic movements in and out of the SPR projects..

6. There is already significant community concern (expressed publicly at meetings of the Sizewell Stakeholder Group) and elsewhere (Ref. 3) that the viability of the existing Evacuation Plan is unproven by fully representative testing, and the extension of the evacuation area to 30km is a yet further concern. It follows that consideration of approval of the EA1N and EA2 projects (and anticipated follow-on projects) must take into consideration the viability of the existing and any new Sizewell Evacuation Plan **on the presumption that the Sizewell C Project is to approved**. This is

obviously a Cumulative Impact issue which the Examiners are asked to carefully address.

7. Based on this information it is clear that in the interests of public safety the proposed EA1N and EA2 projects **cannot be consented** as there can be no confidence that their associated works will not block the Sizewell Emergency Evacuation Route.

Figure 1 **Sizewell Emergency Planning Zones**

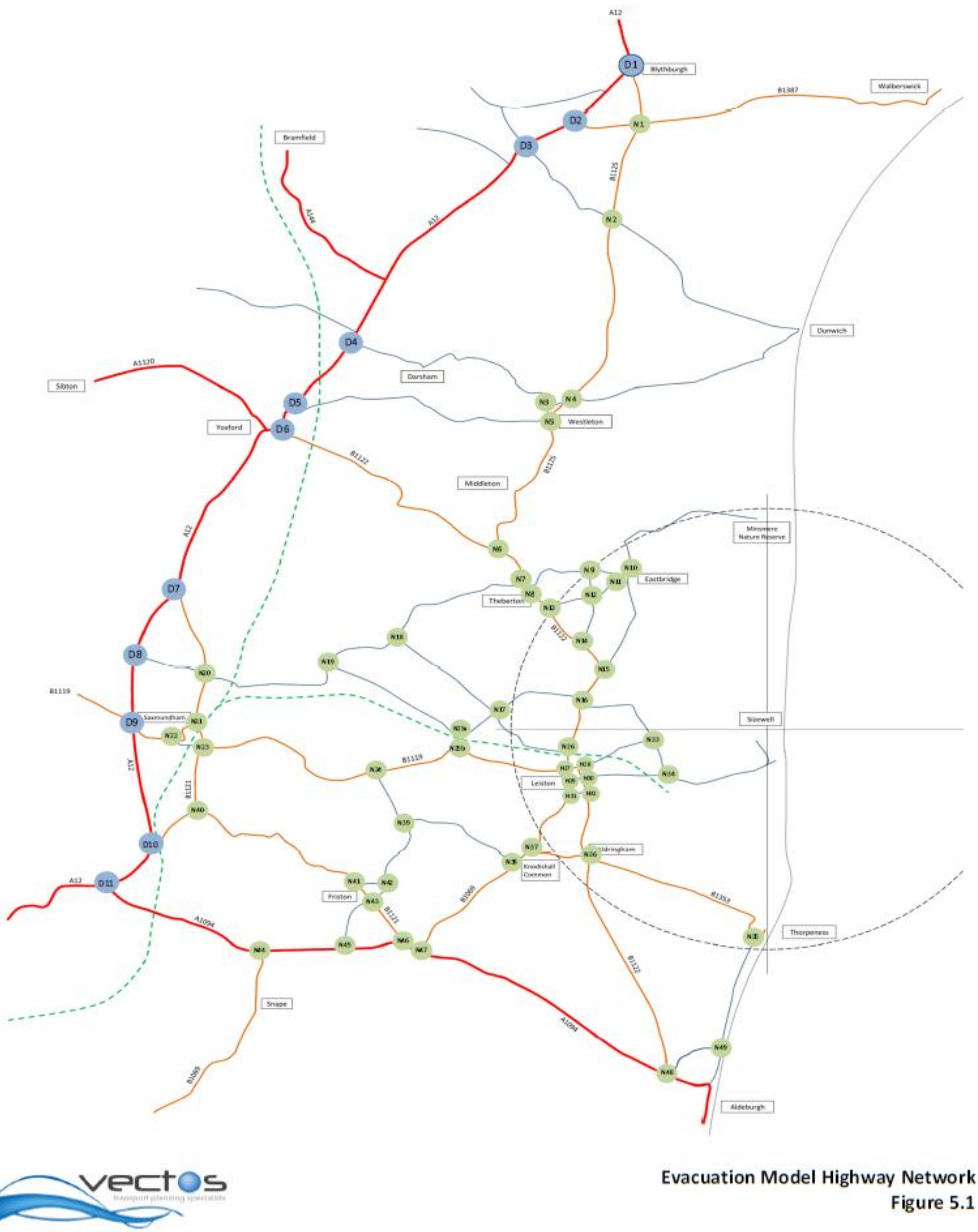

Figure 2 Road network for Emergency Evacuation from the DEPZ

References

Ref. 1 Sizewell Emergency Evacuation Leaflet September 2019
https://community.magnoxsocioeconomic.com/wp-content/uploads/2019/09/V3-A4-LEAFLET-SIZEWELL.pdf

Ref. 2 Vectos Transport Technical Report for Suffolk County Council August 2013.
Copy attached as separate file *VECTOS report from SCC.PDF*

Ref. 3 Public criticism of Sizewell evacuation plans
https://www.ipswichstar.co.uk/news/critics-claim-evacuation-measures-for-sizewell-b-meltdown-are-ridiculous-1-5099149

Suffolk County Council

Sizewell Evacuation

Transport Technical Report

August 2013

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Contents

Appendices

1 INTRODUCTION

1.1 Vectos is retained by Suffolk County Council (SCC) to provide technical transport support to assist SCC with their review of the evacuation arrangements of the population in the vicinity of the existing Sizewell nuclear power stations in the event of an incident at the power stations.

1.2 SCC is currently in the process of undertaking a formal review of their Sizewell Off-site Emergency Plan. The aim of the technical work is to examine the road network in the vicinity of the existing Sizewell nuclear power stations and produce an evacuation plan in order to evacuate the affected population to safety in the event of an emergency scenario at Sizewell.

1.3 In addition, the technical work considers the future growth in the area, based on growth forecasts up to 2027 provided by Suffolk Coastal District Council (SCDC). The technical work assesses the implications of future growth on an evacuation of the area and any potential constraints to growth.

1.4 This report describes the analysis undertaken and the results obtained in preparing the Evacuation Plan.

Project Outcomes

1.5 The project brief states that the technical support will provide the following output:

- An assessment of road network capacity to support evacuation of all permanent and transient population within 4km of the Sizewell B power station, including time to complete evacuation from initiation.
- The technical basis for the assessment, including models used or scientific research referenced.
- Options for evacuation assuming that a contaminated cloud may preclude the use of certain routes that are downwind within a 45 deg arc of the Sizewell B power station.
- Effect of self-evacuation on any deliberate activity if there is a time difference between the public announcement of an emergency and the advice to evacuate.
- Maps for each developed evacuation option showing routes, traffic management elements and any specific congestion pinch points.

- Validation of evacuation assumptions for population indicated in the Project Brief assumptions.
- Validation of evacuation decision timelines indicated in Project Brief assumptions.
- A methodology for use by the Suffolk Joint Emergency Planning Unit that allows it to consider the implications of any future population rises on the evacuation options provided by this work without recourse to the provided of the technical support.
- Indications of any areas within 4km that population limits might be advisable in the future to avoid scenarios where evacuation may not be safely conducted.

Report Structure

1.6 The remainder of this document is structured as follows:

- Section 2 – Concept of Evacuation;
- Section 3 – Approach;
- Section 4 – Assessment Variables and Scenarios;
- Section 5 – Highway Network Characteristics;
- Section 6 – Population Demand Estimates;
- Section 7 – Modelling;
- Section 8 – Evacuation Plan; and
- Section 9 – Conclusions.

2 CONCEPT OF EVACUATION

2.1 This section provides an overview of the evacuation process and any assumptions made about the process used to inform this study.

Evacuation Zone

2.2 The Detailed Emergency Planning Zone (DEPZ) is the area determined by the Office for Nuclear Regulation as being most likely to be affected by a reasonably foreseeable emergency and requiring detailed emergency plans. For the purposes of this report it has been assumed that the DEPZ is 4km from Sizewell B station. This area is illustrated in **Figure 2.1** and includes Leiston, Eastbridge, Aldringham and Thorpeness. At the time of publishing, the actual DEPZ is still being assessed by the Office for Nuclear Regulation.

2.3 The population within the DEPZ is considered to be evacuated at the point that it reaches the A12. From the A12 traffic can travel north and south away from the area.

Evacuation Timeline Assumptions

2.4 The Sizewell operator will make the initial declaration of an Off-site Nuclear Emergency, which will result in, or is likely to result in, the need to consider urgent countermeasures to protect the public outside of the Sizewell security fence from a radiological hazard.

2.5 On declaration of an off-site nuclear emergency, evacuation may be considered as a public countermeasure after understanding where any radiation hazard is; it will not be an automatic countermeasure. However, as soon as possible following the declaration of an Off-site Nuclear Emergency, the evacuation of people within the DEPZ who do not have substantial shelter will be undertaken as an automatic countermeasure. This will apply to the transient population (i.e. people camping/staying in the caravan parks) and pedestrians, cyclists, motorists within the DEPZ. For the purposes of this technical work the transient population and existing traffic on the network within the DEPZ has been assumed to be evacuated but no information is known about pedestrians and they have therefore not been included within the model.

2.6 A further automatic countermeasure is for the population within the DEPZ that do have substantial building for shelter to stay indoors, close doors and windows, and take pre-distributed Potassium Iodate tablets (Sizewell B incident only).

2.7 The Project Brief estimates that:

- 75% of people within the DEPZ will self-evacuate after public declaration of an Off-site Nuclear Emergency rather than adhere to the automatic countermeasure to shelter and potentially take Potassium Iodate tablets;
- 15% of people will require support by the emergency services to evacuate; and
- 10% will elect to remain in their homes.

2.8 The model has been set to assume that 10% of the population elect to remain at home. In order to validate the split between those who self-evacuate and those who will need support by the emergency services to evacuate (i.e. referred to as the vulnerable population within this report), the 'Vulnerabilities' estimates contained in the existing Off-site Evacuation Plan have been used. The remainder of the population has been assumed to self-evacuate.

2.9 The time to evacuate the self-evacuation population is measured from the point of public declaration of an Off-site Nuclear Emergency (Time 0) to when the last member of public has reached the A12. It has been assumed that the self-evacuation population will have finished evacuating before the emergency services begin to evacuate the vulnerable population.

3 APPROACH

3.1 This section summarises the approach used to develop the evacuation model, including the research that the approach is based on.

Background

3.2 Many disasters can lead to situations where people need to be evacuated from the affected area to safety. In such situations it is important to identify routes to enable the evacuation to be completed in the shortest possible time. Evacuation route planning therefore aims to find the optimised evacuation routes.

3.3 There has been a considerable amount of research undertaken on route planning for evacuation scenarios as a result of the risk of natural disasters such as hurricanes and earthquakes and more recently nuclear incidents and terrorist attacks. Research has focussed on methods to improve the planning of the evacuation process to maximise the efficiency of the existing road network.

3.4 Evacuation route planning falls into three categories:

- traffic simulation methods;
- network flow methods (Francis and Chalmet 1984, Kisko and Francis 1985, Ahuja *et al.* 1993, Kisko *et al.* 1998, Hamacher and Tjandra 2001);
- heuristic algorithms (Hoppe and Tardos 1994, Lu *et al.* 2003, 2005, 2007).

3.5 The traffic simulation approach uses traffic simulation models, such as VISSIM and Paramics, to simulate the behaviour of individual vehicles within a road network. However, it would take time to build and run a model and micro-simulation modelling is not normally suitable for testing a lot of scenarios, as required for this project. In addition, their assumption of repeated experience of drivers (e.g. commuting) leading to Wardrop equilibrium and perfect information does not hold for rare events such as emergency evacuations.

3.6 Network flow methods can be divided into two approaches: linear programming and dynamic minimum cost flow problem. However, these approaches require the user to provide an upper bound time of the evacuation which is not easy to do. An under estimate of the time will result in failure to find a solution and an over estimate of the time will lead to unnecessary run time. In addition, whilst these methods generate optimal solutions for moderate size networks such as building evacuation, they are not easily scaled to up a transport network due to the high computational time.

3.7 The third method uses heuristic algorithms (i.e. an algorithm designed to solve a problem quickly when classic methods are too slow). Research in heuristic algorithms has shown a 95% reduction in computational time with only a small degradation of solution quality when compared to network flow methods.

3.8 The initial heuristic approaches only calculated the shortest distance route from a source to the nearest destination without considering the route capacity constraints. More recent heuristic algorithms take account of capacity constraints. A well-known heuristic approach is Capacity Constrained Route Planner (CCRP). CCRP generates routes while constraining them to road capacities.

3.9 CCRP got its first major test in 2003 when it was used to create an alternative evacuation plan for Monticello, Minnesota, USA, a BWE type nuclear reactor. Using GIS, the researchers were able to model the transportation network surrounding the plant by incorporating population data for each part of the network. The resulting plan reduced the evacuation time from four to two and a half hours. Based on their test experience, CCRP was further refined. In 2005, the research team collaborated with many partners, including the Minnesota Department of Transportation, to develop evacuation plans for five locations in the Twin Cities area with up to 150,000 people in a one-mile radius.

3.10 It is important to note that SCC requested a tool that could be used to understand the road network under evacuation conditions without needing any further technical support from Vectos. As such, micro-simulation modelling is not considered appropriate. The CCRP algorithm is considered to be the most appropriate tool to prepare an evacuation plan for Sizewell and is described in more detail below.

Capacity Constrained Route Planner (CCRP)

3.11 The CCRP algorithm uses ‘nodes’ to represent junctions in the road network and ‘edges’ to represent road links between the junctions. Each road link (edge) has a travel time and a maximum capacity (i.e. vehicles per unit of time). In addition the junctions (nodes) have a maximum capacity which represents the maximum number of vehicles that can route through the junction per unit of time.

3.12 Nodes are split into the following three types:

- **Source node:** the area from which the population needs to be evacuated from is split into sub-areas and the centre of each sub-area is the 'source node';
- **Network node:** junctions within the road network between the source and destination nodes; and
- **Destination node:** the junctions that the evacuees need to reach in order to be considered evacuated/to have reached safety.

3.13 CCRP is based on an iterative approach for creating a complete evacuation plan. In each iteration of the model, the algorithm searches for a route *R* with the earliest arrival time to any destination node from any source node, taking previous reservations and possible wait times into consideration. Then, CCRP computes the actual number of evacuees that will travel through route *R*. The maximum number of evacuees to be sent on route *R* is then determined as the minimum of the available capacities on the links on route *R*. CCRP then reserves the node and link capacity on route *R* for these evacuees. The algorithm terminates when all the evacuees have been given an evacuation route and reached the destination nodes.

3.14 In order to develop the Sizewell Evacuation Plan, the CCRP example cited in the research papers has been reproduced and expanded for the Sizewell network. The research paper is included in **Appendix A** of this report as well as a bibliography of other research papers reviewed as part of this work.

4 ASSESSMENT VARIABLES AND SCENARIOS

4.1 This section summarises the assessment variables and the scenarios that have been included within the evacuation model.

Assessment Variables

4.2 **Figure 4.1** below illustrates the variables section of the model.

Figure 4.1 Variables within the Evacuation Model

Variables					
Scenario	**1**				
Time of Day	1	**Day**	**1**	Day	10:00
			2	Night	21:00
			1	North	
			2	East	
			3	South	
Wind Direction	1	**North**	**4**	West	
Flooding	0	**No Flooding**	**0**	No Flooding	
			1	Flooding	
Self Evacuate Population	1	Existing			
	1	Consented			
	0	Aldeburgh Rd			
	0	Valley Rd			
	0	Remaining SHLAA			
	0	Sizewell C			
Vulnerable Population	0	Existing			
Self Evacuate Vehicle Occupancy	**2**				
Vulnerable Vehicle Occupancy	**20**				
% Stay at Home	**10%**				
% of background traffic to evacuate	**50%**				

4.3 The 'Scenario' drop down menu allows the user to select the scenario they would like to test. The variables (e.g. time of day, wind direction, development quantum) then change according to the selected scenario. The vehicle occupancy, percentage of people who choose to stay at home and percentage of background traffic that is needed to evacuate can manually be adjusted. These variables are described in more detail below.

Assessment Years

4.4 The model assessment years have been taken to be 2013 as the base year and 2027 as the future year. 2027 has been selected as the future year to be assessed as the Suffolk Coastal Core Strategy considers the period up to 2027.

Time of Day

4.5 The evacuation plan needs to consider the time of day of the evacuation. For example, were the evacuation to take place during the day, the population to be evacuated from the DEPZ would consist of:

- traffic on the road network at the time of the evacuation;
- Daytime population (Census definition is people aged 16 to 74 who live and work in the area (or do not work) and people aged 16 to 74 who live outside the area and work inside the area);
- People aged over 74 (100% assumed to remain within the DEPZ during the day);
- School pupils;
- Children aged 0-4 not yet at school (100% assumed to remain within the DEPZ during the day); and
- Transient population staying in the camp sites/caravan parks (a worst case assumption that they remain within the DEPZ during the day).

4.6 However, were the evacuation to take place at night the population to be evacuated from the DEPZ would consist of:

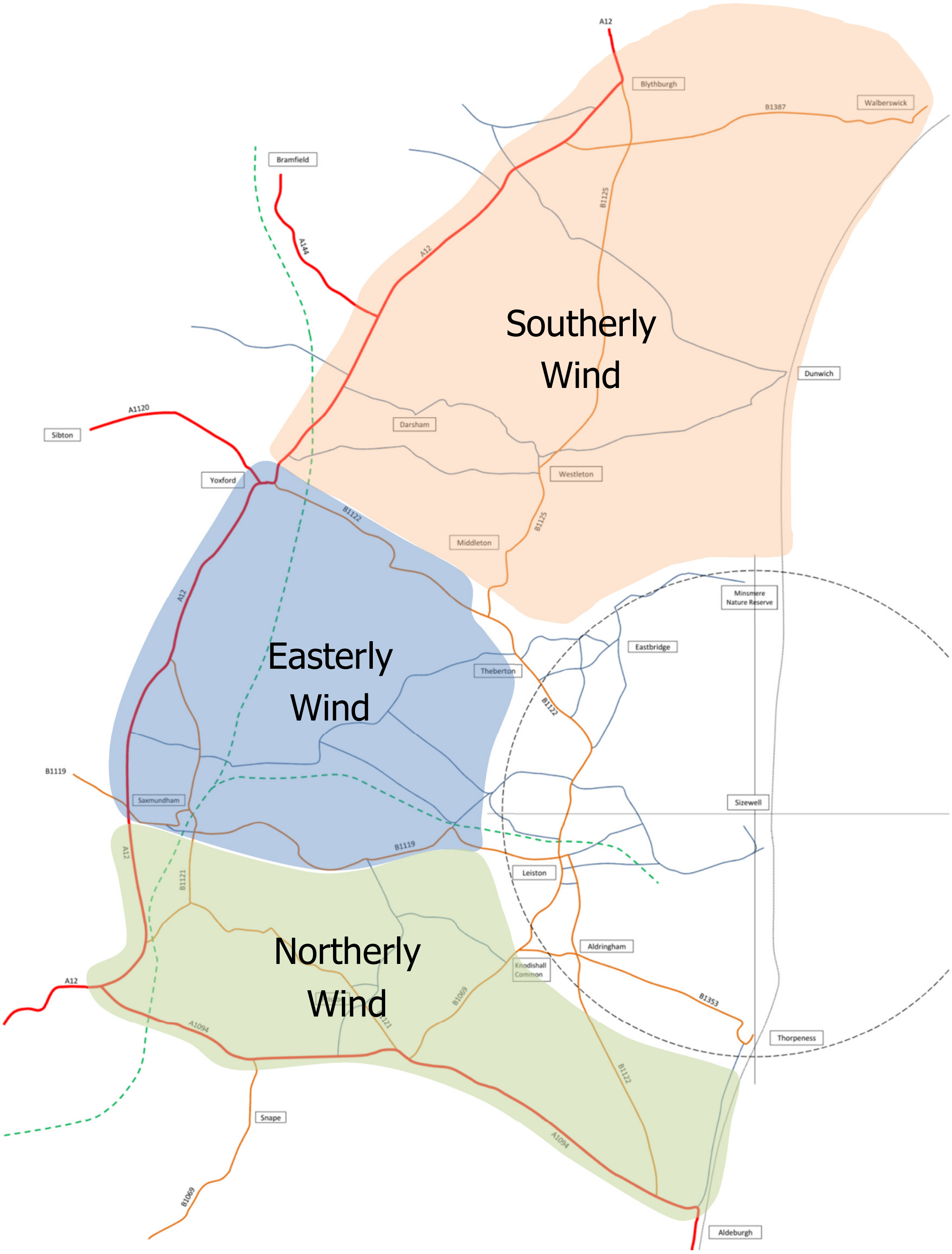
- traffic on the road network at the time of the evacuation;
- Resident population at their home (a worst case assumption of 100%);
- People working a night shift (i.e. at Sizewell nuclear power stations); and
- Transient population staying in the camp sites/caravan parks.

4.7 This report therefore considers the evacuation plan for a week day (09:00-10:00) and a week night (21:00-22:00).

Wind Direction

4.8 In the event of an incident at Sizewell, depending on wind direction, a contaminated cloud may preclude the use of certain routes. As such the wind direction has been included as a variable within the evacuation model. Wind direction is reported by the direction from which the wind originates. If the wind direction is westerly (i.e. blowing from the west towards the east) the contaminated cloud will head to sea and all routes will remain available for evacuation. If the wind is heading in any other direction then some routes would not be able to be used. In order to simulate this, the link and node capacities have been set to zero in the affected area. **Figure 4.2** below illustrates the wind direction areas that have been assumed for the model (i.e. the 'Southerly Wind' area illustrates the road network that has been assumed to be precluded from being used if there was a southerly wind heading north towards Lowestoft).

Figure 4.2: Wind Direction Assumptions



Population

4.9 The population to be evacuated from each 'source node' has been sub-divided into the following population sub groups:

- Existing Population within DEPZ (i.e. those people currently living, working or staying within the DEPZ prior to any future development considerations);
- Consented development;
- Aldeburgh Road development;
- Valley Road development; and
- Remaining Strategic Housing Land Availability Assessment (SHLAA) developments.

4.10 The existing population has been split into the following sub-categories:

- Non-vulnerable population: people who will not require support to evacuate; and
- Vulnerable population: people/institutions that will require support to evacuate (i.e. schools, campsites/caravan parks, nursing homes, care homes and sheltered housing).

4.11 The assumptions made to estimate the number of people in each of the above sub-groups are summarised in **Section 6** of this report.

Vehicle Occupancy

4.12 Data on the average car occupancy in an evacuation is not readily available and therefore an assumption has been made. The model has been set so that the car occupancy of the self-evacuated population is assumed to be an average of 2 people per car. This can be changed in the model if information becomes available. An assumption of 2 people per car has been used as it is higher than the national car occupancy average of 1.6 (National Travel Survey 2010) yet sufficiently low to provide a robust assessment.

4.13 The model has been set so that the average vehicle occupancy for the vulnerable population is 20 people per vehicle. This can also be changed in the model if evidence becomes available. A value of 20 has been used as it is considered that the vulnerable population will be evacuated from the DEPZ in larger vehicles such as buses/coaches.

Population Electing to Remain at Home

4.14 The project brief assumed that 10% of the population would elect to remain in their home even if they were advised to evacuate. The 'Variables' section of the model therefore includes a variable for the percentage of the population electing to remain at home. This has been set at 10% in the model to be consistent with the project brief but can be altered by the model user.

Proportion of Background Traffic to Evacuate

4.15 The traffic data provided by SCC has been analysed and the traffic on the road network within the DEPZ has been estimated for the assessment hours (i.e. 09:00-10:00 and 21:00-22:00). The traffic on the DEPZ road network in these hours is how much traffic flows on the road links over the entire hour. However, it is considered that at point an incident is declared, the 'background' traffic within the DEPZ and surrounding area will become aware of the incident and either avoid entering the DEPZ or evacuate the DEPZ. Therefore, the background traffic to be evacuated from the DEPZ will not be the whole hour of traffic provided in the traffic surveys.

4.16 The model includes a variable whereby the percentage of background traffic to be evacuated from the DEPZ can been altered. It has been set at 50% to provide a robust assessment.

Model Scenarios

4.17 **Figure 4.3** below provides an extract from the 'Variables' section of the Evacuation Model and summarises the scenarios that have been assessed.

4.18 The values within **Figure 4.3** correspond to the values in each variable in **Figure 4.1**. For example, Scenario 1 tests the following variables:

- 'Day time' as this is given a value of '1' in **Figure 4.1**;
- Wind direction 'North' as this is given a value of '1' in **Figure 4.1**;
- No flooding as this is given the value of '0' in **Figure 4.1**; and
- The existing vulnerable population, existing self-evacuation population and the consented development population.

Figure 4.3 Scenarios within the Evacuation Model

Modelling Scenarios											
Scenario Ref	Year	Time of Day	Wind Direction	Flooding	Population						
					Existing Vulnerable	Existing Self Evac	Consented	Aldeburgh Rd	Valley Rd	SHLAA	Sizewell C
1	2013	1	1	0	0	1	1	0	0	0	0
2	2013	1	1	0	0	1	1	1	1	0	0
3	2013	2	1	0	0	1	1	0	0	0	0
4	2013	2	1	0	0	1	1	1	1	0	0
5	2013	1	2	0	0	1	1	0	0	0	0
6	2013	1	2	0	0	1	1	1	1	0	0
7	2013	2	2	0	0	1	1	0	0	0	0
8	2013	2	2	0	0	1	1	1	1	0	0
9	2013	1	3	0	0	1	1	0	0	0	0
10	2013	1	3	0	0	1	1	1	1	0	0
11	2013	2	3	0	0	1	1	0	0	0	0
12	2013	2	3	0	0	1	1	1	1	0	0
13	2013	1	4	0	0	1	1	0	0	0	0
14	2013	1	4	0	0	1	1	1	1	0	0
15	2013	2	4	0	0	1	1	0	0	0	0
16	2013	2	4	0	0	1	1	1	1	0	0
17	2027	1	1	0	0	1	1	1	1	1	0
18	2027	1	1	0	0	1	1	1	1	1	1
19	2027	2	1	0	0	1	1	1	1	1	0
20	2027	2	1	0	0	1	1	1	1	1	1
21	2027	1	2	0	0	1	1	1	1	1	0
22	2027	1	2	0	0	1	1	1	1	1	1
23	2027	2	2	0	0	1	1	1	1	1	0
24	2027	2	2	0	0	1	1	1	1	1	1
25	2027	1	3	0	0	1	1	1	1	1	0
26	2027	1	3	0	0	1	1	1	1	1	1
27	2027	2	3	0	0	1	1	1	1	1	0
28	2027	2	3	0	0	1	1	1	1	1	1
29	2027	1	4	0	0	1	1	1	1	1	0
30	2027	1	4	0	0	1	1	1	1	1	1
31	2027	2	4	0	0	1	1	1	1	1	0
32	2027	2	4	0	0	1	1	1	1	1	1
33	2013	1	1	0	1	0	0	0	0	0	0
34	2013	1	2	0	1	0	0	0	0	0	0
35	2013	1	3	0	1	0	0	0	0	0	0
36	2013	1	4	0	1	0	0	0	0	0	0
37	2013	2	1	0	1	0	0	0	0	0	0
38	2013	2	2	0	1	0	0	0	0	0	0
39	2013	2	3	0	1	0	0	0	0	0	0
40	2013	2	4	0	1	0	0	0	0	0	0

5 HIGHWAY NETWORK CHARACTERISTICS

5.1 The critical elements for determining the effectiveness of the road network to cope with an evacuation are the level of service/capacity of each of the road links and junctions (i.e. an estimate of the vehicular flow at which the link or junction would be 'congested') and the journey times through the study area. This section summarises how the highway network characteristics have been calculated for input into the Evacuation Model.

Highway Network

5.2 The DEPZ is 4km, as the crow flies, from the centre of the Sizewell B nuclear power station. The population within the DEPZ is considered to be evacuated at the point that it reaches the A12. From the A12 traffic can travel north and south away from the area. The highway network that is included within the evacuation model is illustrated in **Figure 5.1** and includes the DEPZ and the highway links between the DEPZ and the A12.

5.3 There are three types of nodes within the Sizewell modelled area:

- **Source node:** the population that is to be evacuated from the DEPZ has been split into Census output areas and the centre of each output area has been taken to be a 'source node' as shown on **Figure 2.1**;
- **Network node:** the 49 junctions (N1 to N49) within the road network between the source and destination nodes (i.e. junctions between Sizewell nuclear power station and the A12); and
- **Destination node:** the 11 junctions (D1 to D11) on the A12 that the evacuees need to reach in order to be considered evacuated/to have reached safety.

5.4 Within the model the source nodes are 'loaded' onto the nearest network node in order for the population within the source node to be evacuated.

Link Capacity

5.5 The 'level of service' or capacity of each road link within the study area for the 'day' and 'night' assessment hours has been estimated using guidance set out in the Design Manual for Roads and Bridges (DMRB). DMRB Volume 5, Section 1, Part 3 (TA 46/97) provides guidance on 'Traffic Flow Ranges for Use in the Assessment of New Rural Roads'.

5.6 Annex D of the guidance describes the Congestion Reference Flow (CRF), which is an estimate of the total Annual Average Daily Traffic (AADT) flow at which the carriageway is likely to be 'congested' in the peak periods. Part of the formula for CRF includes the calculation of capacity, which is taken to be the maximum sustainable hourly lane throughput.

Capacity = A – (B * Pk%H)

Where:

- PK%H is the percentage of 'Heavy Vehicles' in the peak hour (i.e. OGV1, OGV2 and PSVs); and
- A and B are parameters dependant on road standard. For single carriageway roads such as those within the study highway network A is 1380 and B is 15.

5.7 Within the guidance a single carriageway rural road is taken to be 7.3m wide. However, the roads within the study area are narrower than this and therefore the link capacity has been reduced based on the carriageway width of each road link in the network. For each link in the network the ratio of carriageway width to the standard 7.3m width has been calculated and multiplied by 1,380, the standard value of 'A' in the DMRB capacity formula.

5.8 For example, Lovers Lane between King George's Avenue and Valley Road is 6m wide and so in order to calculate the capacity of the northbound link (i.e. Link N34 to N33) the following calculation has been applied:

Link Capacity N34-N33 = (1380 * (6.0/7.3))- (15 *1.7%) = 1109 vehicles per hour

5.9 It has therefore been estimated that the capacity of the northbound Lovers Lane link is 1,109 vehicles per hour. This methodology has been applied to all links on the highway network and a summary of the link capacities is provided in **Appendix B**.

Node Capacity

5.10 In order to determine the maximum vehicular capacity of each of the nodes or junctions in the highway network individual junction models have been built using the industry standard assessment tools of PICADY for priority junctions and LINSIG for signalised junctions. Traffic has been loaded onto the junctions to determine when they reach their design capacity (i.e.

85% for priority junctions and 90% for signalised junctions). At this point the amount of traffic that has been loaded onto each arm is summed to provide the maximum capacity per hour of the junction. A summary of the maximum junction capacity (vehicles per hour) is provided in **Appendix B**.

Journey Times

5.11 The journey time for each road link has been estimated based on ITIS journey time data. ITIS has developed journey time data for the Great Britain road network using GPS technology in 'probe' vehicles. The data collection unit fitted in the probe vehicles supplies real time and historic information on each vehicle's speed and position at any given time. The data is aggregated to determine the average speed for a given stretch of road. A summary of the journey time for each road link is provided in **Appendix B**.

6 POPULATION DEMAND ESTIMATES

6.1 The DEPZ has been sub-divided into Census output areas as illustrated in **Figure 2.1**. This section provides a summary of the approach used and assumptions made to estimate the population to be evacuated from each of the Census output areas within the DEPZ. The Project Brief estimated that there would be 6,228 people within the DEPZ to be evacuated. The analysis in this section enables this to be validated or updated.

Population Sub-Groups

6.2 The population to be evacuated from each 'source node' within the DEPZ has been sub-divided into the following population sub groups:

- Existing Population within DEPZ (existing self-evacuation population and vulnerable population);
- Consented development;
- Aldeburgh Road development;
- Valley Road development;
- Remaining Strategic Housing Land Availability Assessment (SHLAA) developments; and
- Sizewell C peak construction.

6.3 The population for the above sub-groups has been calculated for both the 'day' and 'night' assessment scenarios.

6.4 **Table 6.1** summarises the development that has been included within each of the assessment years. It should be noted that the model can be varied to test each of the developments included in the table in isolation.

Table 6.1: Population included within each Assessment Year

Year	Population	Details
2013	Existing population living/working/staying within the DEPZ	Based on Census data
	Unimplemented consented development	25 dwellings as of 1st April 2013
	Resolution to grant permission	119 dwellings at Aldeburgh Road
		25 dwellings at Valley Road
2027	Strategic Housing Land Availability Assessment	70 units (potential) at St Margarets Crescent
		45 units (potential) Waterloo Avenue
		12-15 units on caravan park off King Georges Avenue
		3-4 units off Lovers Lane
	Sizewell C peak construction	See below

6.5 EDF Energy is proposing to develop a nuclear power station at Sizewell referred to as 'Sizewell C'. The peak construction year for the proposed Sizewell C nuclear power station is not yet known by EDF Energy but the Stage 1 Environmental Report (paragraph 2.4.5) states that it will take 7-9 years to construct, following the site preparation works. Figure 3.2.1 of the report shows that the construction peaks approximately 2 thirds through the main construction period (i.e. 4.5 – 6 years). Based on Figure 3.2.1 of the report it has been estimated that the site preparation works is approximately a third of the duration of the main construction period (i.e. 2-3 years). Therefore, as a worst case scenario, the peak construction will occur 9 years from commencement of the site preparation works. Providing a robust allowance for planning, it has been estimated that the peak construction would be around 2025. For the purposes of the evacuation model, the peak construction at Sizewell C has been assumed to occur in 2027, the period for the Suffolk Coastal Core Strategy.

6.6 The Project Brief does not require the analysis of the potential impact of Sizewell C on the evacuation plan but does require the Suffolk Joint Emergency Planning Unit to be able to use the assessment tool to consider the impact of the development on evacuation in the future. The model has been designed so that potential developments, such as Sizewell C, can be added.

2013 Day Population

6.7 This section summarises how the population to be evacuated from the DEPZ during a weekday (1000-1100) has been derived.

Existing Self-Evacuation Population

6.8 2001 Census data for the output areas has been used to derive the daytime population within the DEPZ. The definition of the daytime population is people aged 16 to 74 who live and work in the area (or do not work) and people aged 16 to 74 who live outside the area and work inside the area.

6.9 The percentage of each output area that falls within the DEPZ has been estimated and multiplied by the daytime population of the output area. The population of 0-4 year olds within each output area has then been added to the daytime population as it has been assumed, as a worst case, that 100% of these people will remain within the area and at home.

Existing Vulnerable Population

Schools

6.10 **Table 6.2** provides the details of the schools within the DEPZ. The staff will be evacuated alongside the pupils as part of the vulnerable population. The 143 staff have been included within the existing daytime population as well as the vulnerable population in order to provide a robust assessment.

Table 6.2 Schools within the DEPZ

Name	Address	Number of People to Evacuate		
		Pupils	Staff	Total
Leiston Primary School	King George's Ave, Leiston, IP16 4JQ	350	23	373
Leiston Middle School	Waterloo Ave, Leiston, IP16 4HF	430	39	469
Alde Valley High School	Seaward Ave, Leiston, IP16 4BG	605	56	661
Summerhill School	Leiston, IP16 4HY	90	25	115
Total		**1,475**	**143**	**1,618**

Camping and Caravan Parks

6.11 Camp sites and caravan parks form part of the vulnerable population as people staying on them do not have the facility of a substantial building for shelter. They will need to be evacuated from the DEPZ as soon as possible after the incident happens. **Table 6.3** provides the details of the camp sites/caravan parks located within the DEPZ.

Table 6.3 Camp sites/Caravan parks within the DEPZ

Name	Address	Pitches	Number of People
Cakes and Ale Park	Abbey Lane, Theberton, IP16 4TE	75	150
Beach View Holiday Park	Sizewell Common, Leiston, IP16 4TU	60	120
Total			**270**

Care and Nursing Homes

6.12 **Table 6.4** provides details of the care homes within the DEPZ.

Table 6.4 Care and Nursing Homes within the DEPZ

Type	Name	Address	Number of People
Care Home	Leiston Old Abbey	Leiston, IP16 4RF	40
Care Home	Smyth House	106 High St, Leiston, IP16 4BZ	15
Care Home	Daneway House	Haylings Rd, Leiston, IP16 4DY	9
Nursing Home	Aldringham Court	Aldbeburgh Rd, Aldringham, IP16 4QF	34
Total			**98**

Sheltered Housing

6.13 **Table 6.5** provides details of the care homes within the DEPZ.

Table 6.5 Sheltered Houses within the DEPZ

Address	Number of Units	Number of People
Paxton Chadwick Close, Leiston, IP16	36 bungalows	72
Charles Adams Close, Leiston, IP16 4LP	42 bungalows	84
Total		**156**

Summary of Vulnerable Population

6.14 **Table 6.6** summarises the vulnerable population within the DEPZ. It makes worst case assumptions about the number of people to be evacuated during the day and night scenarios.

Table 6.6 Summary of Existing Vulnerable Population within the DEPZ

Type of Vulnerable Institution	Day time Number of People
Schools	1,618
Camping and Caravan Parks	270
Care Homes	64
Nursing Homes	34
Sheltered Housing	156
Total	**2,142**

Consented Development

As of 1st April 2013 there were 25 residential units of unimplemented consented development within the DEPZ. In order to estimate the population, the 25 units have been multiplied by the average household occupancy of the Leiston ward (Census 2011), which is 2.7 people per household. The percentage of Leiston ward residents that remain within the ward during the day has been calculated to be 73%, based on 2001 Census data (NB. this data had not been released for the 2011 Census at the time of undertaking the analysis). The resultant daytime population for the consented developments is 49 people (i.e. 25 houses x 2.7 people per house x 73%)

Aldburgh Road and Valley Road

6.15 There is a resolution to granted planning permission for two residential developments in Leiston; Aldburgh Road for 119 units and Valley Road for 25 units. In order to estimate the daytime population for these two developments the same approach has been used as for the consented development. The resultant daytime population for the consented developments is 284 people (i.e. 144 houses x 2.7 people per house x 73%).

Summary of 2013 Day Population

6.16 **Table 6.7** below summarises the population to be evacuated from the DEPZ in the day for the 2013 assessment year.

Table 6.7 2013 'Day' Population to be Evacuated from the DEPZ

Sub-Group	Daytime Population
Existing Self-Evacuation	4,428
Existing Vulnerable	2,142
Consented	49
Aldburgh Road and Valley Road	284
Total	**6,903**

6.17 A more detailed table showing the population estimates for each Census output area is provided in **Appendix C**.

2013 Night Population

6.18 This section summarises how the population to be evacuated from the DEPZ during a week night (2100-2200) has been derived.

Existing Self-Evacuation Population

6.19 2011 Census data for the output areas has been used to derive the resident population at night within the DEPZ. The percentage of each output area that falls within the DEPZ has been estimated and multiplied by the resident population of the output area. As a worst case it has been assumed that 100% of the resident population within the DEPZ will be at their home at the time of the Off-site Nuclear Emergency.

6.20 In addition to the resident population, the night shift workers at the existing Sizewell nuclear power station have been included (i.e. 25 people normal operation). It is recognised that the Operator will be responsible for the evacuation of these workers but they will evacuated using the same road network and therefore need to be considered.

Existing Vulnerable Population

6.21 **Table 6.8** summarises the vulnerable population within the DEPZ that has been considered for the night assessment. It makes a worst case assumption that 100% of the vulnerable population (except the schools) will be within the DEPZ at the time of the Off-site Nuclear Emergency.

Table 6.8 Summary of Existing Vulnerable Population within the DEPZ

Type of Vulnerable Institution	Night time Number of People
Schools	0
Camping and Caravan Parks	270
Care Homes	64
Nursing Homes	34
Sheltered Housing	156
Total	**524**

Consented Development

In order to estimate the night time population, the 25 consented residential units have been multiplied by the average household occupancy of the Leiston ward (Census 2011), which is 2.7 people per household. This assumes a worst case that 100% of the population would be at their home at the time of the Off-site Nuclear Emergency. The resultant night time population for the consented developments is 68 people.

Aldburgh Road and Valley Road

6.22 In order to estimate the night time population for the Aldburgh Road and Valley Road developments the same approach has been used as for the consented development. The resultant daytime population for the consented developments is 389 people (i.e. 144 houses x 2.7 people per house).

Summary of 2013 Night Population

6.23 **Table 6.9** below summarises the population to be evacuated from the DEPZ in the night for the 2013 assessment year.

Table 6.9 2013 'Night' Population to be Evacuated from the DEPZ

Sub-Group	Night time Population
Existing Self-Evacuation	5,847
Existing Vulnerable	524
Consented	68
Aldburgh Road and Valley Road	389
Total	**6,828**

6.24 A more detailed table showing the population estimates for each Census output area is provided in **Appendix C**.

2027 Day Population

Strategic Housing Land Availability Assessment

6.25 The following sites have been identified in the Suffolk Coastal District Council's Strategic Housing Land Availability Assessment (SHLAA) as having the potential to be developed in the period up to 2027:

- 70 residential units at St Margaret's Crescent;
- 45 units at Waterloo Avenue;
- Up to 15 residential units on the redundant caravan park off King George's Avenue; and
- Up to 4 residential units off Lovers Lane.

6.26 The Aldburgh Road and Valley Road developments are also included in the SHLAA but given that there is a resolution to grant planning permission they have been included in the 2013 assessment.

6.27 In order to estimate the daytime population for the remaining SHLAA developments the same approach has been used as for the 2013 consented development. The resultant daytime population for the SHLAA developments is 264 people (i.e. 134 houses x 2.7 people per house x 73%).

2027 Night Population

Strategic Housing Land Availability Assessment

6.28 In order to estimate the night time population for the 134 residential units set out above for the SHLAA the same approach has been used as for the 2013 consented development. The resultant night time population for the SHLAA developments is 362 people (i.e. 134 houses x 2.7 people per house).

Population Validation

6.29 The Project Brief makes the following population assumptions:

- 75% (4,671 people) will self-evacuate after public declaration of an Off-site Nuclear Emergency
- 15% (934 people) will require support by the emergency services to evacuate; and
- 10% (623 people) will elect to remain in their homes.

6.30 **Table 6.10** below provides a comparison of the 2013 Project Brief population estimates with the 2013 estimates derived in this section of the report.

Table 6.10 Comparison of 2013 Evacuation Populations

Sub-Group	Project Brief Population	2013 Day time Population	Night time Population
Self-Evacuate Population	4,671	4,071	5,621
Vulnerable Population	934	2,142	524
Remain at Home	634	690	683
Total	**6,228**	**6,903**	**6,828**

6.31 The day and night time estimates have been taken forward and used in the evacuation model in **Section 7**.

7 MODELLING

7.1 The evacuation model has been run for the various scenarios and this section provides a summary of the results. A model user guide is included in **Appendix D**.

Model Validation

7.2 Before the Sizewell model was built the example used within the research papers for CCRP was reproduced to ensure that the evacuation model provided the same answers.

7.3 In order to validate the model the total population within the source nodes was reduced to 40 vehicles to see how long it would take them to be evacuated. Under these conditions the vehicles should reach the destination nodes within a similar time as in normal conditions on the highway network. The model shows that with this low level of vehicles on the network they would all be evacuated in 13 minutes, which is similar to the travel time under non-evacuation conditions.

Model Results

7.4 This section summarises the model results for the various assessment scenarios.

2013 Existing + Consented Development

7.5 The 2013 existing self-evacuation population and consented development population have been tested for day and night time evacuation and the wind direction cutting off part of the highway network to determine the evacuation routes and timeline under varying conditions. **Table 7.1** below summarises the results.

Table7.1 2013 Existing + Consented Development Evacuation Time

Scenario Ref	Time of Day	Number of Vehicles	Wind Direction	Evacuation Time (minutes)
1	Day	5,179	North	93.0
5			East	93.0
9			South	137.0
13			West	154.0
3	Night	3,720	North	62.0
7			East	62.0
11			South	92.0
15			West	101.0

7.6 **Table 7.1** shows that if the Off-site Nuclear Emergency occurred during the day it would take approximately 50% longer to evacuate the DEPZ to safety than if the incident occurred at night.

7.7 In addition **Table 7.1** shows that if a contaminated cloud precluded the use of the roads to the north the evacuation time would not be increased as the routes to the north are not used in the optimum evacuation routing. If a contamination cloud precluded the use of the roads to the south then it would take approximately 50% longer to evacuate the DEPZ than if the road network were unaffected. Worst of all if a contamination cloud precluded the use of the roads to the west then it would take 60-70% longer than if the road network were unaffected.

2013 Existing + Consented + Resolution to Grant

7.8 The 2013 existing self-evacuation population and consented development population have been tested for day and night time evacuation and the wind direction cutting off part of the highway network to determine the evacuation routes and timeline under varying conditions. **Table 7.2** below summarises the results.

Table7.2 2013 Existing + Consented + Resolution to Grant Permission Evacuation Time

Scenario Ref	Time of Day	Number of Vehicles	Wind Direction	Evacuation Time (minutes)
2	Day	5,306	North	95.0
6			East	95.0
10			South	140.0
14			West	157.0
4	Night	3,895	North	65.0
8			East	65.0
12			South	96.0
16			West	105.0

7.9 **Table 7.2** shows that the two developments that have a resolution to grant planning permission (i.e. Aldburgh Road and Valley Road) would add 2-4 minutes to the evacuation time compared with the 2013 Base + Consented scenario, which equates to 2-4 % increase in evacuation time.

Future Year Growth Implications

7.10 The model has been designed to test any growth scenario. As an example of the potential impact future growth could have on the evacuation time the SHLAA developments (over and above the Aldburgh Road and Valley Road) have been added to the population within the DEPZ. This scenario has been tested for day and night time evacuation and the wind direction cutting off part of the highway network to determine the evacuation routes and timeline under varying conditions. **Table 7.3** below summarises the results.

Table7.3 2027 Base + SHLAA Evacuation Time

Scenario Ref	Time of Day	Number of Vehicles	Wind Direction	Evacuation Time (minutes)
17	Day	5,425	North	97.0
21			East	97.0
25			South	143.0
29			West	161.0
19	Night	4,058	North	68.0
23			East	68.0
27			South	100.0
31			West	109.0

7.11 **Table 7.3** shows that the SHLAA developments would add 2-4 minutes to the evacuation time over and above the 2013 Base + Consented + Resolution to Grant scenario. As with the other development scenarios, the greatest impact of a contamination cloud would be if it precluded the use of the roads to the south.

Vulnerable People Evacuation

7.12 It is assumed that vulnerable groups of people will be evacuated by the emergency services supported by local authorities. The transient population (i.e. camping /caravan parks) has been included within the self-evacuation population as they will be evacuated at the same time, albeit they may require some direction/support from the emergency services (assumed 2 people per vehicle and no account made for emergency service vehicles entering the DEPZ).

7.13 It has been assumed that the remaining vulnerable population (i.e. schools, care homes, nursing homes and sheltered housing) would be evacuated separately by the emergency services in vehicles with an average occupancy of 20 people and that by the time the vulnerable population is evacuated, no background traffic will be on the highway network (set at 0% in the model).

7.14 The 2013 vulnerable population (less transient population) have been tested for day and night time evacuation and the wind direction cutting off part of the highway network to determine the evacuation routes and timeline under varying conditions. The 'remain at home' variable in the model for each of the scenarios is set to 0 as well as the background traffic. **Table 7.4** below summarises the results.

Table7.4 2013 Vulnerable Population Evacuation Time

Scenario Ref	Time of Day	Number of Vehicles	Wind Direction	Evacuation Time (minutes)
33	Day	94	North	12.0
34			East	12.0
35			South	12.0
36			West	15.0
37	Night	13	North	11.0
38			East	11.0
39			South	11.0
40			West	12.0

7.15 **Table 7.4** shows that the vulnerable population could be evacuated in 11-15 minutes at any time of the day if they are evacuated after the self-evacuation population. This does not take into the account the time it takes for the vehicles to be despatched, travel to the vulnerable population and load the vehicles.

7.16 The analysis shows that the wind direction does not impact on the evacuation time, with the exception of a westerly wind. This would increase the evacuation time of the vulnerable population by 1-3 minutes, depending on the time of day.

7.17 In addition, assuming 20 people per vehicle, it would need 13 vehicles to evacuate the vulnerable population in the night and 94 vehicles to evacuate the population in the day.

8 EVACUATION PLAN

8.1 This section summarises the evacuation routes for the worst case scenarios for 2013. The difference between 2013 base + consented development and 2013 base + consented + resolution to grant is minimal and therefore the evacuation plan focusses on the 'with resolution to grant' scenarios. In addition, given that the day time evacuation is the worst case this is focussed on in this section. Therefore this section provides the evacuation routes for the following scenarios:

- 2013 Day Time with Westerly Wind (Scenario 6);
- 2013 Day Time with Southerly Wind (Scenario 2);
- 2013 Day Time with Easterly Wind (Scenario 14); and
- 2013 Day Time with Northerly Wind (Scenario 10).

Evacuation Maps

8.2 The output from the evacuation model is a series of maps for each scenario in time increments. The nodes (junctions) and links are coloured from green being low to red being high as follows:

- Junctions: demand as a percentage of maximum capacity per unit time;
- Links: flow along the link as a percentage of maximum capacity per unit time.

8.3 The thickness of the links also indicates the capacity of the link (i.e. the thicker the links the more traffic it can carry).

2013 Day Time with Westerly Wind (Scenario 6)

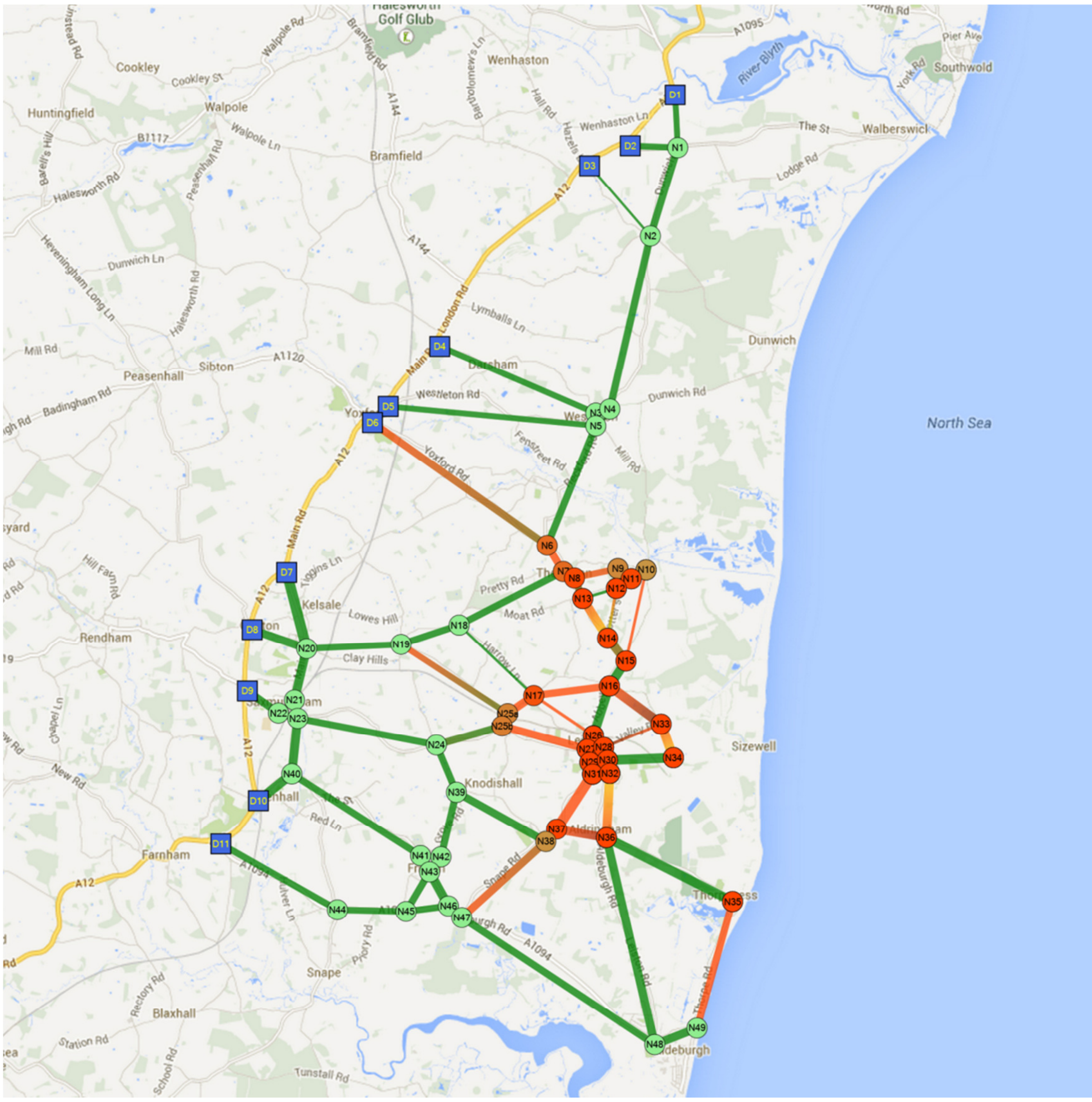
8.4 If the evacuation occurred during the day and when the wind is westerly (i.e. wind blowing from the west towards the east or sea), and therefore all routes are available for use, the optimum evacuation routes are via the following junctions onto the A12:

- D6: A12/B1122 (Yoxford Road);
- D7: A12/B1121 (Main Road), Dorleys Corner;
- D9: A12/Rendham Road;
- D10: A12/B1121 (Main Road), Benhall; and
- D11: A12/A1094

8.5 Node D6 evacuates the greatest amount of traffic (1,302 vehicles) followed by D9 (1,119 vehicles) and D7 and D11 (1,061 and 1,056 respectively). Node D10 evacuates the least amount of traffic (769 vehicles).

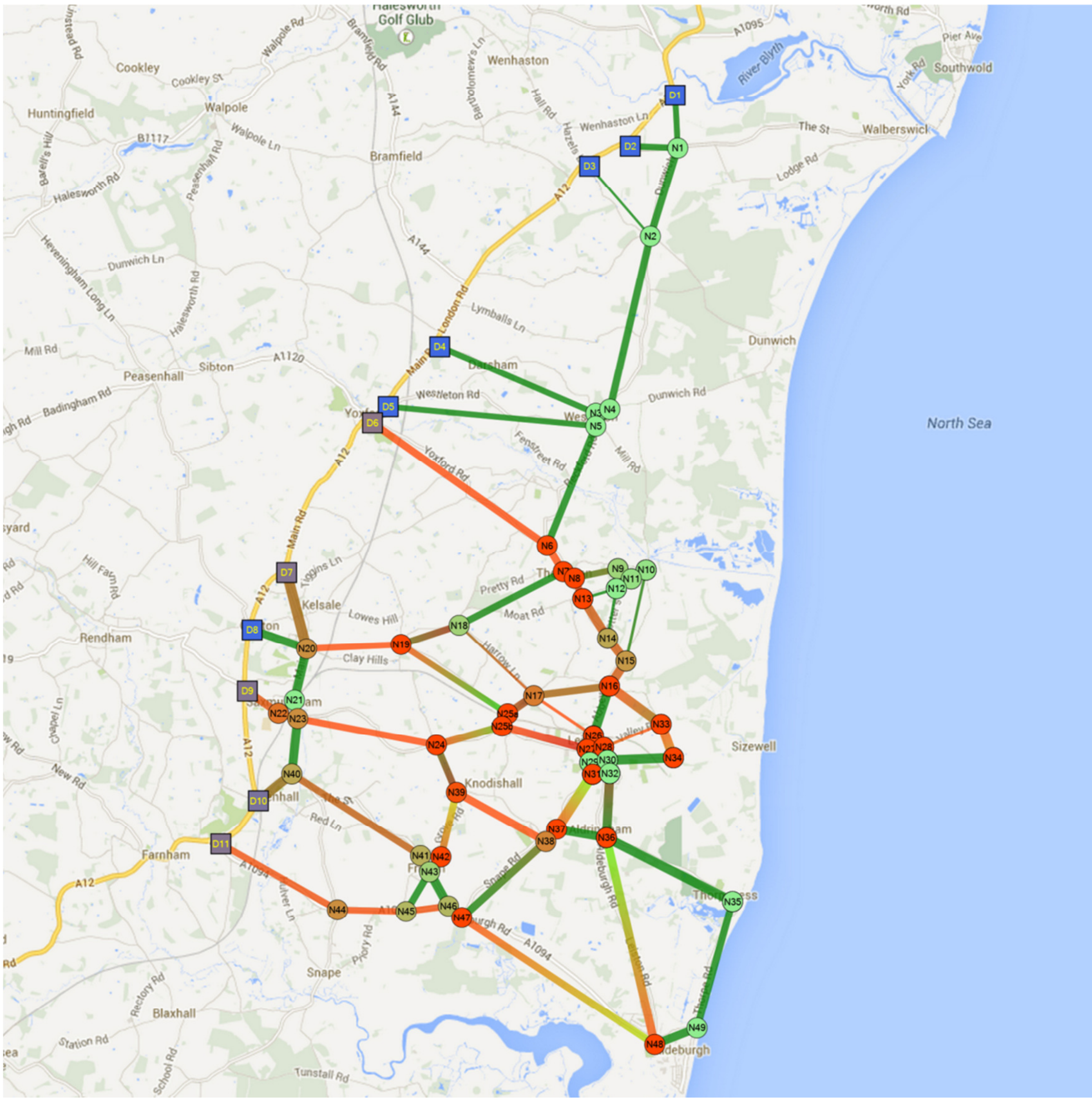
8.6 The first destination junction to be utilised is D6 (A12/B1122 (Yoxford Road)) as illustrated in **Figure 8.1** below for the early phase of the evacuation.

Figure 8.1 2013 Day Time with Westerly Wind (Scenario 6) Early Evacuation Phase



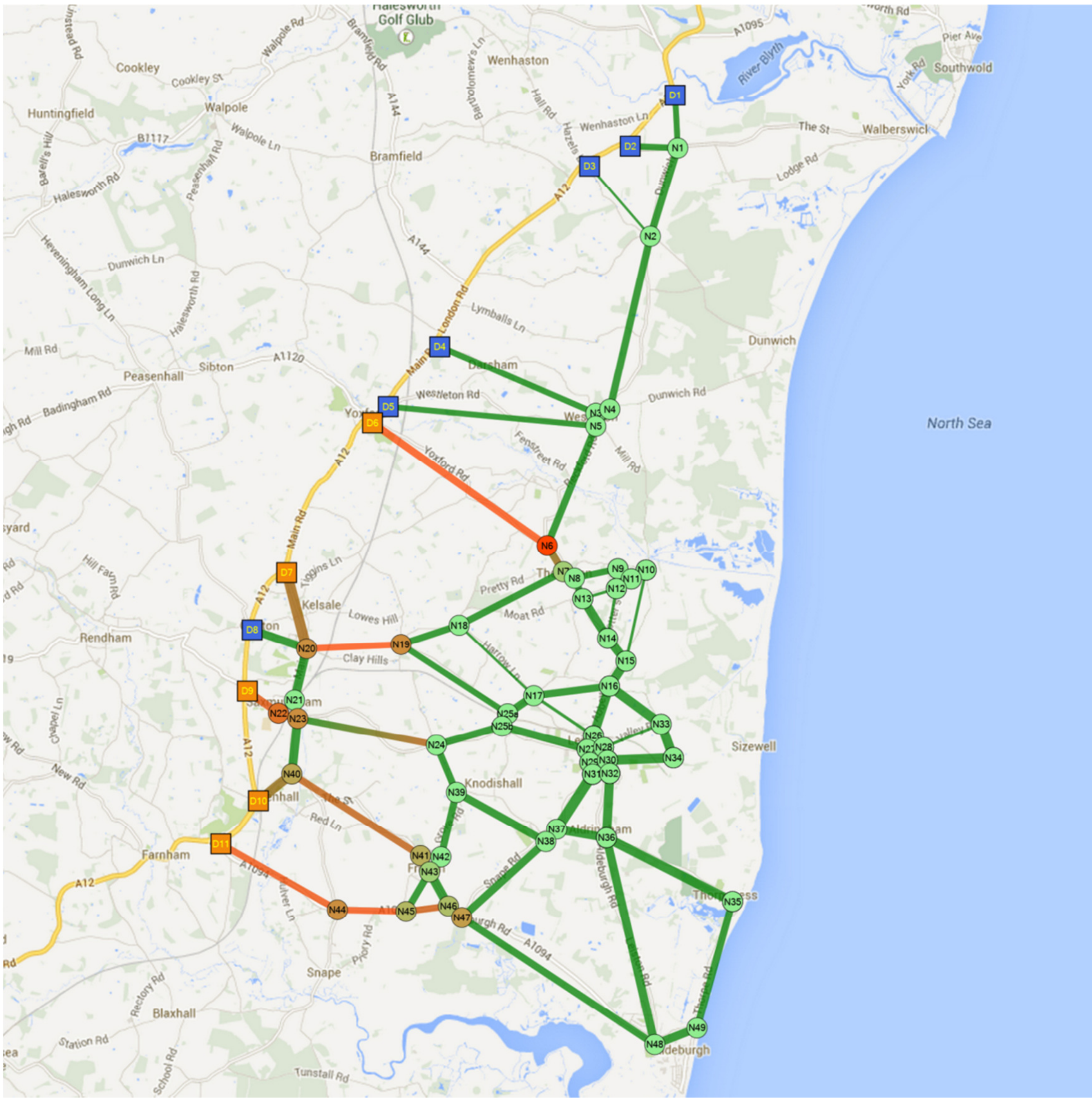
8.7 The next preferred destination node is D11 (A12/A094) followed by D7 (A12/B1121 (Main Road), Dorleys Corner), D9 (A12/Rendham Road) and D10 (A12/B1121 (Main Road), Benhall) as illustrated in **Figure 8.2** below for the mid evacuation phase.

Figure 8.2 2013 Day Time with Westerly Wind (Scenario 6) Mid Evacuation Phase



8.8 **Figure 8.3** below illustrates the final phase of the evacuation for Scenario 6. The last destination nodes to continue to be used are the junctions around Saxmundham (i.e. D7, D9 and D10).

Figure 8.3 2013 Day Time with Westerly Wind (Scenario 6) Final Evacuation Phase



2013 Day Time with Southerly Wind (Scenario 2)

8.9 If the evacuation occurred during the day and when the wind is southerly (i.e. wind is blowing from the south towards the north or Lowestoft), and therefore all routes to the north would not be able to be used, the optimum evacuation routes would remain the same as for the westerly wind scenario set out above. Closing the routes to the north does not impact on either the evacuation time or the route choice.

8.10 **Figures 8.4** to **8.6** below illustrate the early, mid and final phases of the evacuation of the DEPZ if the routes to the north are not able to be used.

Figure 8.4 2013 Day Time with Southerly Wind (Scenario 2) Early Evacuation Phase

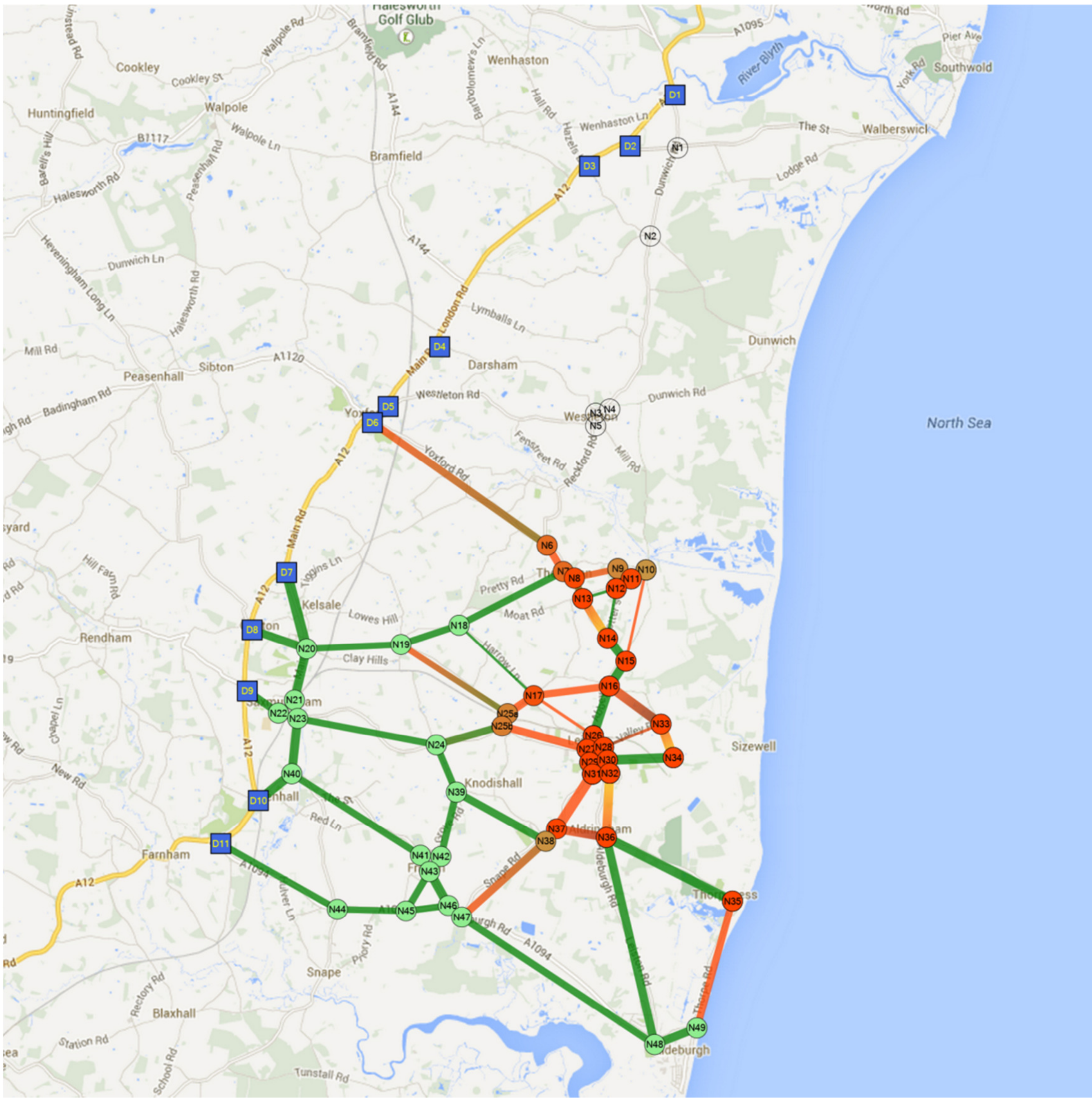


Figure 8.5 2013 Day Time with Southerly Wind (Scenario 2) Mid Evacuation Phase

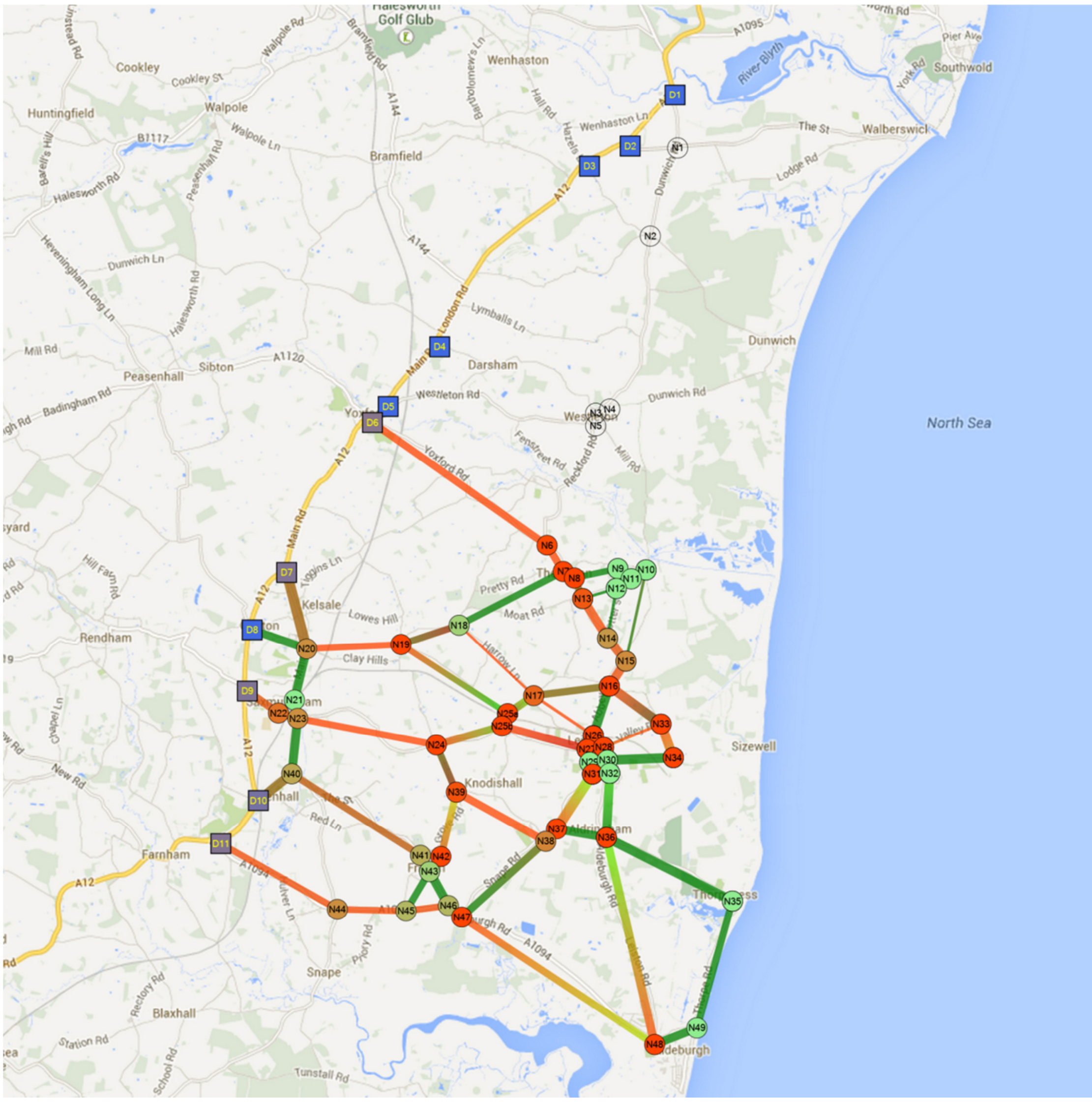
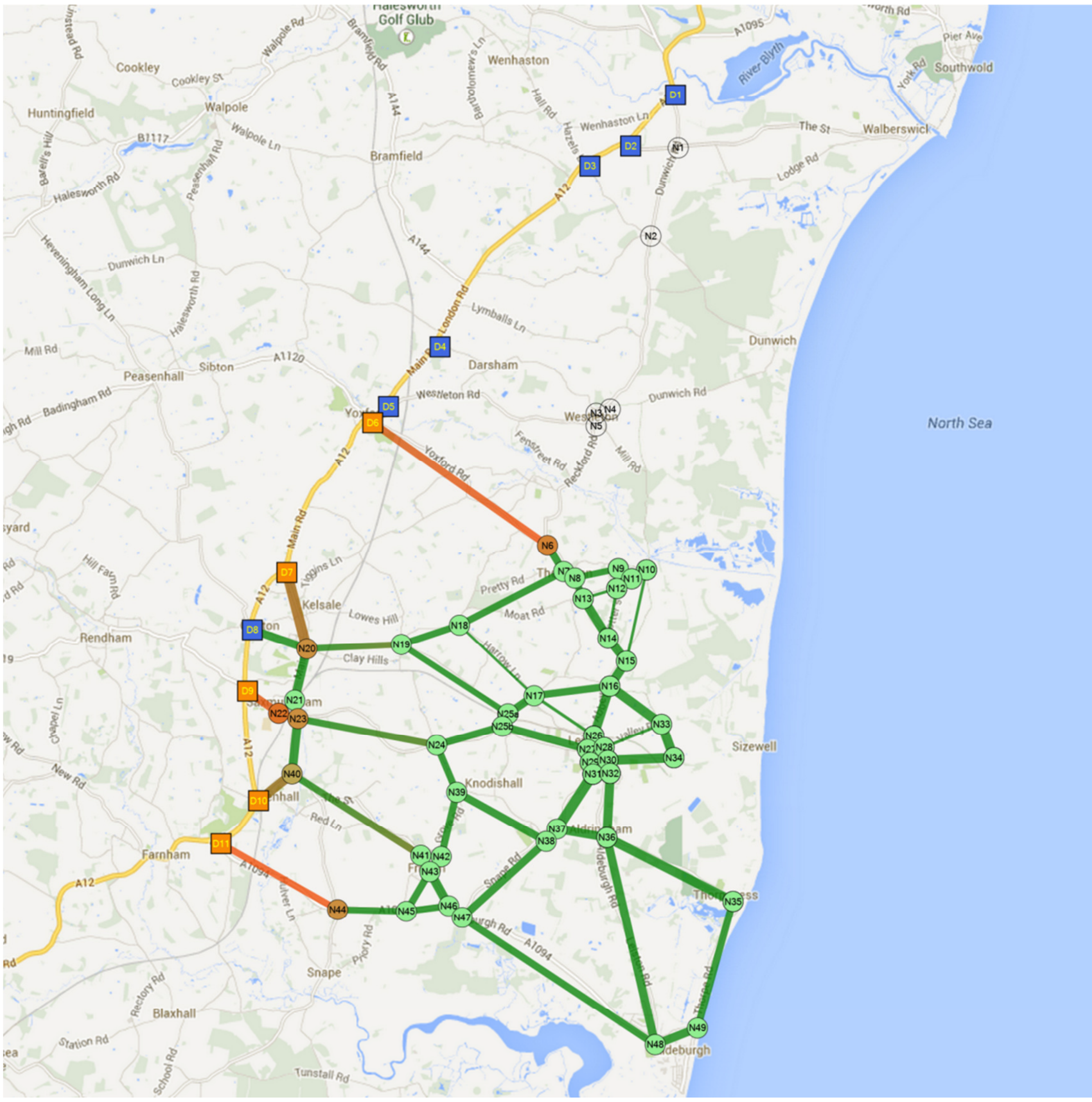


Figure 8.6 2013 Day Time with Southerly Wind (Scenario 2) Final Evacuation Phase



2013 Day Time with Easterly Wind (Scenario 14)

8.14 If the evacuation occurred during the day and when the wind is easterly (i.e. wind blowing from the east towards the west or Saxmundham), and therefore all routes to the west would not be able to be used, the optimum evacuation routes are via the following junctions onto the A12:

- D4: A12/The St;
- D5: A12/Westleton Road;
- D10: A12/B1121 (Main Road), Benhall; and
- D11: A12/A1094.

8.15 **Figures 8.7** to **8.9** below illustrate the early, mid and final phases of the evacuation of the DEPZ if the routes to the west are not able to be used.

Figure 8.7 2013 Day Time with Easterly Wind (Scenario 14) Early Evacuation Phase

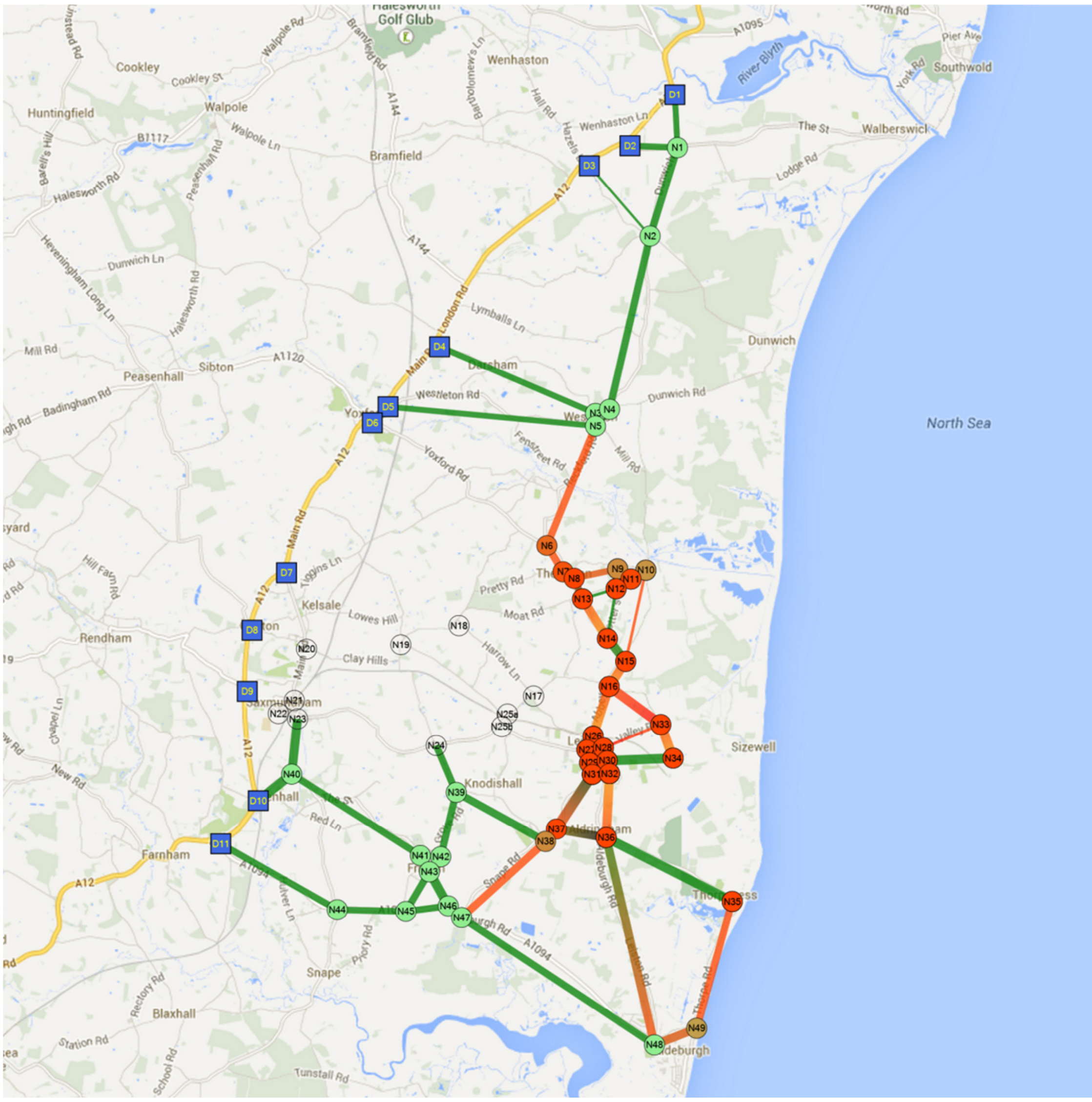


Figure 8.8 2013 Day Time with Easterly Wind (Scenario 14) Mid Evacuation Phase

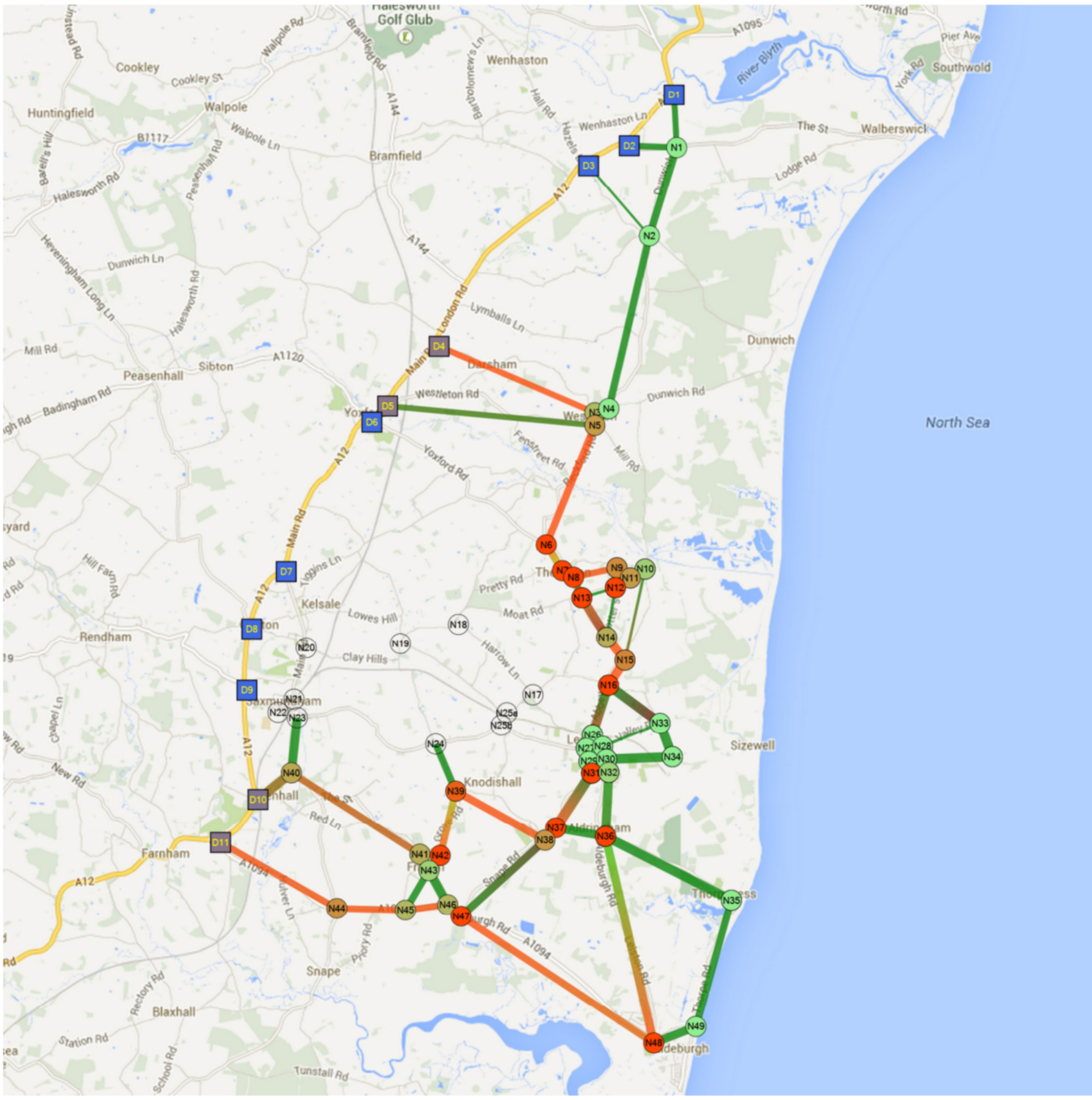
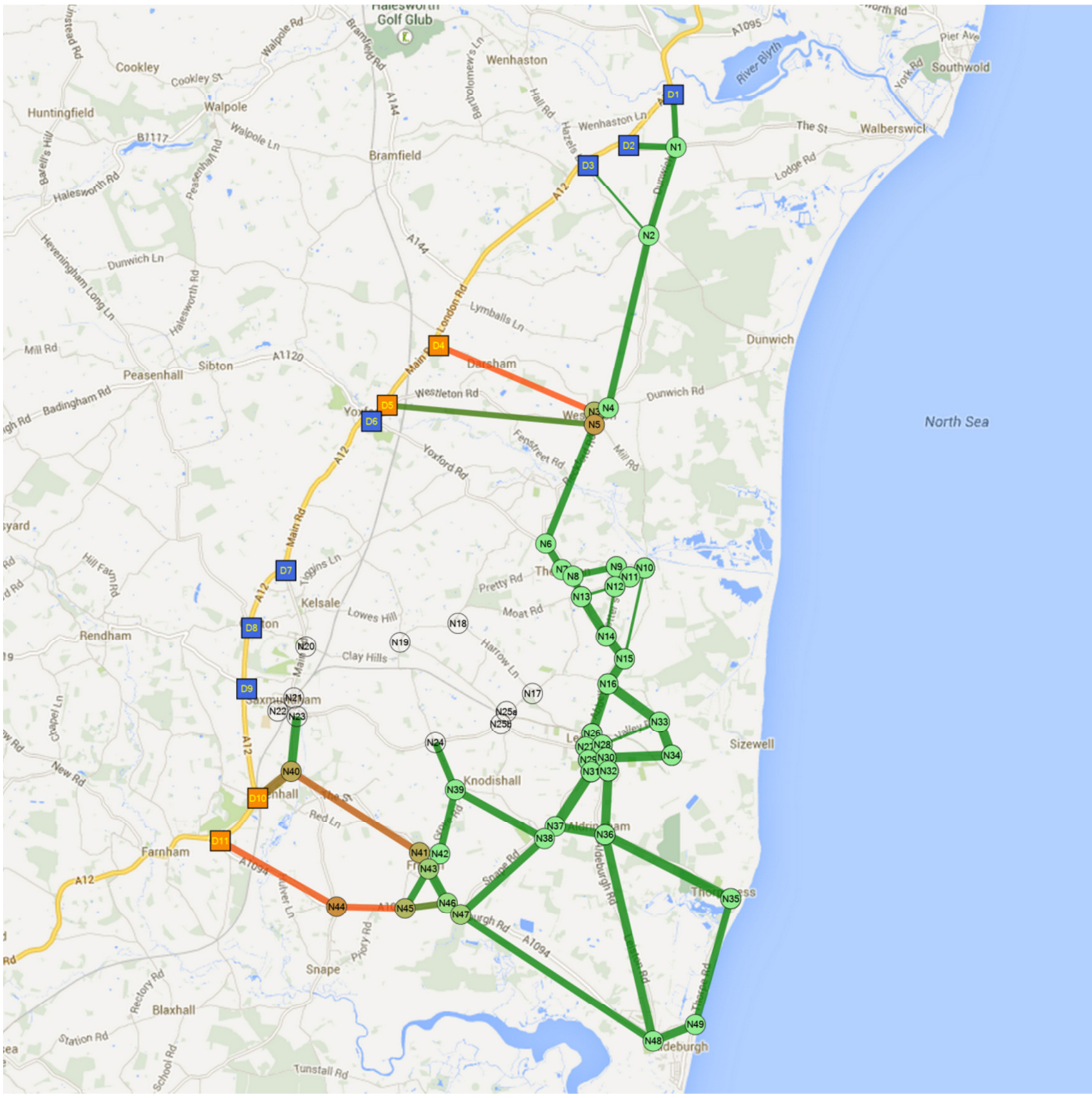


Figure 8.9 2013 Day Time with Easterly Wind (Scenario 14) Final Evacuation Phase



2013 Day Time with Northerly Wind (Scenario 10)

8.16 If the evacuation occurred during the day and when the wind is northerly (i.e. the wind is blowing from the north towards the south or Felixstowe), and therefore all routes to the south would not be able to be used, the optimum evacuation routes are via the following junctions onto the A12:

- D6: A12/B1122 (Yoxford Road);
- D7: A12/B1121 (Main Road), Dorleys Corner;
- D9: A12/Rendham Road;

8.17 Node D6 evacuates the greatest amount of traffic (1,949 vehicles) followed by D9 (1,721 vehicles) and D7 (1,636).

8.18 **Figures 8.10** to **8.12** below illustrate the early, mid and final phases of the evacuation of the DEPZ if the routes to the south are not able to be used.

Figure 8.10 2013 Day Time with Northerly Wind (Scenario 10) Early Evacuation Phase

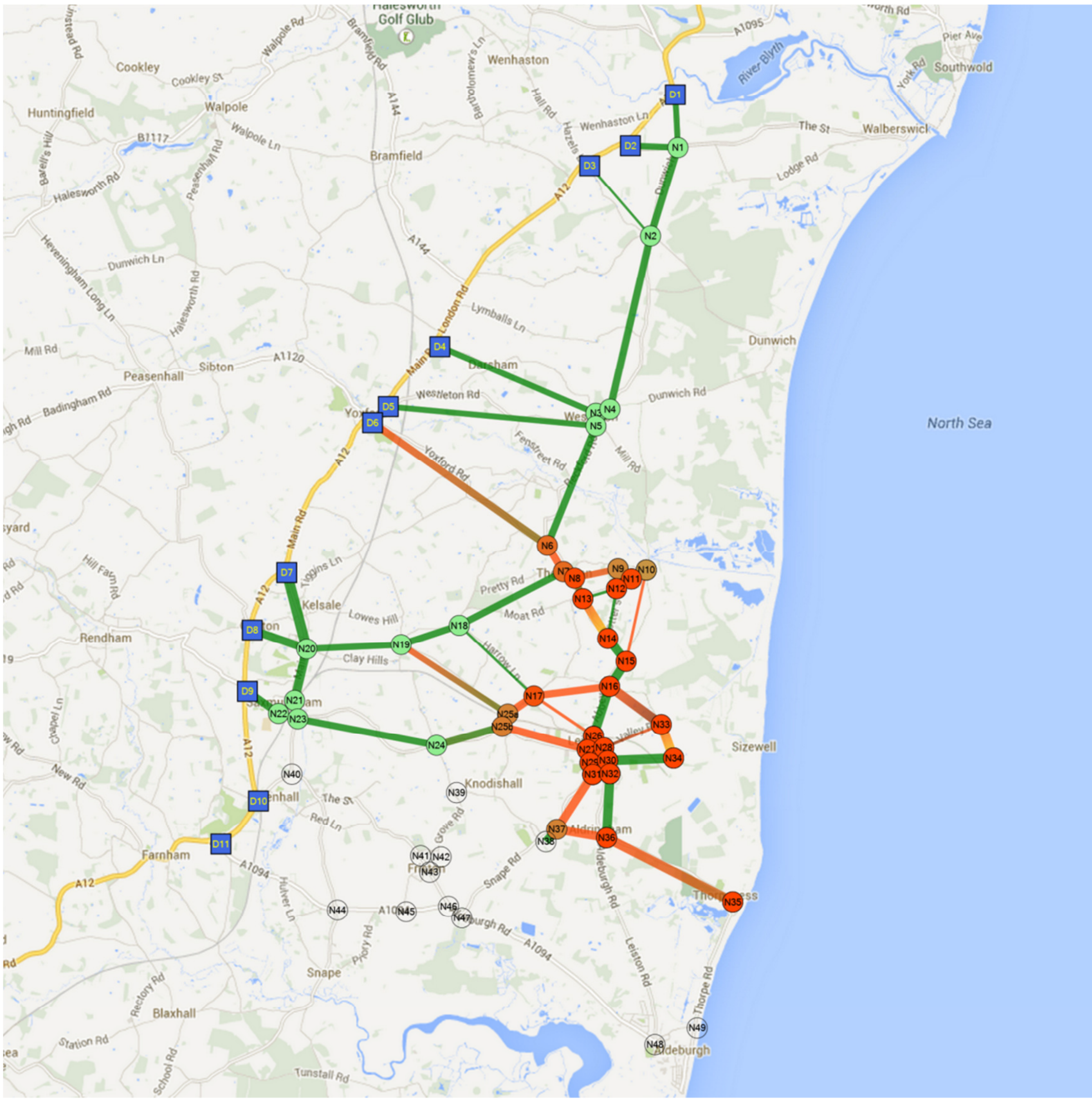


Figure 8.11 2013 Day Time with Northerly Wind (Scenario 10) Mid Evacuation Phase

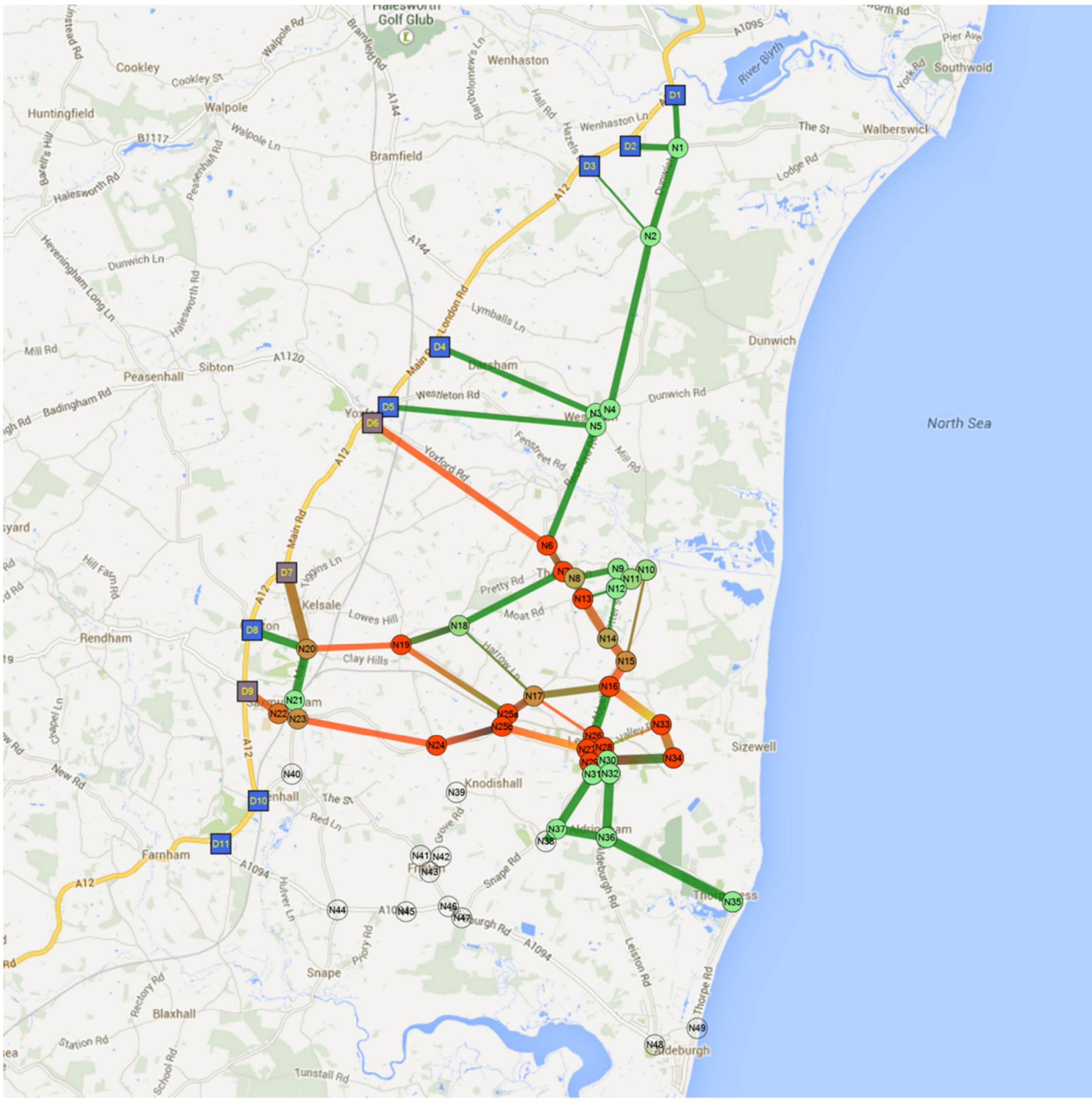
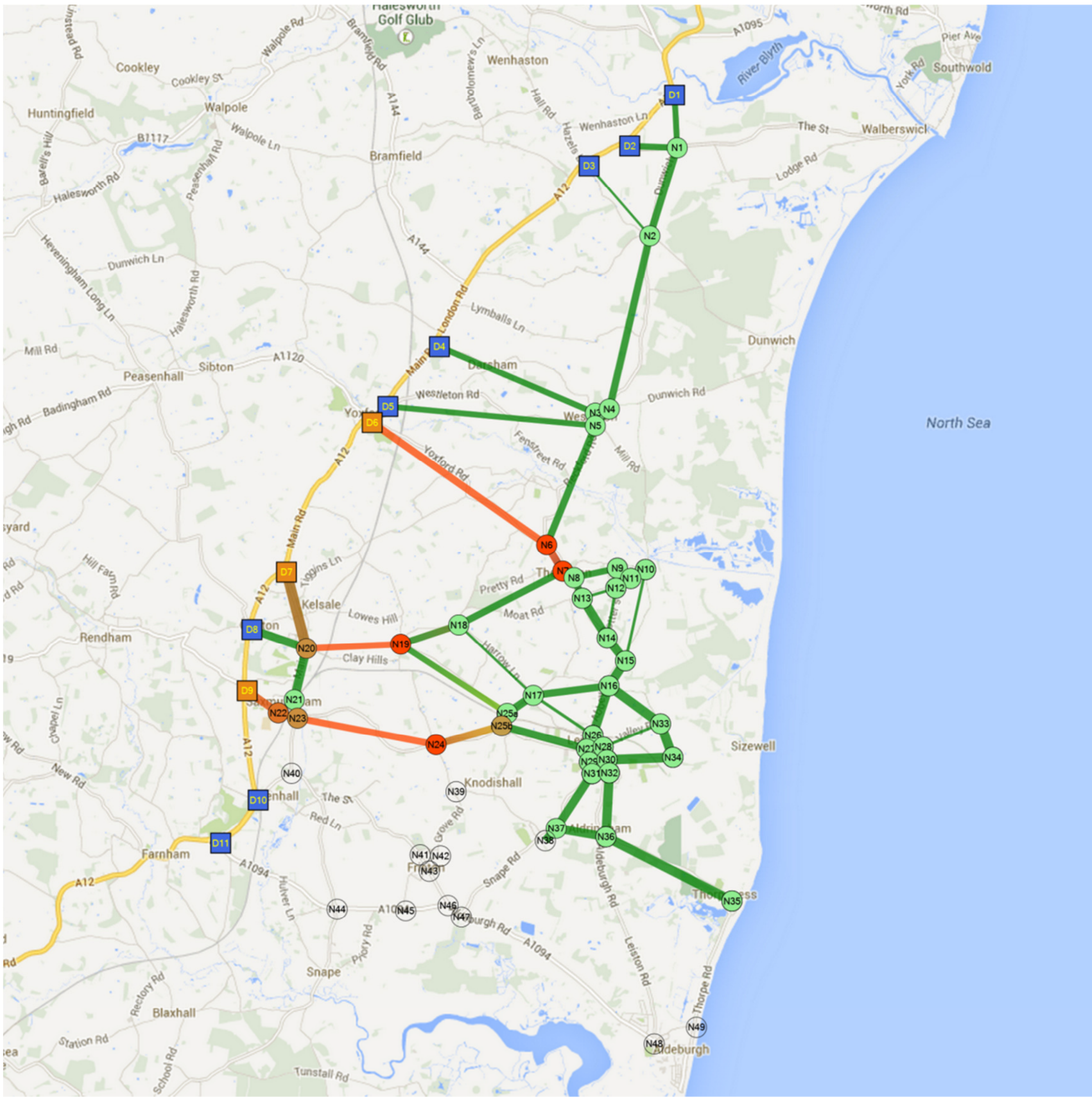


Figure 8.12 2013 Day Time with Northerly Wind (Scenario 10) Final Evacuation Phase



2013 Vulnerable Evacuation

8.19 The model shows that the optimum evacuation routes for the vulnerable population are via the following junctions onto the A12:

- D6: A12/B1122 (Yoxford Road);
- D7: A12/B1121 (Main Road), Dorleys Corner;
- D9: A12/Rendham Road; and
- D11: A12/A1094.

8.20 Node D6 evacuates the greatest amount of the vulnerable population (55 vehicles) followed by D7 (25 vehicles) and D11 and D9 (12 and 1 vehicle respectively).

9 SUMMARY AND CONCLUSIONS

9.1 The aim of the technical work is to examine the road network in the vicinity of the existing Sizewell nuclear power stations and produce an evacuation plan in order to evacuate the affected population to safety in the event of an emergency scenario at Sizewell. In addition, the technical work considers the future growth in the area, based on growth forecasts up to 2027 provided by Suffolk Coastal District Council (SCDC). The technical work assesses the implications of future growth on an evacuation of the area and any potential constraints to growth.

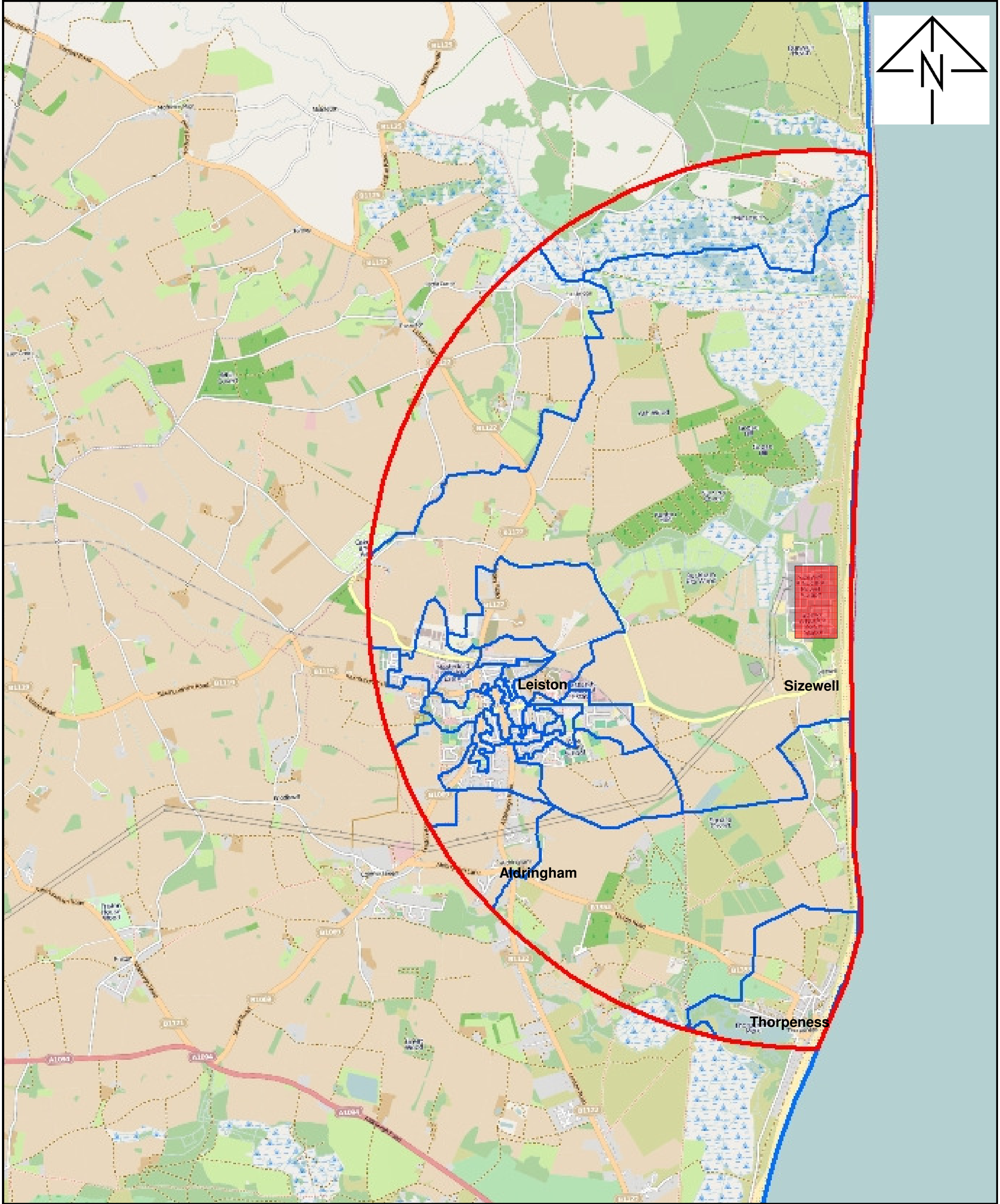
9.2 This technical work uses the heuristic algorithm 'Capacity Constrained Route Planner' (CCRP), to generate optimum evacuation routes while constraining them to road capacities. The CCRP algorithm has previously been used to create and evacuation plan for Monticello, Minnesota, USA, a BWE type nuclear reactor.

9.3 The evacuation model has been used to test a number of different variables to determine the optimum evacuation routes for each scenario and the evacuation time. The following conclusions can be made:

- If all of the roads were available to use under the 2013 Base +Consented Development scenario it would take around 93 minutes to evacuate the DEPZ in the day and around 62 minutes in the night (assuming that everyone evacuates on Time 0). Therefore it would take approximately 50% longer to evacuate the DEPZ to safety in the daytime than in the night.
- If a contaminated cloud precluded the use of the roads to the north the evacuation time would not be increased as the routes to the north are not used in the optimum evacuation routing. If a contamination cloud precluded the use of the roads to the south then it would take approximately 50% longer to evacuate the DEPZ than if the road network were unaffected. Worst of all if a contamination cloud precluded the use of the roads to the west then it would take 60-70% longer than if the road network were unaffected.
- The two developments with a resolution to grant permission (i.e. Valley Road and Aldburgh Road) would add 2-4 minutes to the evacuation time.
- The addition of the SHLAA developments, over and above Valley Road and Aldburgh Road, would add a further 2-4 minutes to the evacuation time.

- The vulnerable population could be evacuated in around 11-15 minutes at any time of the day, regardless of wind direction.
- The evacuation of the vulnerable population would require around 94 vehicles to evacuate the population in the day and 13 vehicles to evacuate the population at night, assuming a vehicle occupancy of 20 people per vehicle.

FIGURES



Census 2011 Output Areas

4Km Evacuation Zone

Census 2011 Output Area Boundary

Sizewell A & B Site

vectos
transport planning specialists
Network Building, 97 Tottenham Court Road, London W1T 4TP
Tel: 020 7580 7373 Email: london@vectos.co.uk www.vectos.co.uk

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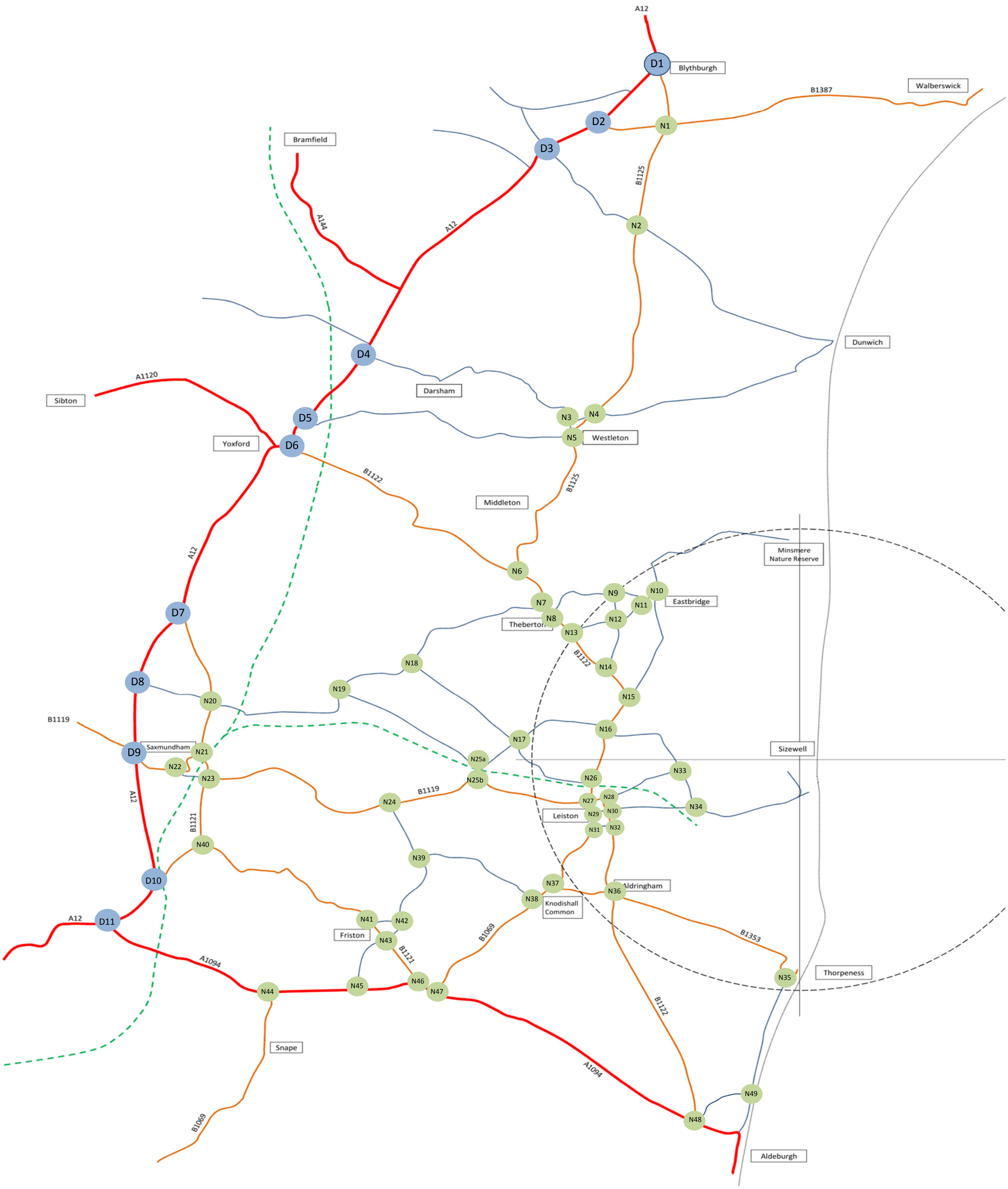

Evacuation Model Highway Network
Figure 5.1

Reference	Node Type	Location
D1	Destination Node	A12/Dunwich Rd
D2	Destination Node	A12/B1387 (The St)
D3	Destination Node	A12/Hazels Lane
D4	Destination Node	A12/The St
D5	Destination Node	A12/Westleton Rd
D6	Destination Node	A12/B1122 (Yoxford Rd)
D7	Destination Node	A12/B1121 (Main Rd), Dorleys Corner
D8	Destination Node	A12/Carlton Rd
D9	Destination Node	A12/Rendham Rd
D10	Destination Node	A12/B1121 (Main Rd), Benhall
D11	Destination Node	A12/A1094
S1	Source Node	
S2	Source Node	
S3	Source Node	
S4	Source Node	
S5	Source Node	
S6	Source Node	
S7	Source Node	
S8	Source Node	
S9	Source Node	
S10	Source Node	
S11	Source Node	
S12	Source Node	
S13	Source Node	
S14	Source Node	
S15	Source Node	
S16	Source Node	
S17	Source Node	
S18	Source Node	
S19	Source Node	
S20	Source Node	
S21	Source Node	
S22	Source Node	
S23	Source Node	
S24	Source Node	
N1	Network Node	B1387 The St/B1125 Dunwich Rd
N2	Network Node	B1125/Westleton Rd
N3	Network Node	Darsham Rd/The Hill
N4	Network Node	B1125/The Hill/Dunwich Rd
N5	Network Node	B1125/Yoxford Rd
N6	Network Node	B1125/B1122 Leiston Rd
N7	Network Node	B1122 Leiston Rd/Pretty Rd
N8	Network Node	B1122 Leiston Rd/Church Rd
N9	Network Node	Church Rd/Chapel Rd
N10	Network Node	Baker's Hill/Minsmere Nature Reserve Access
N11	Network Node	Chapel Rd/Baker's Hill
N12	Network Node	Baker's Hill/Onners Lane/Potter's St
N13	Network Node	B1122/Moat Rd
N14	Network Node	B1122/Potter's St
N15	Network Node	B1122/Minsmere Nature Reserve Access
N16	Network Node	B1122/Lover's Lane
N17	Network Node	Abbey Lane/Harrow Lane
N18	Network Node	Harrow Lane/Hawthorn Rd
N19	Network Node	Hawthorn Rd/Unnamed Rd (RAF Leiston)
N20	Network Node	B1121 Main Rd/Clay Hills
N21	Network Node	B1121 Main Rd/Fairfield Rd
N22	Network Node	B1119 Rendham Rd/Chantry Rd
N23	Network Node	B1121 High St/B1119 Mill Rd
N24	Network Node	B1119 Saxmundham Rd/Grove Rd
N25a	Network Node	B1119 Saxmundham Rd/Abbey Lane (north of railway)
N25b	Network Node	B1119 Saxmundham Rd/Abbey Lane (south of railway)
N26	Network Node	B1122 Abbey Rd/Westward Ho
N27	Network Node	B1069 Park Hill/B1119 Waterloo Ave
N28	Network Node	Main St/B1122 High St/Valley Rd
N29	Network Node	Park Hill/Victory Rd/Cross St
N30	Network Node	High St/Cross St/Sizewell Rd
N31	Network Node	Haylings Rd/Kings Rd
N32	Network Node	High St/Kings Rd
N33	Network Node	Lover's Lane/Valley Rd/Sandy Lane
N34	Network Node	Lover's Lane/King George's Ave
N35	Network Node	B1353 The Haven/Aldeburgh Rd
N36	Network Node	B1122 Aldeburgh Rd/B1353 Aldingham Lane
N37	Network Node	B1069 Leiston Rd/B1353 Aldringham Lane
N38	Network Node	B1069 Leiston Rd/School Rd (Mill Rd)
N39	Network Node	School Rd/Grove Rd
N40	Network Node	B1121 Main Rd/B1121 Church Hill
N41	Network Node	B1121 Saxmundham Rd/Church Rd
N42	Network Node	Church Rd/Grove Rd
N43	Network Node	B1121 Aldeburgh Rd/Grove Rd
N44	Network Node	A1094/B1069 Church Rd
N45	Network Node	A1094/Mill Rd
N46	Network Node	A1094/B1121 Aldeburgh Rd
N47	Network Node	A1094/B1069 Snape Rd
N48	Network Node	A1094/B1122 Leiston Rd
N49	Network Node	Church Farm Road/Thorpe Rd

APPENDIX A

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Capacity Constrained Routing Algorithms for Evacuation Planning: A Summary of Results, Qingsong Lu, Betsey George and Shashi Shekhar

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Capacity Constrained Routing Algorithms for Evacuation Planning: A Summary of Results*

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Abstract. Evacuation planning is critical for numerous important applications, e.g. disaster emergency management and homeland defense preparation. Efficient tools are needed to produce evacuation plans that identify routes and schedules to evacuate affected populations to safety in the event of natural disasters or terrorist attacks. The existing linear programming approach uses time-expanded networks to compute the optimal evacuation plan and requires a user-provided upper bound on evacuation time. It suffers from high computational cost and may not scale up to large transportation networks in urban scenarios. In this paper we present a heuristic algorithm, namely Capacity Constrained Route Planner(CCRP), which produces sub-optimal solution for the evacuation planning problem. CCRP models capacity as a time series and uses a capacity constrained routing approach to incorporate route capacity constraints. It addresses the limitations of linear programming approach by using only the original evacuation network and it does not require prior knowledge of evacuation time. Performance evaluation on various network configurations shows that the CCRP algorithm produces high quality solutions, and significantly reduces the computational cost compared to linear programming approach that produces optimal solutions. CCRP is also scalable to the number of evacuees and the size of the network.

Keywords: evacuation planning, routing and scheduling, transportation network.

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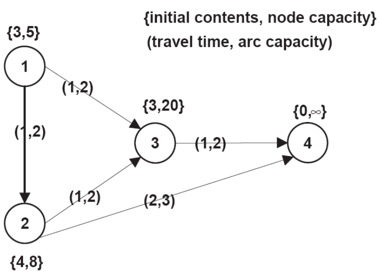
C. Bauzer Medeiros et al. (Eds.): SSTD 2005, LNCS 3633, pp. 291–307, 2005.

1 Introduction

Evacuation planning is critical for numerous important applications, e.g. disaster emergency management and homeland defense preparation. Traditional evacuation warning systems simply convey the threat descriptions and the need for evacuation to the affected population via mass media communication. Such systems do not consider capacity constraints of the transportation network and thus may lead to unanticipated effects on the evacuation process. For example, when Hurricane Andrew was approaching Florida in 1992, the lack of effective planning caused tremendous traffic congestions, general confusion and chaos [1]. Therefore, efficient tools are needed to produce evacuation plans that identify routes and schedules to evacuate affected populations to safety in the event of natural disasters or terrorist attacks [12,14,7,8].

The current methods of evacuation planning can be divided into two categories, namely traffic assignment-simulation approach and route-schedule planning approach. The traffic assignment-simulation approach uses traffic simulation tools, such as DYNASMART [27] and DynaMIT [5], to conduct stochastic simulation of traffic movements based on origin-destination traffic demands and uses queuing methods to account for road capacity constraints. However, it may take a long time to complete the simulation process for a large transportation network. The route-schedule planning approaches use network flow and routing algorithms to produce origin-destination routes and schedules of evacuees on each route. Many research works have been done to model the evacuation problem as a network flow problem [15,4] and to find the optimal solution using linear programming methods. Hamacher and Tjandra [17] gave an extensive literature review of the models and algorithms used in these linear programming methods. Based on the triple-optimization results by Jarvis and Ratliff [20], linear programming method for evacuation route planning works as follows. First, it models the evacuation network into a network graph, as shown by network G in Figure 1, and it requires the user to provide an estimated upper bound T of the evacuation egress time. Second, it converts evacuation network G to a time-expanded network, as shown by G_T in Figure 2, by duplicating the original evacuation network G for each discrete time unit $t = 0, 1, \ldots, T$. Then, it defines the evacuation problem as a minimum cost network flow problem [15,4] on the time-expanded network G_T. Finally, it feeds the expanded network G_T to minimum cost network flow solvers, such as NETFLO [21], to find the optimal solution. For example, EVACNET [9,16,22,23] is a computer program based on this approach which computes egress time for building evacuations. It uses NETFLO code to obtain the optimal solution. Hoppe and Tardos [18,19] gave a polynomial time bounded algorithm by using ellipsoid method of linear programming to find the optimal solution for the minimum cost flow problem. Theoretically, ellipsoid method has a polynomial bounded running time. However, it performs poorly in practice and has little value for real application [6].

Linear programming approach can produce optimal solutions for evacuation planning. It is useful for evacuation scenarios with moderate size networks, such as building evacuation. However, this approach has the following limita-



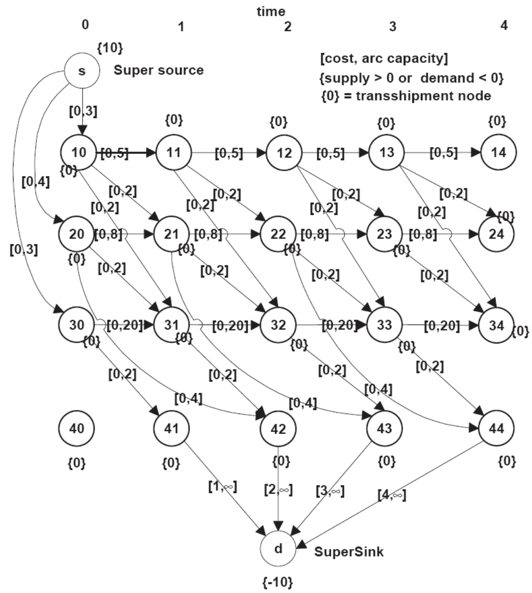


Fig. 1. Evacuation Network G, (source: [17])

Fig. 2. Time-expanded Network G_T, with T=4, (source: [17])

tions. First, it significantly increases the problem size because it requires time-expanded network G_T to produce a solution. As can been seen in Figures 1 and 2, if the original evacuation network G has n nodes and the time upper bound is T, the time-expanded network G_T will have at least $(T+1)n$ nodes. This approach may not be able to scale up to large size transportation networks in urban evacuation scenarios due to high computational run-time caused by the tremendously increased size of the time-expanded network. Second, linear programming approach requires the user to provide an upper bound T of the evacuation time in order to generate the time-expanded network. It is almost impossible to precisely estimate the evacuation time for an urban scenario where the number of evacuees is large and the transportation network is complex. An under-estimated time bound T will result in failure of finding a solution. In this case, the user will have to increase the value of T and re-run the algorithm until a solution can be reached. On the other hand, an over-estimated T will result in an over-expanded network G_T and hence lead to unnecessary storage and run-time.

Heuristic routing and scheduling algorithms can be used to find sub-optimal evacuation plan with reduced computational cost. It is useful for evacuation scenarios with large size networks and scenarios that do not require an optimal plan, but need to produce an efficient plan within a limited amount of time. However, old heuristic approaches only compute the shortest distance route from a source to the nearest destination without considering route capacity constraints. It cannot produce efficient plans when the number of evacuees is large and the evacuation network is complex. New heuristic approaches are needed to account for capacity constraints of the evacuation network. Lu, Huang and Shekhar [26] proposed prototypes of two heuristic capacity constrained routing algorithms, namely SRCCP and MRCCP, and tested its performance using small size building networks. SRCCP assigns only one route to each source node. It has very fast run-time but the solution quality is very poor and hence has little value for real application. MRCCP assigns multiple routes to each source node and produces high quality solution with much less run-time compared to that of linear programming approach. However, its scalability to large size networks is unsatisfactory because it has a computational cost of $O(p \cdot n^2 logn)$ (where n the is number of nodes and p is the number of evacuees). In this paper, we present an improved algorithm called Capacity Constrained Route Planner (CCRP). CCRP can reduce the run-time to $O(p \cdot nlogn)$ by conducting only one shortest path search in each iteration instead of the multiple searches used in MRCCP. We also present the analysis of its algebraic cost model and provide the results of performance evaluation using large size transportation networks.

In the CCRP algorithm, we model capacity as a time series because available capacity of each node and edge may vary during the evacuation. We use a generalized shortest path search algorithm to account for route capacity constraints. This algorithm can divide evacuees from each source into multiple groups and assign a route and time schedule to each group of evacuees based on an order that is prioritized by each group's destination arrival time. It then reserves route capacities for each group subject to the route capacity constraints. The quickest route available for one group is re-calculated in each iteration based on the available capacity of the network. Performance evaluation on various network configurations shows that the CCRP algorithm produces high quality solutions, and significantly reduces the computational cost compared to linear programming approach. CCRP is also scalable to the number of evacuees and the size of the network. A case study using a nuclear power plant evacuation scenario shows that this algorithm can be used to improve existing evacuation plans by reducing evacuation time.

We also explored the possibility of formulation of a new optimal algorithm using A* search[28,29]. It addresses the limitations of linear programming approach by using only the original evacuation network to find the optimal solution and it does not require the user to provide an upper bound of the evacuation time. Details of the A* search formulation and the proof of monotonicity and admissibility of this A* search algorithm are available in [25]. It is not included in this paper due to space constraints.

Outline: The rest of the paper is organized as follows. In Section 2, the problem formulation is provided and related concepts are illustrated by an example evacuation network. Section 3 describes the Capacity Constrained Route Planner (CCRP) algorithm and the algebraic cost model. In Section 4, we present the experimental design and performance evaluation. We summarize our work and discuss future directions in Section 5.

2 Problem Formulation

We formulate the evacuation planning problem as follows:

Given: A transportation network with non-negative integer capacity constraints on nodes and edges, non-negative integer travel time on edges, the total number of evacuees and their initial locations, and locations of evacuation destinations.

Output: An evacuation plan consisting of a set of origin-destination routes and a scheduling of evacuees on each route. The scheduling of evacuees on each route should observe the capacity constraints of the nodes and edges on this route.

Objective: (1) Minimize the evacuation egress time, which is the time elapsed from the start of the evacuation until the last evacuee reaches the evacuation destination. (2) Minimize the computational cost of producing the evacuation plan.

Constraint: (1) Edge travel time preserves FIFO (First-In First-Out) property. (2) Edge travel time reflects delays at intersections. (3) Limited amount of computer memory.

We illustrate the problem formulation and a solution with an example evacuation network, as shown in Figure 3. In this evacuation network, each node is shown by an ellipsis. Each node has two attributes: maximum node capacity and initial node occupancy. For example, at node N1, the maximum capacity is 50, which means this node can hold at most 50 evacuees at each time point, while the initial occupancy is 10, which means there are initially 10 evacuees at this node. In Figure 3, each edge, shown as an arrow, represents a link between two nodes. Each edge also has two attributes: maximum edge capacity and travel time. For example, at edge N4-N6, the maximum edge capacity is 5, which means at each time point, at most 5 evacuees can start to travel from node N4 to N6 through this link. The travel time of this edge is 4, which means it takes 4 time units to travel from node N4 to N6. This approach of modelling a evacuation scenario to a capacitated node-edge graph is similar to those presented in Hamacher [17], Kisko [23] and Chalmet [9].

As shown in Figure 3, suppose we initially have 10 evacuees at node N1, 5 at node N2, and 15 at node N8. The task is to compute an evacuation plan that evacuates the 30 evacuees to the two destinations (node N13 and N14) using the least amount of time.

Example 1 (An Evacuation Plan). Table 1 shows an example evacuation plan for the evacuation network in Figure 3. In this table, each row shows one group of evacuees moving together during the evacuation with a group ID, source node, number of evacuees in this group, the evacuation route with time schedule, and the destination time. The route is shown by a series of node number and the time schedule is shown by a start time associated with each node on the route. Take source node N8 for example; initially there are 15 evacuees at N8. They are divided into 3 groups: Group A with 6 people, Group B with 6 people and

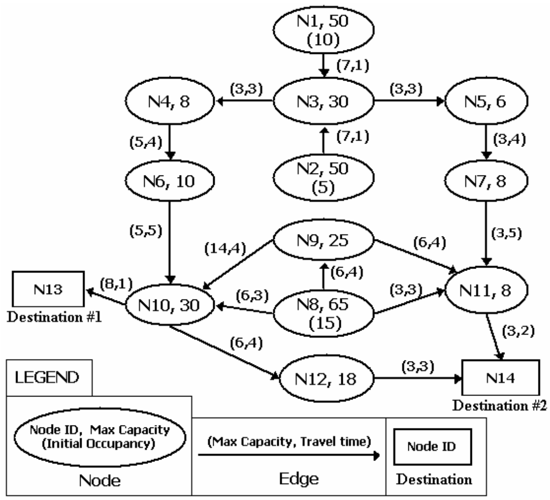


Fig. 3. Node-Edge Graph Model of Example Evacuation Network

Group C with 3 people. Group A starts from node N8 at time 0 to node N10, then starts from node N10 at time 3 to node N13, and reaches destination N13 at time 4. Group B follows the same route of group A, but has a different schedule due to capacity constraints of this route. This group starts from N8 at time 1 to N10, then starts from N10 at time 4 to N13, and reaches destination N13 at time 5. Group C takes a different route. It starts from N8 at time 0 to N11, then starts from N11 at time 3 to N14, and reaches destination N14 at time 5. The procedure is similar for other groups of evacuees from source node N1 and N2. The whole evacuation egress time is 16 time units since the last groups of people (Group H and I) reach destination at time 16. This evacuation plan is an optimal plan for the evacuation scenario shown in Figure 3.

In our problem formulation, we allow time dependent node capacity and edge capacity, but we assume that edge capacity does not depend on the actual flow amount in the edge. We also allow time dependent edge travel time, but we require that the network preserve the FIFO (First-In First-Out) property.

Alternate problem formulations of the evacuation problem are available by changing the objective of the problem. The main objective of our problem formulation is to minimize the evacuation egress time. Two alternate objectives are: (1) Maximize the number of evacuees that reach destination for each time unit; (2) Minimize the average evacuation time for all evacuees. Jarvis and Ratliff presented and proved the *triple optimization theorem* [20], which illustrated the properties of the solutions that optimize the above objectives of the evacuation problem. A review of linear programming approaches to solve these problem formulations was given by Hamacher and Tjandra [17].

Table 1. Example Evacuation Plan

Group of Evacuees				
ID	**Source**	**Number**	**Route with Schedule**	**Dest.Time**
A	N8	6	N8(T0)-N10(T3)-N13	4
B	N8	6	N8(T1)-N10(T4)-N13	5
C	N8	3	N8(T0)-N11(T3)-N14	5
D	N1	3	N1(T0)-N3(T1)-N4(T4)-N6(T8)-N10(T13)-N13	14
E	N1	3	N1(T0)-N3(T2)-N4(T5)-N6(T9)-N10(T14)-N13	15
F	N1	1	N1(T0)-N3(T1)-N5(T4)-N7(T8)-N11(T13)-N14	15
G	N2	2	N2(T0)-N3(T1)-N5(T4)-N7(T8)-N11(T13)-N14	15
H	N2	3	N2(T0)-N3(T3)-N4(T6)-N6(T10)-N10(T15)-N13	16
I	N1	3	N1(T1)-N3(T2)-N5(T5)-N7(T9)-N11(T14)-N14	16

3 Proposed Approach

Linear programming approach can produce optimal solutions for evacuation planning. It is useful for evacuation scenarios with moderate size networks, such as building evacuation. However, it may not be able to scale up to large size transportation networks in urban evacuation scenarios due to high computational cost caused by the tremendously increased size of the time-expanded network. Heuristic routing and scheduling algorithms can be used to find sub-optimal evacuation plan with reduced computational cost. It is useful for evacuation scenarios with large size networks and scenarios that do not require an optimal plan, but need to produce an efficient plan within a limited amount of time.

In this section, we present a heuristic algorithm, namely Capacity Constrained Route Planner (CCRP), that produces sub-optimal solutions for evacuation planning. We model edge capacity and node capacity as a time series instead of fixed numbers. A time series represents the available capacity at each time instant for a given edge or node. We propose a heuristic approach based on an extension of shortest path algorithms [13,11] to account for capacity constraints of the network.

3.1 Capacity Constrained Route Planner (CCRP)

The Capacity Constrained Route Planner (CCRP) uses an iterative approach. In each iteration, the algorithm first searches for route R with the earliest destination arrival time from any source node to any destination node, taking previous reservations and possible waiting time into consideration. Next, it computes the actual amount of evacuees that will travel through route R. This amount is affected by the available capacity of route R and the remaining number of evacuees. Then, it reserves the node and edge capacity on route R for those evacuees. The algorithm continues to iterate until all evacuees reach destination. The detailed pseudo-code and algorithm description are shown in Algorithm 1..

The CCRP algorithm keeps iterating as long as there are still evacuees left at any source node (line 1). Each iteration starts with finding the route R with the

Algorithm 1. Capacity Constrained Route Planner (CCRP)

Input:
1) $G(N, E)$: a graph G with a set of nodes N and a set of edges E;
   Each node $n \in N$ has two properties:
      $Maximum\_Node\_Capacity(n)$: non-negative integer
      $Initial\_Node\_Occupancy(n)$: non-negative integer
   Each edge $e \in E$ has two properties:
      $Maximum\_Edge\_Capacity(e)$: non-negative integer
      $Travel\_time(e)$: non-negative integer
2) S: set of source nodes, $S \subseteq N$;
3) D: set of destination nodes, $D \subseteq N$;

Output: Evacuation plan:Routes with schedules of evacuees on each route

Method:

Pre-process network: add super source node s_0 to network,
   link s_0 to each source nodes with an edge which
   $Maximum\_Edge\_Capacity() = \infty$ and $Travel\_time() = 0$; (0)
while any source node $s \in S$ has evacuee do { (1)
   find route $R < n_0, n_1, \ldots, n_k >$ with time schedule $< t_0, t_1, \ldots, t_{k-1} >$
      using one generalized shortest path search from super source s_0
         to all destinations, (where $s \in S$, $d \in D$, $n_0 = s$, $n_k = d$)
      such that R has the earliest destination arrival time among
         routes between all (s,d) pairs,
      and $Available\_Edge\_Capacity(e_{n_i n_{i+1}}, t_i) > 0, \quad \forall i \in \{0, 1, \ldots, k-1\}$,
      and $Available\_Node\_Capacity(n_{i+1}, t_i + Travel\_time(e_{n_i n_{i+1}})) > 0,$
         $\forall i \in \{0, 1, \ldots, k-1\}$; (2)
   $flow = \min($ number of evacuees still at source node s,
      $Available\_Edge\_Capacity(e_{n_i n_{i+1}}, t_i), \quad \forall i \in \{0, 1, \ldots, k-1\}$,
      $Available\_Node\_Capacity(n_{i+1}, t_i + Travel\_time(e_{n_i n_{i+1}}))$,
         $\forall i \in \{0, 1, \ldots, k-1\}$;
      ); (3)
   for $i = 0$ to $k - 1$ do { (4)
      $Available\_Edge\_Capacity(e_{n_i n_{i+1}}, t_i)$ reduced by $flow$; (5)
      $Available\_Node\_Capacity(n_{i+1}, t_i + Travel\_time(e_{n_i n_{i+1}}))$ reduced by $flow$; (6)
   } (7)
} (8)
Output evacuation plan; (9)

earliest destination arrival time from any sources node to any destination node based on the current available capacities (line 2). This is done by generalizing Dijkstra's shortest path algorithm [13,11] to work with the time series node and edge capacities and edge travel time. Route R is the route that starts from a source node and gets to a destination node in the least amount of time and available capacity of the route allows at least one person to travel through route R to a destination node.

Compared with the earlier MRCCP algorithm [26], major improvements in CCRP lie in line 0 and line 2. In MRCCP, finding route R (line 2) is done by running generalized shortest path searches from each source node. Each search is terminated when any destination node is reached. In CCRP, this step is improved by adding a super source node s_0 to the network and connecting s_0 to all source nodes(line 0). This allows us to complete the search for route R by using only one single generalized shortest path search, which takes the super source s_0 as the start node. This search terminates when any destination node is reached. Since the super source s_0 is connected to each source nodes by an edge with infinite capacity and zero travel time, it can be easily proved that the shortest route found by this search is the route R we need in line 2. This improvement significantly reduces the computational cost of the algorithm by one degree of magnitude compared with MRCCP. We give a detailed analysis of the cost model of CCRP algorithm in the next section.

3.2 Algebraic Cost Model of CCRP

We now provide the algebraic cost model for the computational cost of the proposed CCRP algorithm. We assume that n is the number of nodes in the evacuation network, m is the number of edges, and p is the number of evacuees.

The CCRP algorithm is an iterative approach. In each iteration, the route for one group of people is chosen and the capacities along the route are reserved. The total number of iterations equals the number of groups generated. In the worst case, each individual evacuee forms one group. Therefore, the upper bound of the number of groups is p, i.e. the number of iterations is $O(p)$. In each iteration, the computation of the route R with earliest destination arrival time is done by running one generalized Dijkstra's shortest path search. The worst case computational complexity of Dijkstra's algorithm is $O(n^2)$ for dense graphs [11]. Various implementations of Dijkstra's algorithm have been developed and evaluated extensively [4,10,32]. Many of these implementations can reduce the computational cost by taking advantage of the sparsity of the graph. Transportation road networks are very sparse graphs with a typical edge/node ratio around 3. In CCRP, we implement Dijkstra's algorithm using heap structures, which runs in $O(m + nlogn)$ time [4,10]. For sparse graphs, $nlogn$ is the dominant term. The generalization of Dijkstra's algorithm to account for capacity constraints affects only how the shortest distance to each node is defined. It does not affect the computational complexity of the algorithm. Therefore, we can complete the search for route R with $O(nlogn)$ run-time. The reservation step is done by updating the node and edge capacities along route R, which has a cost of $O(n)$. Therefore, each iteration of the CCRP algorithm is done in $O(nlogn)$ time. As we have seen, it takes $O(p)$ iterations to complete the algorithm. The cost model of the CCRP algorithm is $O(p \cdot nlogn)$. CCRP is an improved algorithm based on the same heuristic method of MRCCP [26] which has a run-time of $O(p \cdot n^2 logn)$. CCRP reduces the computational cost of MRCCP by one degree of magnitude.

The computational cost of linear programming approach depends on the method used to solve the minimum cost flow problem. Hoppe and Tardos [18] showed that this problem can be solved using ellipsoid method which is theoretically polynomial time bounded. However, the computational complexity of

Table 2. Comparison of Computational Costs (n: number of nodes, p: number of evacuees, T: user-provided upper-bound on evacuation time)

Algorithm	Computational Cost	Solution Quality
CCRP	$O(p \cdot nlogn)$	Sub-optimal
MRCCP	$O(p \cdot n^2 logn)$	Sub-optimal
Linear Programming Approach	at least $O((T \cdot n)^6)$	Optimal

ellipsoid method is at least $O(N^6)$[6](where N is the number of nodes in the network). Since linear programming approach requires a time-expanded network, N equals to $(T+1)n$ (where n is the number of nodes in the original evacuation network, T is the user-provided evacuation time upper bound).

Table 2 provides a comparison of CCRP, MRCCP, and the linear programming approach. As can be seen, linear programming approach produces optimal solutions but suffers from high computational cost. Both CCRP and MRCCP reduce the computation cost by producing sub-optimal solution, while CCRP gives better computational cost than MRCCP.

Lemma 1: CCRP is strictly faster than MRCCP.

The computational costs of CCRP and MRCCP are $O(p \cdot nlogn)$ and $O(p \cdot n^2 logn)$ respectively, as shown in Table 2.

4 Experiment Design and Performance Evaluation

Performance evaluation of the CCRP algorithm was done by conducting experiments using various evacuation network configurations. In this section, we present the experiment design and an analysis of the experiment results.

4.1 Experiment Design

Figure 4 describes the experiment design to evaluate the performance of the CCRP algorithm. The purpose is to compare the algorithm run-time and solution quality of the proposed CCRP algorithms with that of MRCCP [26] and NETFLO [21] which is a popular linear programming package used to solve minimum cost flow problems.

First, we used NETGEN [24] to generate evacuation networks with evacuees. NETGEN is a program that generates transportation networks with capacity constraints and initial supplies based on input parameters. In our experiments, the following three were selected as independent parameters to test their impacts on the the performance of the algorithms: number of evacuees initially in the network, number of source nodes, and network size represented by number of nodes. Number of edges is treated as a dependent parameter as we set the number of edges to be equal to 3 times the number of nodes because 3 is the typical edge/node ratio for real transportation road networks. Next, the same evacuation network generated by NETGEN was fed to the CCRP and MRCCP algorithms. Before feeding the network to NETFLO, we used a network transformation tool to transform the evacuation network into a time-expanded network, which is required by minimum cost flow solvers as NETFLO to solve evacuation problems [17,9]. This process requires an input parameter T which is the estimated upper-bound on evacuation egress time. If the evacuation cannot be completed by time T, NETFLO will return no solution. In this case, we must increase T to create a new time-expanded network and try to run NETFLO again until a solution can be reached. Finally, after CCRP, MRCCP and NETFLO produced a solution for each test case, the evacuation egress time, which represents the solution quality, and the algorithm run-time were collected and analyzed in the data analysis module.

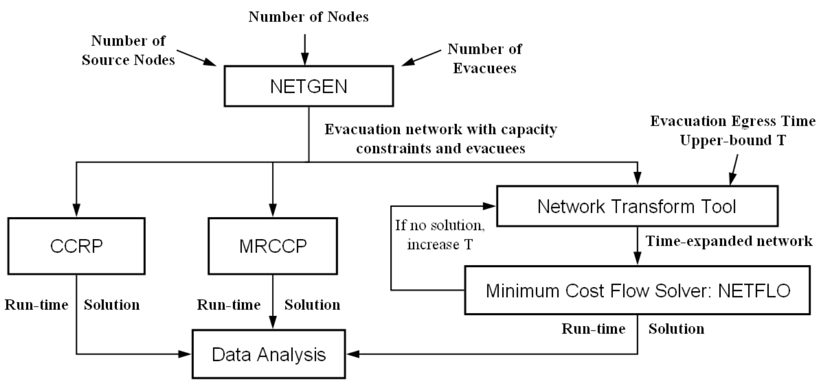


Fig. 4. Experiment Design

The experiments were conducted on a workstation with Intel Pentium IV 2GHz CPU, 2GB RAM and Debian Linux operating system.

4.2 Experiment Results and Analysis

We want to answer three questions: (1) How does the number of evacuees affect the performance of the algorithms? (2) How does the number of source nodes affect the performance of the algorithms? (3) Are the algorithms scalable to the size of the network, particularly will they handle large size transportation networks as in urban evacuation scenarios?

Experiment 1: How does the number of evacuees affect the performance of the algorithms?
The purpose of the first experiment is to evaluate how the number of evacuees affects the performance of the algorithms. We fixed the number of nodes and the number of source nodes of the network, and varied the number of evacuees

to observe the quality of the solution and the run-time of CCRP, MRCCP and NETFLO algorithms.

The experiment was done with four test groups. Each group had a fixed network size of 5000 nodes and fixed number of source nodes at 1000, 2000, 3000, and 4000 respectively. We varied the number of evacuees from 5000 to 50000. Here we present the experiment results of the test group with number of source nodes fixed at 2000. We omit the results from the other three groups since this group shows a typical result of all test groups. Figure 5 shows the solution quality represented by evacuation egress time and Figure 6 shows the run-times of the three algorithms.

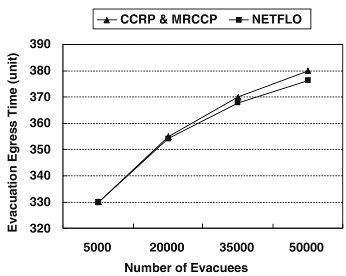


Fig. 5. Quality of Solution With Respect to Number of Evacuees

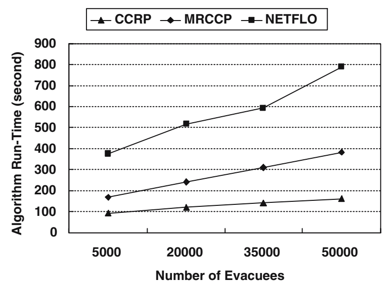


Fig. 6. Run-time With Respect to Number of Evacuees

Since CCRP and MRCCP use the same heuristic method to find solution, it is expected that CCRP and MRCCP produced solutions with the same evacuation egress time for each test case. As seen in Figure 5, CCRP and MRCCP produced very high quality solution compared with the optimal solution produced by NETFLO. The solution quality of CCRP and MRCCP drops slightly as the the number of evacuees grows. In Figure 6, we can see that, in each case, the run-time of CCRP remains half that of MRCCP and less than 1/3 that of NETFLO. In addition, the CCRP run-time is scalable to the number of evacuees while the run-time of NETFLO grows much faster.

This experiment shows: (1) CCRP produces high quality solutions with much less run-time than that of NETFLO. (2) The run-time of CCRP is scalable to the number of evacuees.

Experiment 2: How does the number of source nodes affect the performance of the algorithms?

In the second experiment, we evaluate how the number of source nodes affects the performance of the algorithms. We fixed the number of nodes and the number of evacuees in the network, and varied the number of source nodes to observe the quality of the solution and the run-time. In this experiment, by varying the number of source nodes, we actually create different evacuee distributions in the network. A higher number of source nodes means that the evacuees are more scattered in the network.

Again, the experiment was done with four test groups. Each group had a fixed network size of 5000 nodes and fixed number of evacuees at 5000, 20000, 35000, and 50000 respectively. We varied the number of source nodes from 1000 to 4000. Here we present the experiment results of the test group with number of evacuees fixed at 5000. It shows a typical result of all test groups. Figure 7 shows the solution quality represented by evacuation egress time and Figure 8 shows the run-times of the three algorithms.

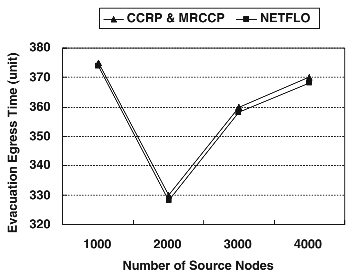


Fig. 7. Quality of Solution With Respect to Number of Source Nodes

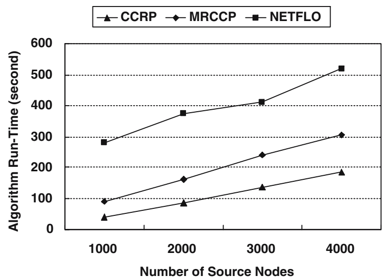


Fig. 8. Run-time With Respect to Number of Source Nodes

As seen in Figure 7, in each test case, CCRP and MRCCP produced high quality solution (within 5 percent longer evacuation time) and the number of source nodes has little effect on the solution quality. It is also noted that the evacuation time is non-monotonic with respect to the number of source nodes and we plan to explore the potential reasons in future works.

Figure 8 shows that the run-time of all three algorithms are scalable to the number of source nodes. However, the run-time of CCRP remains less than half that of NETFLO.

This experiment shows: (1)The solution quality of CCRP is not affected by the number of source nodes. (2) The run-time of CCRP is scalable to the number of source nodes.

Experiment 3: Are the algorithms scalable to the size of the network?
In the third experiment, we evaluate how the network size affects the performance of the algorithms. We fixed the number of evacuees and the number of source nodes in the network, and varied the network size to observe the quality of solution and the run-time of the algorithms.

The experiment was done with a fixed number of evacuees at 5000 and the number of source nodes at 10. We varied the number of nodes from 50 to 50000. Figure 9 shows the solution quality represented by evacuation egress time and Figure 10 shows the run-times.

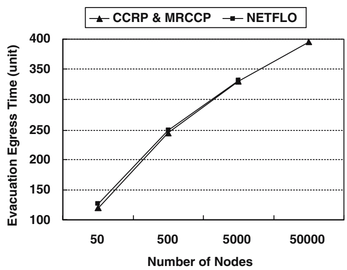
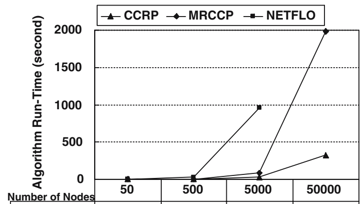


Fig. 9. Quality of Solution With Respect to Network Size



Number of Nodes	50	500	5000	50000
CCRP	0.1	1.5	23.1	316.4
MRCCP	0.1	2.8	78.5	1980.1
NETFLO	0.3	25.6	962.1	

Fig. 10. Run-time With Respect to Network Size

Note: x-axis(number of nodes) in Figure 9 and 10 is on a logarithmic scale rather than linear. Run-time of CCRP and MRCCP in Figure 10 grow in small polynomial.

There is no data point for NETFLO at network size of 50000 nodes. We were unable to run NETFLO for this setup because the size of the time-expanded network became too large (more than 20 million nodes and 80 million edges)that NETFLO could not produce solution.

As seen in Figure 9, in each of the first three test case, CCRP and MRCCP produced high quality solution (within 5 percent longer evacuation time) and the solution quality becomes closer to optimal solution as the network size increases. Figure 10 is shown with a data table of each run-time. The x-axis(number of nodes) of Figure 10 is on a logarithmic scale rather than linear and the run-time of CCRP and MRCCP grow in small polynomial. It can be seen that the run-time of CCRP is scalable to the network size while the NETFLO run-time grows exponentially.

This experiment shows: (1) Given a fixed number of evacuees and source nodes, the solution quality of CCRP increases as the network size increases. (2) The run-time of CCRP is scalable to the size of the network.

We also conducted experiments using a real evacuation scenario. The Monticello nuclear power plant is about 40 miles to the northwest of the Twin Cities. Evacuation plans need to be in place in case of accidents or terrorist attacks. The evacuation zone is a 10-mile radius around the nuclear power plant as defined by Minnesota Homeland Security and Emergency Management [3].

The experiment was done using the road network around the evacuation zone provided by the Minnesota Department of Transportation [2], and the Census 2000 population data for each affected city. The total number of evacuees is about 42,000. The old hand-crafted evacuation plan has an evacuation egress time of 268 minutes. CCRP algorithm produced a much better plan with evacuation time of only 162 minutes. This experiment shows that our algorithm is effective in real evacuation scenarios to reduce evacuation time and improve existing plans.

Our approach was presented in the UCGIS Congressional Breakfast Program on homeland security[30], and the Minnesota Homeland Security and Emergency Management newsletter[31]. It was also selected by the Minnesota Department of Transportation to be used in the evacuation planning project for the Twin Cities Metro Area, which involves a road network of about 250,000 nodes and a population of over 2 million people.

5 Conclusions and Discussions

In this paper, we proposed a new capacity constrained routing algorithm for evacuation planning problem. Existing linear programming approach uses time-expanded network and requires user provided upper bound on evacuation time. To address these limitations, we presented a heuristic algorithm, namely Capacity Constrained Route Planner(CCRP), which produces sub-optimal solution for evacuation planning problem without using time-expanded networks. We provided the algebraic cost model and the performance evaluations using various network configurations. Experiments show that CCRP algorithm produces high quality solution and significantly reduces the computational cost compared to linear programming approach which produces optimal solution. It is also shown that the CCRP algorithm is scalable to the number of evacuees and the size of the transportation network. A case study using real evacuation scenario shows that CCRP algorithm can be used to improve existing evacuation plans by reducing total evacuation time.

The limitation of CCRP algorithm remains the follows. First, we assume that maximum capacity of an edge does not depend on traffic flow amount on the edge. We understand that it is a challenging task to accurately model the capacity of each road segment in a real evacuation scenario as the actual traffic flow rate may depend on vehicle speed as well as road occupancy. Second, the generalized shortest path algorithm we used in CCRP requires that the edge travel time reflects traffic delays at intersections. For future work, we plan to incorporate existing research results, such as Ziliaskopoulos and Mahmassani [33], to better address this problem.

To address the sub-optimality issue of the CCRP algorithm, we also explored the possibility of formulating the evacuation problem as a search problem using A* algorithm. Our A* search formulation addresses the limitations of linear programming approach by only using the original evacuation network to find optimal solution. Thus, it does not require prior knowledge of evacuation time. We proved that the heuristic function used in our A* formulation is monotone and admissible thus guaranteeing the optimality of the solution. Details of the A* search formulation can be found in [25]. It is not included in this paper due to space constraints.

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APPENDIX B

Link and Node Capacities and Journey Times

Node Capacity

Node Reference	Node Type	Node Location (Junction or ONS Output Area)	X Co-ordinate	Y Co-ordinate	Total Node Capacity (veh/hr)
D1	Destination Node	A12/Dunwich Rd	645290	275315	1715
D2	Destination Node	A12/B1387 (The St)	644427	274335	2371
D3	Destination Node	A12/Hazels Lane	643644	273900	2238
D4	Destination Node	A12/The St	640964	270324	2419
D5	Destination Node	A12/Westleton Rd	640124	269171	2508
D6	Destination Node	A12/B1122 (Yoxford Rd)	639871	268713	2550
D7	Destination Node	A12/B1121 (Main Rd), Dorleys Corner	638271	265828	2020
D8	Destination Node	A12/Carlton Rd	637658	264680	2382
D9	Destination Node	A12/Rendham Rd	637615	263350	2291
D10	Destination Node	A12/B1121 (Main Rd), Benhall	637927	261245	3579
D11	Destination Node	A12/A1094	637169	260482	2488
S1	Source Node	N10	645232	266177	
S2	Source Node	N12	644659	265722	
S3	Source Node	N34	645857	262516	
S4	Source Node	N35	647194	259558	
S5	Source Node	N26	644319	262891	
S6	Source Node	N36	644619	261033	
S7	Source Node	N31	644353	262227	
S8	Source Node	N27	644324	262628	
S9	Source Node	N26	644319	262891	
S10	Source Node	N26	644319	262891	
S11	Source Node	N34	645857	262516	
S12	Source Node	N32	644583	262217	
S13	Source Node	N31	644353	262227	
S14	Source Node	N31	644353	262227	
S15	Source Node	N31	644353	262227	
S16	Source Node	N30	644538	262467	
S17	Source Node	N32	644583	262217	
S18	Source Node	N32	644583	262217	
S19	Source Node	N30	644538	262467	
S20	Source Node	N30	644538	262467	
S21	Source Node	N29	644351	262427	
S22	Source Node	N27	644324	262628	
S23	Source Node	N26	644319	262891	
S24	Source Node	N26	644319	262891	
N1	Network Node	B1387 The St/B1125 Dunwich Rd	645415	274300	1684
N2	Network Node	B1125/Westleton Rd	645014	272602	1246
N3	Network Node	Darsham Rd/The Hill	644039	269192	2279
N4	Network Node	B1125/The Hill/Dunwich Rd	644309	269272	1519
N5	Network Node	B1125/Yoxford Rd	644014	268952	1756
N6	Network Node	B1125/B1122 Leiston Rd	643229	266554	1129
N7	Network Node	B1122 Leiston Rd/Pretty Rd	643639	265972	1785
N8	Network Node	B1122 Leiston Rd/Church Rd	643754	265872	2083
N9	Network Node	Church Rd/Chapel Rd	644639	266202	1136
N10	Network Node	Baker's Hill/Minsmere Nature Reserve Access	645232	266177	1855
N11	Network Node	Chapel Rd/Baker's Hill	645097	266107	1339
N12	Network Node	Baker's Hill/Onners Lane/Potter's St	644659	265722	644
N13	Network Node	B1122/Moat Rd	644014	265529	2061
N14	Network Node	B1122/Potter's St	644492	265117	2027
N15	Network Node	B1122/Minsmere Nature Reserve Access	644845	264425	1748
N16	Network Node	B1122/Lover's Lane	644527	263845	1402
N17	Network Node	Abbey Lane/Harrow Lane	643222	263662	1314
N18	Network Node	Harrow Lane/Hawthorn Rd	641562	264869	1756
N19	Network Node	Hawthorn Rd/Unnamed Rd (RAF Leiston)	640569	264498	1325
N20	Network Node	B1121 Main Rd/Clay Hills	638706	264265	1375
N21	Network Node	B1121 Main Rd/Fairfield Rd	638571	263377	1847
N22	Network Node	B1119 Rendham Rd/Chantry Rd	638213	263127	1109
N23	Network Node	B1121 High St/B1119 Mill Rd	638633	263024	1445
N24	Network Node	B1119 Saxmundham Rd/Grove Rd	641350	262561	1736
N25a	Network Node	B1119 Saxmundham Rd/Abbey Lane (north of railway)	642670	263166	1109
N25b	Network Node	B1119 Saxmundham Rd/Abbey Lane (south of railway)	642662	263126	1365
N26	Network Node	B1122 Abbey Rd/Westward Ho	644319	262891	1954
N27	Network Node	B1069 Park Hill/B1119 Waterloo Ave	644324	262628	1705
N28	Network Node	Main St/B1122 High St/Valley Rd	644466	262665	1363
N29	Network Node	Park Hill/Victory Rd/Cross St	644351	262427	1508
N30	Network Node	High St/Cross St/Sizewell Rd	644538	262467	1375
N31	Network Node	Haylings Rd/Kings Rd	644353	262227	1341
N32	Network Node	High St/Kings Rd	644583	262217	1071
N33	Network Node	Lover's Lane/Valley Rd/Sandy Lane	645620	263164	1757
N34	Network Node	Lover's Lane/King George's Ave	645857	262516	1704
N35	Network Node	B1353 The Haven/Aldeburgh Rd	647194	259558	1736
N36	Network Node	B1122 Aldeburgh Rd/B1353 Aldingham Lane	644619	261033	1476
N37	Network Node	B1069 Leiston Rd/B1353 Aldringham Lane	643711	261098	1601
N38	Network Node	B1069 Leiston Rd/School Rd (Mill Rd)	643478	260958	1970
N39	Network Node	School Rd/Grove Rd	641735	261655	1075
N40	Network Node	B1121 Main Rd/B1121 Church Hill	638570	261907	1455
N41	Network Node	B1121 Saxmundham Rd/Church Rd	641095	260489	1584
N42	Network Node	Church Rd/Grove Rd	641487	260516	1829
N43	Network Node	B1121 Aldeburgh Rd/Grove Rd	641269	260226	1645
N44	Network Node	A1094/B1069 Church Rd	639546	259298	1328
N45	Network Node	A1094/Mill Rd	640866	259365	2308
N46	Network Node	A1094/B1121 Aldeburgh Rd	641781	259445	2291
N47	Network Node	A1094/B1069 Snape Rd	641963	259297	1320
N48	Network Node	A1094/B1122 Leiston Rd	645873	257052	2095
N49	Network Node	Church Farm Road/Thorpe Rd	646610	257369	1792

Link Capacity and Travel Time

Link Reference		Travel Time (sec)	Link Capacity (Node A to Node B) veh per hr	Link Capacity (Node B to Node A) veh per hr
Node A	Node B			
N34	N33	55	1109	1038
N34	N30	101	1107	1112
N33	N16	117	1112	1101
N33	N28	117	331	331
N28	N30	18	1028	975
N28	N27	15	1088	1110
N30	N29	24	1103	1088
N30	N32	25	1004	965
N32	N31	21	1087	1003
N32	N36	85	1064	1094
N27	N26	24	1302	1289
N27	N25b	135	902	897
N27	N29	17	965	990
N29	N31	16	1022	990
N31	N37	101	1211	1179
N37	N38	19	1206	1173
N36	N37	65	1005	969
N35	N36	230	1100	1064
N36	N48	273	1119	1119
N49	N35	180	930	930
N49	N48	66	1004	1019
N48	N47	262	1001	1025
N47	N38	166	1119	1119
N38	N39	156	929	914
N47	N46	13	1056	1068
N46	N43	61	1118	1103
N46	N45	54	1081	1081
N45	N43	78	830	834
N45	N44	74	1071	1080
N44	D11	154	1014	1023
N43	N41	23	1119	1119
N43	N42	31	276	276
N42	N41	31	323	323
N42	N39	101	836	836
N41	N40	218	905	917
N40	D10	72	1188	1200
N40	N23	79	1211	1197
N23	N22	56	936	933
N22	D9	47	1029	999
N22	N21	57	323	323
N21	N23	29	990	1022
N23	N24	233	1005	1025
N24	N39	86	836	836
N24	N25b	113	911	930
N25a	N19	195	741	741
N25a	N17	59	945	945
N25a	N25b	5	945	945
N17	N26	117	347	347
N17	N16	117	851	851

N17	N18	164	323	323
N18	N7	187	836	836
N18	N19	101	836	836
N19	N20	172	836	836
N20	N21	65	1212	1239
N20	D8	94	1025	1025
N20	D7	115	1296	1269
N26	N16	55	1056	1043
N16	N15	36	1064	1045
N15	N14	33	1036	1016
N15	N10	148	323	323
N14	N13	44	1036	1016
N14	N12	70	323	323
N12	N11	47	323	323
N11	N10	12	323	323
N11	N9	39	323	323
N9	N12	39	323	323
N12	N13	55	323	323
N9	N8	86	741	741
N13	N8	25	989	972
N8	N7	8	1272	1256
N7	N6	47	1027	1010
N6	N5	177	923	917
N6	D6	231	966	947
N5	D5	300	741	741
N5	N3	15	741	741
N5	N4	25	923	917
N4	N3	31	741	741
N3	D4	270	741	741
N4	N2	227	908	945
N2	D3	150	323	323
N2	N1	113	908	945
N1	D2	63	789	765
N1	D1	63	758	787

Key

(shaded) due to narrow road width (i.e. less than 4m) the single lane capacity has been assumed to be the 2-way capacity.

APPENDIX C

Population Estimates

Daytime Population to be Evacuated

Node Ref	OA Census Reference	Existing Non-Vulnerable (People)	Existing Transient (People)	Existing Vulnerable (People)	Consented (People)	Aldeburgh Road (People)	Valley Road (People)	Remaining SHLAA (People)
D1								
D2								
D3								
D4								
D5								
D6								
D7								
D8								
D9								
D10								
D11								
S1	E00154133	25	0	0				
S2	E00154059	42	150	0				
S3	E00153923	1144	0	40				8
S4	E00153735	153	0	0				
S5	E00153736	131	120	34				
S6	E00153737	111	0	0				
S7	E00153928	97	0	0				
S8	E00153937	66	0	0				89
S9	E00153934	313	0	0				138
S10	E00153921	95	0	199	8			30
S11	E00153925	259	0	0				
S12	E00153932	163	0	0	6			
S13	E00153933	170	0	9		235		
S14	E00153920	132	0	0	6			
S15	E00153931	134	0	0				
S16	E00153927	280	0	15				
S17	E00153929	136	0	0				
S18	E00153930	148	0	1034				
S19	E00153926	90	0	72				
S20	E00153924	249	0	0	24			
S21	E00153922	94	0	0				
S22	E00153919	190	0	469	4			
S23	E00153936	85	0	0			49	
S24	E00153935	122	0	0	2			
S25	N9							
S26	N10							
S27	N11							
S28	N12							
S29	N13							
S30	N14							
S31	N15							
S32	N16							
S35	N26							
S36	N27							
S37	N28							
S38	N29							
S39	N30							
S40	N31							
S41	N32							
S42	N33							
S43	N34							
S44	N35							
S45	N36							
Source Total (People)		4428	270	1872	49	235	49	264

Night time Population to be Evacuated

Node Ref	OA Census Reference	Existing Non-Vulnerable (People)	Existing Transient (People)	Existing Vulnerable (People)	Consented (People)	Aldeburgh Road (People)	Valley Road (People)	Remaining SHLAA (People)
D1								
D2								
D3								
D4								
D5								
D6								
D7								
D8								
D9								
D10								
D11								
S1	E00154133	18	0	0				
S2	E00154059	56	150	0				
S3	E00153923	163	0	40				11
S4	E00153735	185	0	0				
S5	E00153736	192	120	34				
S6	E00153737	230	0	0				
S7	E00153928	256	0	0				
S8	E00153937	122	0	0				122
S9	E00153934	356	0	0				189
S10	E00153921	261	0	84	11			41
S11	E00153925	325	0	0				
S12	E00153932	255	0	0	8			
S13	E00153933	313	0	9		321		
S14	E00153920	328	0	0	8			
S15	E00153931	300	0	0				
S16	E00153927	197	0	15				
S17	E00153929	260	0	0				
S18	E00153930	305	0	0				
S19	E00153926	245	0	72				
S20	E00153924	275	0	0	32			
S21	E00153922	251	0	0				
S22	E00153919	387	0	0	5			
S23	E00153936	288	0	0			68	
S24	E00153935	280	0	0	3			
S25	N9							
S26	N10							
S27	N11							
S28	N12							
S29	N13							
S30	N14							
S31	N15							
S32	N16							
S35	N26							
S36	N27							
S37	N28							
S38	N29							
S39	N30							
S40	N31							
S41	N32							
S42	N33							
S43	N34							
S44	N35							
S45	N36							
Source Total (People)		5847	270	254	68	321	68	362

APPENDIX D

Model User Guide

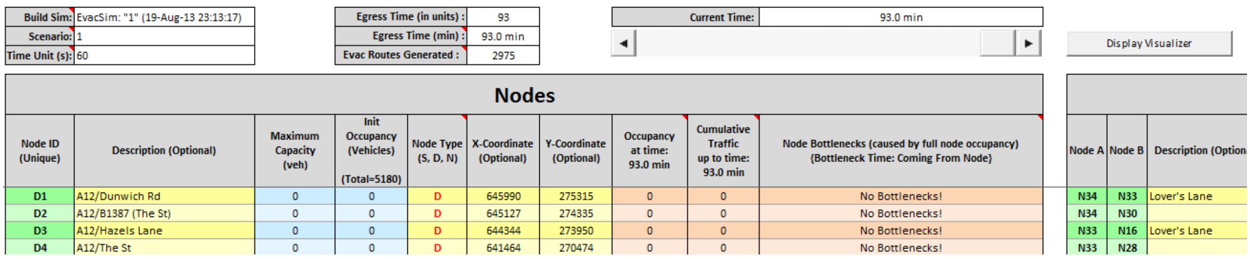
Evacuation Model User Guide

1. In order to run the model the model ‘EvacSim 190813 Final’ must be saved in the same folder as the Excel Add-In file ‘EvacSim.Addin’.

2. When making changes to the model ‘EvacSim 190813 Final’ it is best to save it to a folder that does not have the Add-In file within it as otherwise the model will run each time a change is made and will slow the editing process down. Only have the Add-In file located in the same folder as the model when the model needs to be run.

3. The only section of the model that the user should change is in the ‘Variables’ worksheet. The user should choose which scenario they would like to run. The scenarios are referenced 1 to 40 and each scenario is described in the table on the right hand side of the Variables worksheet. In addition the user can vary the following parameters within the Variables worksheet:
   - Self-Evacuate Vehicle Occupancy (default is 2)
   - Vulnerable Vehicle Occupancy (default is 20)
   - % Stay at Home (default is 10%)
   - % of background traffic to evacuate (default is 50%)

4. Once the scenario and other Variable parameters are chosen the model will run for a few moments. The inputs and results of the run can be seen in the ‘Evac Simulation’ worksheet. The image below provides a screenshot of part of the ‘Evac Simulation’ worksheet.



Build Sim:	EvacSim: "1" (19-Aug-13 23:13:17)
Scenario:	1
Time Unit (s):	60

Egress Time (in units) :	93
Egress Time (min) :	93.0 min
Evac Routes Generated :	2975

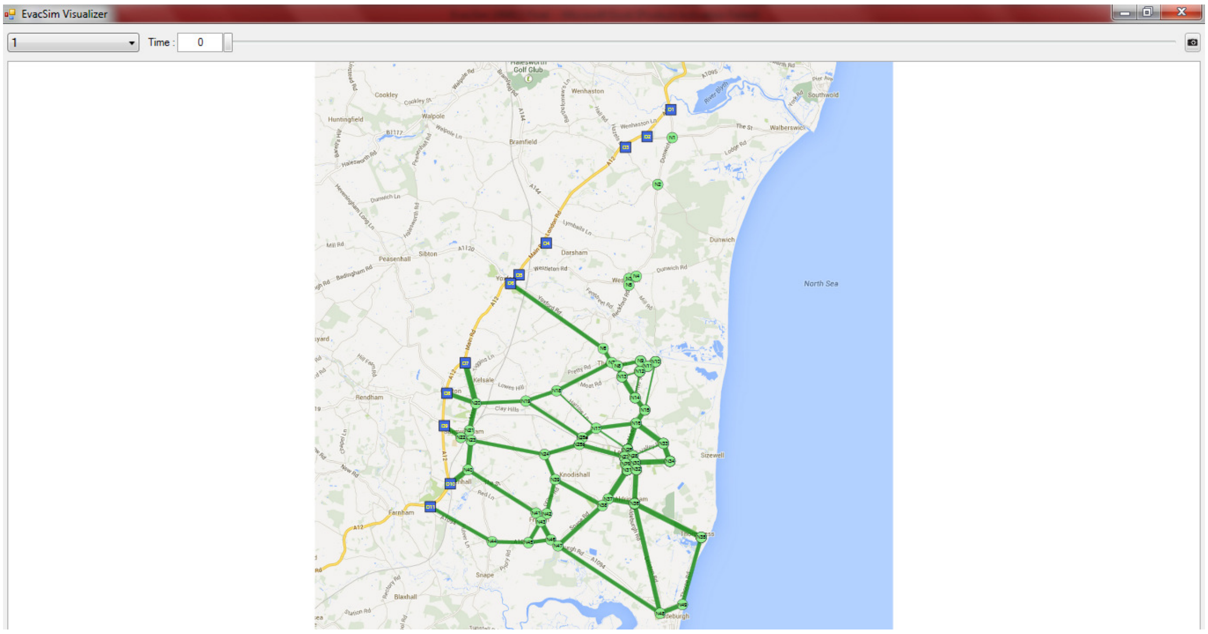
Current Time:	93.0 min

Display Visualizer

Nodes									
Node ID (Unique)	Description (Optional)	Maximum Capacity (veh)	Init Occupancy (Vehicles) (Total=5180)	Node Type (S, D, N)	X-Coordinate (Optional)	Y-Coordinate (Optional)	Occupancy at time: 93.0 min	Cumulative Traffic up to time: 93.0 min	Node Bottlenecks (caused by full node occupancy) {Bottleneck Time: Coming From Node}
D1	A12/Dunwich Rd	0	0	D	645990	275315	0	0	No Bottlenecks!
D2	A12/B1387 (The St)	0	0	D	645127	274335	0	0	No Bottlenecks!
D3	A12/Hazels Lane	0	0	D	644344	273950	0	0	No Bottlenecks!
D4	A12/The St	0	0	D	641464	270474	0	0	No Bottlenecks!

Node A	Node B	Description (Option
N34	N33	Lover's Lane
N34	N30	
N33	N16	Lover's Lane
N33	N28	

5. In the top left hand corner of this worksheet it will tell the user which scenario has been run and the time units that the model is running in (default is 60 seconds and should not be changed). The next column along the top of this worksheet tells the user what the evacuation or ‘Egress’ time is (in the example below it is 93 minutes). This column also tells the user how many iterations of the model were needed in order for all of the population to be evacuated (i.e. ‘Evac Routes Generated’). The next column along the top of the worksheet enables the user to scroll through the model run starting at Time 0 until the end of the evacuation. In order to view the visualizer the user should press the ‘Display Visualizer’ button. This will pop up a new window with the map of the evacuation model and a time scroll bar across the top.



6. The user can select the scenario to the displayed in the top left hand drop down menu (note the model will need to have run the scenario for it to appear on the list) and then scroll through the evacuation timebar and see how the traffic evacuates the area. At any point in time the user can click the 'camera' button in the top right hand corner and this will allow the image to be saved.

7. When in the 'Evac Simulation' worksheet the green cells provide the node or link reference, the yellow cells provide description information, the blue cells are the input values and the red cells provide the output. When the timebar is at Time 0 the 'Initial Occupancy' column should show how many vehicles are within each Source Node at the start of the evacuation. When the timebar is at the end of the evacuation all of the vehicles should have moved into the 'Occupancy at Time X' column within the 11 destination nodes. The bottleneck column tells the user at which points in the evacuation were the nodes or link operating at capacity.

Build Sim:	EvacSim: "1" (19-Aug-13 23:13:17)
Scenario:	1
Time Unit (s):	60

Egress Time (in units) :	93
Egress Time (min) :	93.0 min
Evac Routes Generated :	2975

Current Time:	93.0 min

Display Visualizer

Nodes

Node ID (Unique)	Description (Optional)	Maximum Capacity (veh)	Init Occupancy (Vehicles) (Total=5180)	Node Type (S, D, N)	X-Coordinate (Optional)	Y-Coordinate (Optional)	Occupancy at time: 93.0 min	Cumulative Traffic up to time: 93.0 min	Node Bottlenecks (caused by full node occupancy) {Bottleneck Time: Coming From Node}
D1	A12/Dunwich Rd	0	0	D	645990	275315	0	0	No Bottlenecks!
D2	A12/B1387 (The St)	0	0	D	645127	274335	0	0	No Bottlenecks!
D3	A12/Hazels Lane	0	0	D	644344	273950	0	0	No Bottlenecks!
D4	A12/The St	0	0	D	641464	270474	0	0	No Bottlenecks!
D5	A12/Westleton Rd	0	0	D	640474	269321	0	0	No Bottlenecks!
D6	A12/B1122 (Yoxford Rd)	2550	0	D	640171	269013	1276	1276	No Bottlenecks!
D7	A12/B1121 (Main Rd), Dorleys Corn	2020	0	D	638521	266128	1048	1048	No Bottlenecks!
D8	A12/Carlton Rd	2382	0	D	637858	265030	0	0	No Bottlenecks!
D9	A12/Rendham Rd	2291	0	D	637765	263850	1058	1058	No Bottlenecks!
D10	A12/B1121 (Main Rd), Benhall	3579	0	D	637977	261745	760	760	No Bottlenecks!
D11	A12/A1094	2488	0	D	637256	260913	1039	1039	No Bottlenecks!
S1		0	11	S	645432	266177	0	11	No Bottlenecks!
S2		0	94	S	644859	265822	0	94	No Bottlenecks!
S3		0	515	S	645957	262566	0	515	No Bottlenecks!
S4		0	69	S	647094	259808	0	69	No Bottlenecks!

Node A	Node B	Description (Option
N34	N33	Lover's Lane
N34	N30	
N33	N16	Lover's Lane
N33	N28	
N28	N30	
N28	N27	
N30	N29	
N30	N32	
N32	N31	
N32	N36	
N27	N26	
N27	N25b	
N27	N29	
N29	N31	
N31	N37	

WRITTEN REPRESENTATION FOR
SPR EA1N and EA2 PROJECTS (DEADLINE 1)

SAFETY - CONSTRUCTION & OPERATIONAL

Interested Party: SASES **PINS Refs:** 20024106 & 20024110

Date: 24 October 2020 **Issue:** 2

Summary

1. Section 4.11 (Safety) of the Overarching National Policy Statement for Energy (EN-1) addresses the subject of Safety and makes clear that the Applicant should consult with the Health and Safety Executive on matters of Safety. Within the Applicant's DCO submission no evidence has been presented to show that there has been any consultation regarding overall safety during the Construction and Operational Phases of the Project. This section of the Written Representation deals with perceived shortcomings in the Applicant's Environmental Impact Assessment (EIA).

General

2. EN-1 acknowledges that some energy infrastructure will be subject to Control of Major Accident Hazards (COMAH) regulations, and addresses the matter primarily in terms of hazardous materials. This energy infrastructure is somewhat different in that whilst stocks of hazardous materials are low there remains an ever present safety concern regarding the large quantity of power being transmitted in cables from the off-shore substations to Friston. The risks related to accidental snagging of cables laid on the sea bed is addressed by the Applicant, but the consideration of risks to onshore cables and substation(s) appears scant. Here, the preparation of a 'Credible Accident' assessment or a Failure Modes and Effects Analysis would have been of value to show that the Applicant had fully considered the risk to safety arising from equipment failure, fire, lightning strike, malicious intervention, etc.

3. It is not the purpose of this submission to comment upon the safety issues relating to offshore infrastructure nor to comment upon on-site work practices as adopted by the Applicant: these should remain a matter of exchange between the Health & Safety Executive and the Applicant. The remainder of this representation note is thus confined to an appraisal of the Applicant's approach to safety, as it impinges on the local residents living in the development area, and is restricted to the Construction and Operational Phases of the Project.

Construction Phase

4. By any measure, the build of the EA1(N) and EA2 wind farms plus the onshore cable system and substations (including the National Grid infrastructure/connection

hub) is a large undertaking, requiring several thousand man-years of work to complete. Much of this work will require the human operative to work in close proximity to heavy machinery, both onshore and offshore, and clearly Health & Safety of the workforce is paramount.

5. This a ‘roads-based’ development, in that all materiel enters and leaves the construction site(s) via the public road network, which from the A12 totals about 24 km in length. Within the extended site, construction traffic will cross and re-cross the public road system and public Rights of Way, and thus there remains for the period of the build, an existential threat to the safety of local residents. It should be noted that all public roads in the development area are single carriageway, and except in a few places, lack adjacent footpaths. These roads are shared by motorists, goods vehicles, pedestrians, horse riders and cyclists. They are wholly unsuited for HGVs of the type needed to support this development. Residents’ safety is thus dependent on careful and considerate behaviour by the Applicant’s workforce and that of its subcontractors, which is and will remain so for the period of construction, outside the control of local residents. The Applicant has produced an Outline Construction Traffic Management Plan, [Volume 8.9 refers PINS APP-586], which advocates a somewhat convoluted plan to regulate HGVs, with identifier plates, but there seems to be no regulation of the lower class of vehicles, such as Light Goods Vehicles (LGVs), Light Commercial Vehicles (LCVs) and site worker vehicles. See also Written Representation concerning Transport & Traffic.

6. Chapter 26 Traffic and Transport of the ES [PINS APP-074] reference 6.1.26) assessed the impact of site construction traffic, which included: pedestrian amenity, severance, road safety and driver delay following ‘embedded mitigation would not be “significant”. From a residents’ perspective ‘zero impact’ would have been a better objective. In short, the safety of residents in the environment of increased traffic flow will be down to careful and considerate behaviour of the Applicant’s workforce, which is a largely a matter beyond their immediate control.

7. The Applicant should thus bring forward a Traffic Management plan that **will** ensure that the safety of all local residents is **not adversely** impacted by traffic engaged in any capacity regarding construction of the substations and onshore cable infrastructure.

Operational Phase

General

8. The lifetime of the onshore cable and substations is not expressly defined within the Applicant’s DCO submission, but is generally accepted as being in excess of 25 years, possibly as much as 40 years. No information is given regarding pre-planned upgrades or major maintenance. It is to be expected that functional equipment will deteriorate as a consequence of:

- Materials Ageing
- Onset of corrosion
- Ingress of moisture
- Leakage of cooling fluids (including gases)

- Weakening of clamps, straps, insulation, and the core laminations of large transformers as a consequence of long term vibration.

9. Additionally, in the shorter term there would appear to be the risk of ingress of moisture to the cable route junction boxes along the cable route and the cable sealing ends at the interface with the overhead pylons. It appears that no consideration has been given to the need for submersible pumps. If so, then reasons should be presented as to why these are considered unnecessary.

10. The Project Description, Chapter 6, of the Environmental Statement [APP-054] contains just two paragraphs (paras 576 & 577) that directly address risks associated with the onshore cables and substations. This seems a wholly inadequate response given the importance of these parts of the infrastructure.

Fire and Explosion Risk

11. At 1.7 GW, the combined output of the EA1(N) and EA2 windfarms will be some 40% greater than that of Sizewell B nuclear power station. All this power is brought to Friston via a series of underground cables, junction boxes, switchgear, reactors, harmonic filters and transformers, to be converted to a form suitable to the overhead grid system, by four 'super-grid' high voltage ac (HVAC) transformers.

12. All electrical transmission systems generate heat, particularly where junctions and switches are concerned. Paragraph 576 informs the reader that the cable runs include a system to detect insulation failure, but gives no indication of the likely response time. Is this sufficiently fast to prevent catastrophic failure? Though omitted in SPR's submission, most large transformers also include instrumentation to detect overheating.

13. High power items like the super-grid transformers rely upon the circulation of cooling liquids, usually involving a flammable oil and normally stored in an overhead reservoir. Across the world, fire and explosion at substations is not unknown, and a leading supplier of substation components estimates the risk of a transformer fire to be slightly less than 1% for the lifetime of the equipment: this is small, but not negligible. A failure in a 400 MVA transformer winding leading to a short circuit lasting perhaps just one tenth of a second could result in an arc-blast and theoretically, dump about the same energy as detonating 10 kilogrammes of high explosive.[1]

14. The substations will be sited close to residential property and adjacent to woodland. The risk of fire, smoke and toxic fumes, however small is a matter of concern to nearby residents. In Paragraph 577 of the Project Description [APP-054] [6.1.6 Chapter 6] the Applicant acknowledges that substation fires ***can*** create a local hazard, but fails to outline what measures would be needed in the event of such a fire. The nearest fire stations are in Leiston, Saxmundham and Aldeburgh: these rely upon volunteers. A description of fire prevention/mitigation measures adopted for the EA1 substation at Bramford would have aided comprehension of the Applicant's proposals for the Friston site.

[1] TNT has a specific thermal energy content (stoichiometric conditions) of 4.184 MJ/kg

15. In various parts of the DCO submission, the Applicant notes the intention for the substations to be unmanned, but that there will be a system of emergency lighting. No explanation is supplied regarding what emergencies are considered.

16. There is no evidence presented within the Applicant's documentation of the intention to keep a reserve pond of water set aside for fire suppression. Generally, water and high voltages are kept separate, but for those parts where fire suppression is appropriate, some limited store, such as kept at minor airfields would seem sensible. Other substations, eg Rampion, have included a 120000 litre pond for fire suppression purposes. It may be that the Applicant is relying on an adequate supply of suitable water being always available in the proposed SUDS ponds needed to mitigate the risk of flooding. If so, a suitable footnote should have been included in the Project Description. In prolonged dry periods, such ponds risk drying out.

Sulphur Hexafluoride (SF_6) Gas

17. The Applicant envisages the use of Gas Insulated Switch Gear at both EA1(N) and EA2 substations, and current design practice relies on sulphur hexafluoride (SF_6), a heavy and suffocating, (but non-toxic) gas. It is man-made and also a potent 'greenhouse' gas. The use of SF_6 use is being actively discouraged at international levels. This observation was made by Rt Hon Member for Suffolk Coastal, Thérèse Coffey, at the recent virtual Open Floor Hearings. The DCO submission does not seem to include any statement regarding the management of accidental leaks.

Cumulative Impact

18. Of increasing concern to the residents of Friston, is the strong likelihood that the National Grid infrastructure/connection hub will be used to accommodate high power sources such as Nautilus and EuroLink also requiring below ground cables: likewise Greater Gabbard and Galloper windfarm extensions, now called Five Estuaries and North Falls, plus the NGET SCD1 and SCD2 Interconnectors. Concerns regarding safety during the Operational Phase are magnified by the recognition that the Friston site may be used to manage power levels way beyond that which is the subject of this DCO.

Conclusion

19. The Project Description [APP-054] Paragraph 584 concludes with the statement:

"….the risk of major accidents and/or disasters occurring associated with any aspect of the project during construction, operation and decommissioning phases is negligible… "

20. No numerical or anecdotal evidence is supplied to substantiate this claim, and it is recommended that the Examination Panel seek a peer review of the design of the onshore substation(s) including that of the NG substation and associated HV cable system, by experts properly qualified to assess high voltage electricity transmission systems.