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Minimising the Risk of Transporting Hazardous Goods Around Perth

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Abstract

Hazardous goods delivered in or through Perth are meant to use the major distributor roads in Main Roads WA road hierarchy for as much of the trip as is convenient. This acknowledges the facts that these urban distributor roads tend to have a below average accident rate, but that many delivery sites are off these roads.

Some councils objected to some of these roads being recommended for the distribution of these goods, because of high levels of population density along some of these roads The Department of Minerals & Energy, which licences the both storage and delivery of hazardous goods wanted to find a better set of routes.

This approach uses mathematical modelling to estimate the shortest routes and those that put the fewest people at risk of being dangerously close to a spill This information can help recommend which routes make up a network to distribute hazardous goods, and which parts of this network are in the greatest need of improvement.

This approach will allow the total exposure to the total population of Perth to be reduced, but, inevitably, there will be an increase in exposure for those on certain parts of the network It is case of some individuals being disadvantaged for the common good of all The approach will help decision makers to show why they made these decisions.

Not all the improvements are to the road component, as changes to the surroundings and to the emergency response ability are also possible ways to reduce risk to accepted levels This suggests that not only road agencies are responsible for this network

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Introduction

This project aims to show how hazardous goods* flow around Perth and what level of societal risk exposure that gives. It then shows what alternative level of exposure could be attained, and for how much change in travel cost. It also helps identify the locations where risk lowering effort would be most productive.

**Hazardous goods are substances prescribed under the Explosives and Dangerous Goods Act whose transport in designated quantities requires a Dangerous Goods Licence.*

It shows how standard operations research techniques can be used to provide some of the data that policy makers need. The process used shadow costs calculated by the Transport Algorithm (see Appendix A for a short explanation of this algorithm) to provide the flows from the limited number of sources to the two thousand sites around Perth that are licensed to store hazardous goods. Two parameters were used to test the minimum cost routes and the goods flows on road links around Perth. The two parameters used were distance (an economic cost) and personal/environmental risk exposure. The software calculates and plots the lowest economic cost routes; the lowest personal/environmental risk exposure routes; and dangerous goods flows.

Societal risk exposure was based on the accident rates on the roads that were used or proposed, together with measured personal and environmental risks. Personal risk calculation was done in two ways. The number of people at a particular level of risk of fatality within a certain distance of roads were estimated. The Fire & Rescue Service (now FESA) provided its rating of the consequence of an accident around the various sites where hazardous goods are stored. Environmental risk was rated by the Waters & Rivers Commission (WRC) according to how damaging a leak would be to water supplies.

The project has five planned stages: data collection; software tailoring; desktop route selection; negotiation with risk owners; and implementing risk lowering policies and practices. This paper tackles the first three of these only.

The background

The Department of Minerals & Energy (DoME) controls the distribution and storage of hazardous goods in WA. It requires carriers to use the safest routes for the delivery of these goods and in accordance with a 19992 working party report adopted by government suggests using the roads in Main Roads of WA's (MRWA) primary level of the road hierarchy because they are generally the roads with the lowest accident rate likely to cause explosions/spillages. While this is largely true, some of these roads go through densely populated areas, particularly the busy roads in the older parts of Perth.

Risk assessment was undertaken in Brisbane for a similar purpose (Middleton, Walker & Tsoukas 1992), where cordon counts of hazardous goods traffic were made to give likely flows, then the various areas were rated for exposure. This showed the higher exposure areas, from which came advice on the preferable routes around Brisbane.

Improvements in data availability since that study was done allowed us to do better than merely reproducing the Brisbane work by applying more numerate exposure factors to supplement the FESA assessment of risk.

The approach taken

There are under a dozen major sources of hazardous goods (Fremantle port, Forrestfield rail yards, Kwinana, North Fremantle and Kewdale are the largest) and these deliver to about two thousand hazardous goods storage sites around Perth, with a further three thousand sites in the rest of the State.

Using the transportation algorithm to generate the shortest routes from these few sources to the many storage sites we simulated the delivery practice of drivers. We used the MRWA crash data base to plot dangerous goods vehicle crash/spillage probabilities on this network

To further simulate the number of people exposed and the impact on groundwater we classified hazardous goods in two main personal risk location categories:

- explosives, petrol and LPG (for roads other than through tunnels there is under 1% probability of a fatality from a fire or explosion for anyone at a 100 metre radius of an incident); and
- toxic gases and liquids (extended exposure at a 500 metre radius will cause less than 1% probability of fatality).

We also applied an environmental risk rating developed by the WRC. This rating reflects the exponential increase in harm that the Commission believes a spill can do in various locations. Its ratings are: 16 where no development is to take place; 4 no further development is to take place; 2 where limited development can take place; and 1 for unrestricted areas.

By linking the transport algorithm output to mapping software we are able in 'real time' to observe changing vehicle flows, varying societal/personal/environmental risk exposures and transport operator economic costs. This shows, for example, that on roads very close to the depots there are high numbers of vehicles, but these soon fall off, as trucks go in different directions to the various delivery sites.

Data collection; software tailoring; and route selection

Data collection

Sources of data

DoME provides information about the location, size and good stored at all hazardous goods sites around the State. Some of these sites are supplied from outside Perth eg fuel sites supplied from the regional ports.

We assume that the amount of goods delivered to a site is proportional to the storage capacity on the site. As an example, a petrol station may have a storage capacity of a hundred tonnes of fuel for ten pumps to last for two months business. It therefore requires twenty five full truck loads a year to deliver six hundred tonnes of petrol. Each tonne of storage capacity requires about a quarter of a truck delivery a year.

Some hazardous goods for the country do start in Perth. Most of these goods derive from a few sites, including the Forrestfield rail site where interstate trains stop, from Fremantle harbour and from Kwinana and Kewdale. We constructed dummy sites on the major roads out of Perth to estimate the flow of these goods through Perth.

A road network is selected from MRWA's Perth road network. Any roads which are unlikely to be used (for example, because there are no possible delivery sites in the area) were excluded to assist in the data preparation and computation processes. The network data gives the length and node identities for each link, which allows the transportation algorithm to work out the shortest routes for all sources and destinations.

The accident statistics are supplied by MRWA, which collects this data in WA. Accidents are those reported, which includes those causing injury or major property damage, but excludes the smaller accidents which are unlikely to cause any spill

The number of people exposed is based on census numbers and population density around each link. The exposure radius should be five hundred metres from the road for chlorine and ammonia, the two common Class 2.3 gases in Perth and one hundred metres from the road for other hazardous products. In dormitory suburbs, census numbers give an overestimate of exposure, while it is an underestimate for working suburbs (eg Perth CBD and Kwinana). At this stage of the project we take census numbers to be a first approximation of exposure to use this approximation for the people along the routes.

The FESA rating takes account of the type of goods stored, population density, environmental matters, the economic worth of the area and the number and types of surrounding vulnerable sites, including schools and hospitals. The rating is based on the Brisbane study and gives a rating from zero to 520.

Setting up the network

The MRWA metropolitan network has seventy thousand non-directional links, giving nearly one hundred and forty thousand one way links. There are benefits in computational time in trimming out the links that are not useful, but one must ensure that the resulting network is connected, without cut off links in it.

The roads were selected as being either the MRWA freight network, or being between the different sites and this network. Arcview was used to select roads within a certain distance of each site, based on the shortest distance from that site and the freight network. This cut out about half the network, leaving about ninety thousand one way links

Data on population densities, crash rates and exposure are attached to each link.

There are two groups of runs These are:

To and from sites for general hazardous goods, ie all goods except Class 2.3 (poisonous gases, basically) and the population within 100 metres of any point on the network used, plus

To and from sites storing Class 2.3 gases, and the population within five hundred metres of any point on the network, and

To and from sites storing all categories except Classes 2 and 4 (gases and flammable solids) and the WRC rating of the effect of a spill.

The results can be mapped, showing the distance and exposure now, together with the distance and exposure when the exposure is minimised. Maps can also show which links take more traffic under the safety scenario, and which carry less.

When one has the data, one must decide which parts of the network to look at first. In many cases, the routes are similar in both the shortest distance and lowest exposure runs, so that the differences are the areas that should be investigated and talked about

Links with high flows tend to have a high exposure because the likelihood of an accident increases with the number of vehicles. Links that carry a high flow under both the exposure and distance scenario deserve investigation about how the exposure can be reduced, either by lowering the risk of an accident or finding a way to reduce the number of people at risk. If the flow is high for the distance run, but lower for the exposure run, one should consider ways to entice vehicles from one route to the other Areas where the flows and exposures are low under both scenarios will deserve less investigation.

Negotiation

There are several groups involved, just as there are several ways to improve the exposure. Groups include councils, road users, transporters and users of these goods, emergency services, and the public at large.

Ways to improve the exposure include the following:

i banning the use of some roads past hospitals and densely populated areas, which is nearly unenforceable if there are delivery sites on these roads, for example, hospitals

ii improving certain roads and intersections to reduce the likelihood of an accident

iii excluding these vehicles at certain times, for example school hours or the morning and afternoon rush hours or requiring night deliveries

iv modifying adjoining sites, for example by moving the entrance of a school to a side road from a major road v improving equipment at nearby emergency response sites, for example by having absorbent stockpiled near roads where a spill would have major effects on ground water

vi improving other roads to entice traffic out of high exposure areas

In general, there will be several approaches that can be used, so that negotiations will bring out the best mix of actions to improve the situation. One problem will be funding. This will require good will and good imagination to get things done quickly and well.

Implementation

Discussions should have given the areas that need attention first. The concept of 'duty of care' may provide pressure for certain groups to act.

If DoME recommends a set of routes to use and there is an accident, it should be able to say why it has suggested that these routes be used, and should show that someone has acted to ensure that these routes are not needlessly dangerous. The 'someone' may be the education department, Main Roads, the carrier or customer, or the local council, if these have knowingly left unreasonable hazard on the network.

If the carrier was on a route that DoME recommended he avoid, then he has some explaining to do. In some cases, where he is delivering to a site that is not otherwise accessible, he is in the clear, but others might not be.

Results

The initial results suggest that reality is correct. There are very few reported injuries from hazardous goods accidents because the level of exposure is low. It appears that total travel in the metropolitan area is of the order of sixteen million vehicle kilometres This should result in ten accidents if these drivers were as careless as you or I and it seems they are more careful than the average driver. Since each accident has a 6% chance of a spill/leak/fire (WS Atkins 1995), one would expect an incident where people are in the exposure area every eighteen months or so.

The annual DoME reports suggest that the leaks occur predominantly in the transfer yards, while most accidents on the roads occur in the country as a result of a major accident – generally a vehicle going off the road unexpectedly.

The following tables give an idea of truck movements around Perth.

Annual traffic task

Category of load	*Tonnage pa*	*Truck loads pa*	*Truck loads per day*
All hazardous goods	10 800 000	450 000	1 800
General hazardous goods	10 400 000	435 000	1 735
Chlorine, ammonia etc	400 000	15 000	65

Vehicle movements and exposure consequences

	Tonne kilometres pa	*Vehicle kilometres pa*	*Exposure –fatalities pa*
Minimum distance	368 million	15.4 million	7.6
Using major/freight routes	380 million	15.8 million	5.7
Minimum exposure	500 million	20.9 million	1.9

Truck movements per day on various links

Laden vehicles per day	*Number of links*	*Length in kilometres*
Over 500	61	26
100 to 500	823	471
10 to 100	587	220
1 to 10	1 723	488
Under 1	13 760	1 700
Not selected		Over 12 000

Expected years between fatalities

Years between fatalities	*Number of links*	*Length in kilometres*
More than 5 and up to 10	5	1
More than 10 and up to 100	137	28
More than 100 and up to 1000	974	508
More than 1000	15 840	1 710
Not selected		Over 12 000

There are repercussions from this work. For some time, local government has not been content with the method by which funds are distributed for road provision If road use is brought in as a factor to increase payments to a council, then the present distribution may change.

In the city, road pavements are built heavily to reduce future repair inconvenience. If hazardous goods flows are a reason for upgrades (better intersections, signals, etc) then they become a factor in distributing funds from councils with low hazardous goods flows to other councils. Dormitory suburbs will suffer as funds are sent towards industrial suburbs.

The first map shows the routes that were predicted for the movement of hazardous goods around Perth. There are basically three sources, at Fremantle Harbour, Kwinana and Kewdale, where the train freight terminal is. Fuel is delivered by pipeline from Kwinana Refinery to Kewdale, while some is imported via Fremantle.

The next map shows the heavily used routes around Perth. Only links where there are, or may be, over 100 loads a day are shown. These are shown as either "Traffic falls", where the traffic falls by at least 10 a day from more than 100 loads a day when going from the shortest route to lowest exposure scenario, "Traffic rises" shows the routes where traffic increases by at least 10 loads per day to over 100 loads a day when going from the shortest route to lowest exposure scenario. There are also some routes where the traffic remains at over 100 loads a day under both scenarios.

You may notice there are breaks in the links. This is where vehicles turn off, reducing traffic on the route below 100 loads a day, and where vehicles from other routes join.

Conclusion

This work suggests how hazardous goods are being distributed around Perth. It provides numbers that suggest why some routes are preferable to others. Safety is an emotive area, but we can show why society is better off if goods flow one way rather than another and suggest just what level of exposure a person is at from this traffic. We can suggest areas that seem to benefit most from improvements in the road or surroundings. We can also suggest different ways for carriers to act.

It is up to others to use this information. But we have the means to update this information so that we can see where future improvements are needed.

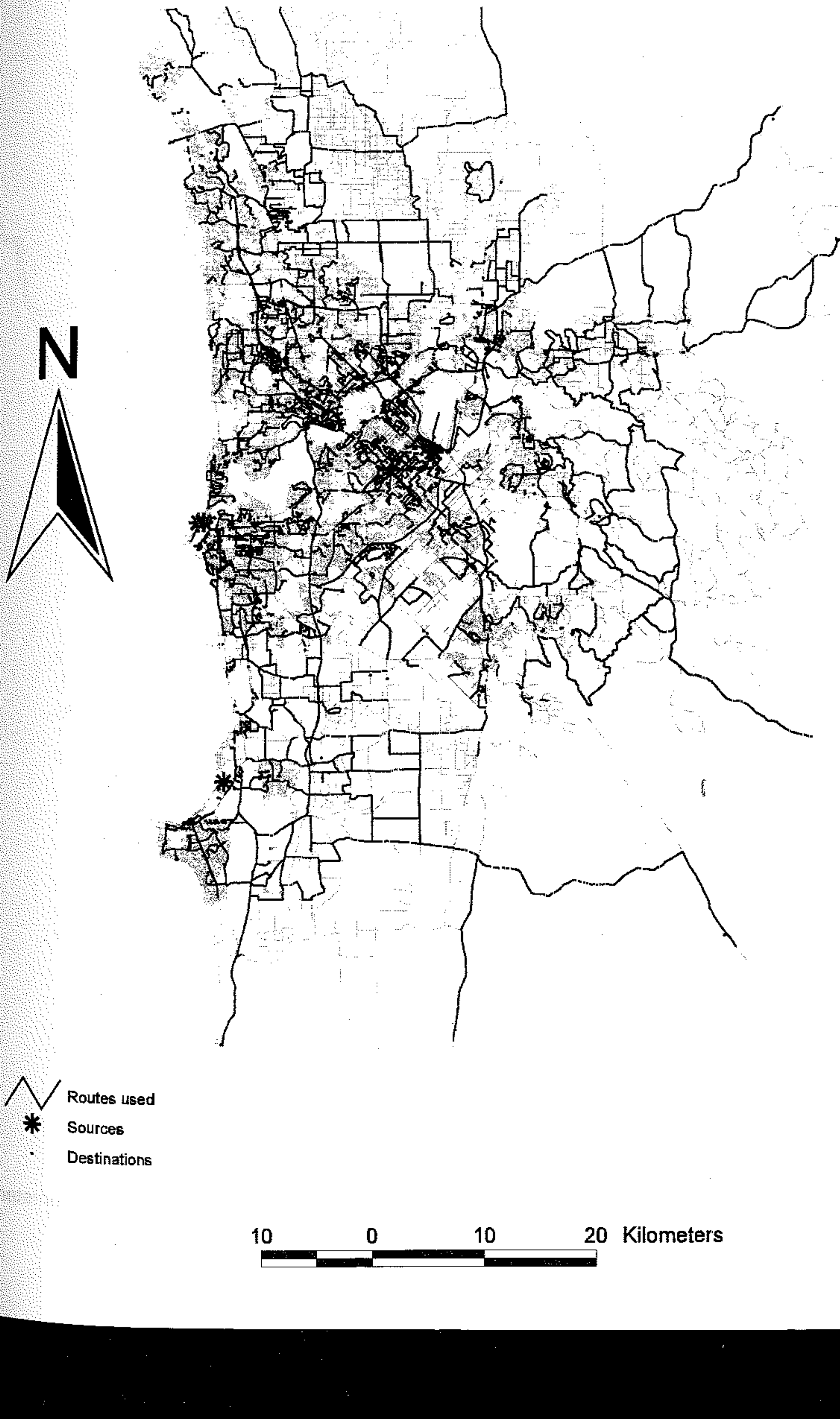
References

Middleton, G, Walker, M & Tsoukas, J (1992) A exposure assessment model for the movement of dangerous goods by road *Proceedings 16th ARRB Conference Part 4*

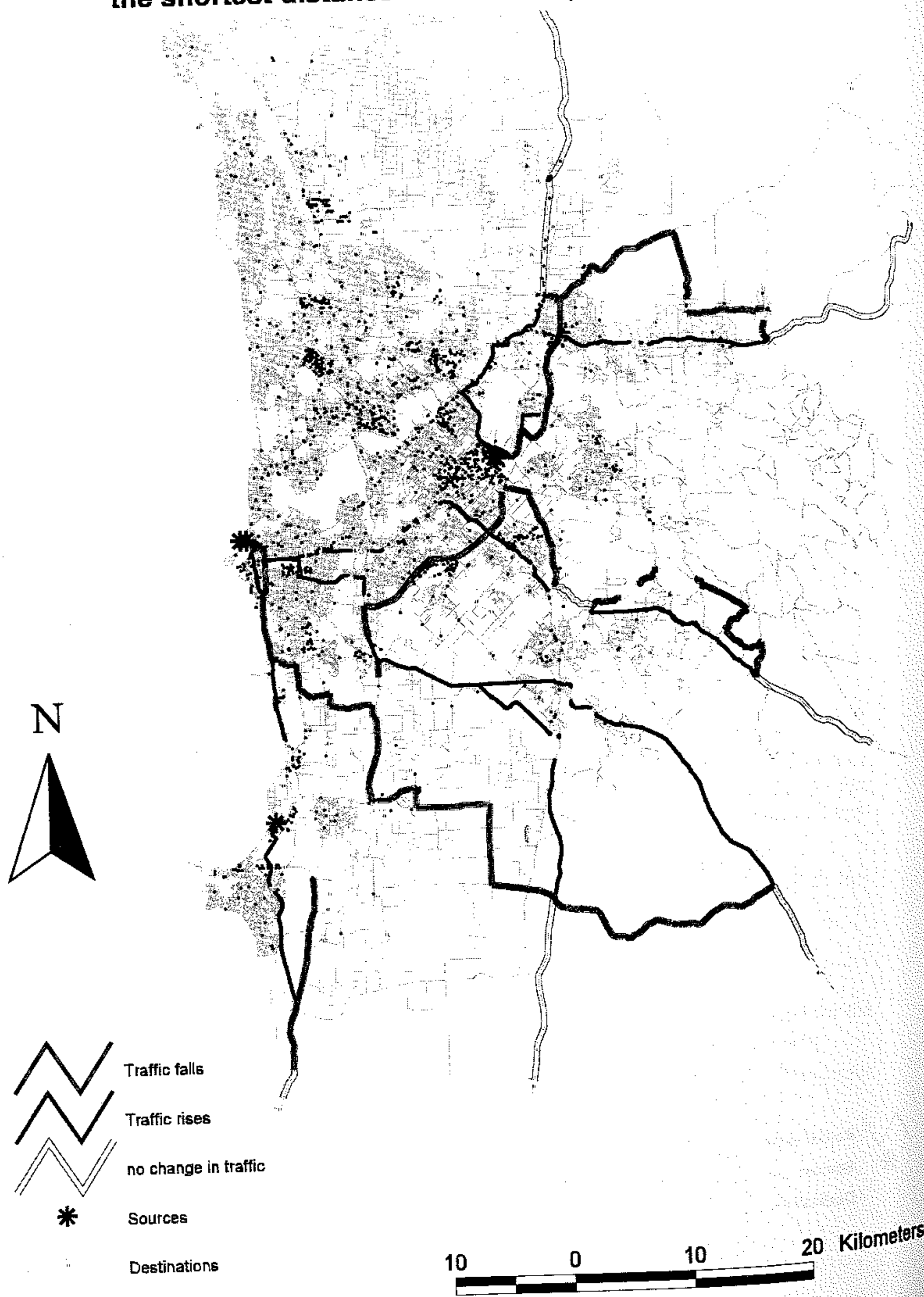
Bureau Veritas (1998) Assessment of Risk Associated with the Transport of Dangerous Goods *Study for Main Roads, Western Australia*

Atkins WA (1995) Exposure assessment study for Stage 1 Perth to Darwin National Highway *Study for Main Roads, Western Australia*

Links predicted for the transport of hazardous goods



Links with over 100 loads per day under either the shortest distance or lowest exposure scenario



Appendix A

The Transport Algorithm

This algorithm is used to minimise the cost of delivery from several sources to several destinations. Mathematically, the conditions are

Minimise $\sum$cost x flow over all links

Subject to:

Flow in + Supply = Flow out + Demand for each node and

$Flow_{min} <= Flow <= Flow_{max}$ for each link

The cost is either distance or exposure in this process. The following sample data table is an extract from some of the data. It includes the identity of each end of a link, the supply from sites on that link and the demand to sites on it. Flow is shown for the low exposure run (ie where exposure is used as a cost) and for the distance run (columns 5 & 6) while the next two columns show the cost in kilometres or micro-people exposure for that flow. The final two columns show the extra cost of putting the first unit of flow along that link when it is not used for that cost.

The first row of the table show that there is an extra overall distance cost of 2 units(cell J1) to deliver along that link compared to the shortest distance route.

The next two rows show that there are extra distance and exposure costs (columns J & K rows 2 & 3) to use these links. The fourth row (195 to 158) has a flow of 586 units (E4 for low exposure flow, F4 for shortest distance flow), which gives a distance cost and an exposure cost (H4 and G4 respectively). There is no increase in distance or exposure *over the optimum* if an extra unit went along that link, even though the actual distance and exposure would increase because of the extra traffic.

Row 6 (1099 to 1038) is the lowest exposure route, but is not a shortest distance route. By using this link, total distance is increased by 117 2 km (ie Cell F6 x K6 = 1 172 x 0.1) over the optimum.

Row 7 is a shortest distance route, not a lowest exposure route. Using it increases the exposure by a negligible amount (cell G7 x J7 = 1 172 x under 0.1) so that this is a road where exposure is increased negligibly by using the shortest route.

Links where the shadow exposure and shortest distance flows (Columns J & G) are high are the first links to be investigated to improve network safety, as are those with a high shadow distance and high flow (Columns K & F) need to be investigated from an economic viewpoint.

SAMPLE DATA

Row	Start of link	End of link	Supply	Demand	Flow at low exposure	Flow for short distance	Exposure cost	Distance cost	Extra exposure for an extra unit flow	Extra distance for an extra unit flow
A	B	C	D	E	F	G	H	I	J	K
1	155	158		586.0					2.0	
2	158	195		586.0					20.0	1.2
3	168	195		586.0					22.0	1.2
4	195	158		586.0	586.0	586.0	5 860.0	351.6		
5	238	195		586.0	1 172.0	1 172.0	8 204.0	468.8		
6	1099	1038			1 172.0		57 428.0			0.1
7	1186	1060				1 201.0		1 441.2		
8	2028	2032		138.0	138.0	370.0				
9	2209	2032		138.0					146.0	2.6

An example of how risk compounds

A link 100 metres long with an accident rate of 2 per million vehicle kilometres is likely to have an accident for every 5 million laden trucks that pass. If 200 loaded trucks a day pass (more than travel on 98% of the Perth road network) one would expect an accident on that stretch every 100 years. If there is an accident, there is a 6% chance of a spill and fire, so that one would expect one leak and fire every sixteen hundred years If there are 200 people within 100 metres of the fire,10% are likely to be killed - those very close have a low chance of surviving, while those even 60 metres away have a 99% chance of survival (Bureau Veritas 1998) So one expects about 20 fatalities from a fire that could happen once every sixteen hundred years, or one fatality per four million truck trips along that short stretch.