FIRE STATION OR PIZZA DELIVERY OUTLET: THE LOCATION METHODOLOGY IS THE SAME.

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1.0 INTRODUCTION

This paper will demonstrate that facility location software designed for locating warehouses, distribution centres or pizza delivery outlets can be used to determine the location of fire stations.

2.0 THE RESOURCE ALLOCATION MODEL

In June 1999, a project was set up to develop a Resource Allocation Model that would deliver a consistent and repeatable methodology for the resourcing of the New Zealand Fire Service. The model was developed using a risk-based approach.

The model was broken down into 5 modules. These were:

- Risk Assessment
- Mapping
- Fireground Incident Analysis
- Operational Resourcing
- Costing

This paper addresses the first two modules that relate directly to the Station Location methodology

3.0 RISK ASSESSMENT MODULE

The module concerned with assessment of risk determines overall community (or fire district) risk rather than site-specific risk. The approach developed is applied to the allocation of resources but will also help to identify high-risk communities where there would be benefit in targeting fire safety resources.

3.1 Historical Fire Data

Data on structural fire incidents contained in the New Zealand Fire Service - Fire Incident Reporting System (FIRS) was used to assess the historical risk for a community. Data was available in a consistent format for the years 1991 to 1998. The incident location was recorded using an address, which is not an appropriate input format for computer analysis. One of the first tasks was to convert each incident address into a set of spatial co-ordinates. This process is called geocoding. In the new FIRS 2000 system, incidents are assigned a GIS location automatically when the emergency call is received, and the process of geocoding is no longer necessary.

The FIRS data was located using the address recorded for each fire incident. This had to correspond with the address data contained in the mapping database. A process of “fuzzy logic” was used to try to make the most of a large amount of data of varying quality. The quality of the address information stored in FIRS made it possible to geocode about 74% of all calls. Most of those that could not be assigned to a specific geographic location lie in rural areas outside defined urban fire districts. The New Zealand Fire Service is formally responsible only for fires in urban districts, though it does assist where it can outside of these districts.

Once the geocoding was complete, it was possible to plot the incidents on a digital map for any part of the country.

In the future it will be possible to use a correlation based on the socio-economic factors to develop risk maps. For the present, historical data has been used. It has been shown that the numbers of incidents in the years 1991 to 1994 predict the fire incidence in the years 1995 to 1998 with an accuracy of about 80%. Whilst we cannot necessarily expect these trends to be maintained, the use of historical data is thought to be sufficiently accurate until better predictors can be developed. Accordingly for residential fire risk, historical FIRS data was be used to predict future expected fire calls.

For commercial fires, the number of fires in each district would be too small for historical data to provide a predictor of fire risk in the commercial sector by building use type.

3.2 Residential Fire Risk

Residential structure fires represent approximately 80 percent of all structure fires attended by the New Zealand Fire Service annually, and about 10 percent of all incidents to which the Fire Service responds. Nearly all fire deaths and a very large proportion of all fire injuries occur in residential fires.

3.3 Commercial Fire Risk

Commercial fires represent a much smaller proportion of the New Zealand Fire Service's structure fire and emergency response activity than residential fires, but these incidents have the potential to damage New Zealand's economic prosperity.

Secondary industry (manufacturing) - the nation's largest employment sector, experiences 27 times more fires on average per year than the average of all New Zealand businesses on a per establishment (location) basis.

Incendiary fires represent a significant proportion of all commercial fires (27 percent over the eight-year period); the industries with the poorest incendiary fire records appear to be those that experience frequent industrial tension or cater to young people.

Industries whose activities tend to be concentrated in rural or remote areas, such as utilities and agriculture, tend to experience greater property damage than those whose activities tend to be concentrated in urban centres; this suggests that prompt Fire Service attendance may have a positive influence in controlling fire damage.

3.4 Determining Optimum Station Locations

The object is to determine the optimum location of Fire Service stations so that the risk within a Fire District may be covered adequately. It is assumed that early attendance at an incident is a prerequisite of good risk management. It is therefore necessary to locate stations so that the overall likely time of attendance is minimised on a risk basis for the greatest expected number of incidents.

3.5 Attendance Times

The assumption is that the sooner the Fire Service arrives at an incident, the more difference they can make to the outcome. There is some debate as to the time before which the greatest improvements can be achieved, because so much is dependent on the state of fire development at the time of the call.

Some statistical analysis was carried out to try to determine the attendance time after which fire losses become more significant. The data did not reveal any very clear information, but it does appear that incidents attended prior to 10 minutes from the time of the fire call tend to show less damage and less fire spread than incidents attended later.

The time of attendance at an incident is composed of a number of components, including the time that the communications centre takes to process the call, the time that it takes the crew on a station to mobilise and the time of travel to an incident.

The 50% and 90% percentile travel times achieved at present were broken down nationally. Based on the data it appears that in 90% of cases nationally the first appliance travels to the incident in around 6 minutes from starting to move.

4.0 MAPPING MODULE

The optimisation of station location has been undertaken using a well-established software tool called TransCAD. This is an integrated Geographic Information System (GIS) and transportation analysis tool designed primarily for the management and analysis of transportation data. It also contains an advanced set of analytical tools for specific applications. One of these tools is for sophisticated facility location. TransCAD has been used in the four previous pilot projects analysing Station Location within New Zealand, and it has proved to be efficient for this process.

4.1 Base Map

In order to carry out the optimisation the software needs to have access to a digital map of the area under consideration. Most nationally available road centreline databases for use with GIS software have their origin in the Digital Cadastral Database (DCDB) from Land Information New Zealand (LINZ), a government agency. Providers of GIS products take this database, modify it and then on-sell it to the end user.

The Fire Service has used three mapping suppliers for the various station location projects.

All the maps supplied were found to be inaccurate, with many errors and omissions. An extensive validation and updating process was undertaken to ensure that the map accurately reflect the real road network. The Auckland project had fire crews drive every street in urban Auckland to achieve this. For all areas other than Auckland, the project made use of a map from NZ Aerial Mapping. Because the Communications Centres use it, it is subject to continual validation and updating.

4.2 Further Map Modifications

4.2.1. One-way Streets

The identification and mapping of one-way streets is an important part of the map validation process. Failure to adequately map an existing one-way system can have a major effect on proposed station location. Cities with extensive one-way systems where this is especially relevant are New Plymouth, Christchurch, and Wellington.

4.2.2. Turn Penalties

In any city road network there are places where certain turns are impossible. Such things as turning across median strips, or intersections where turning is prohibited are examples of this. The software is able to restrict turns on the network by use of a specific *Turn Penalty Table.*

4.2.3. 2-Way Flows

The mapping software allows for each street to have two values applied to every road segment. This has been applied to steep streets, where obviously the fire engine can make better time proceeding downhill.

4.2.4. Hills

Particularly hilly cities like Wellington and Dunedin require modification of assigned road speeds to compensate for their topography. In the case of Wellington, some suburbs have very narrow steep streets, with a lack of off-street parking; these were given a road speed value of only 20 km/hr.

4.2.5. Time of Day

Modifying road speeds to compensate for rush-hour flows was investigated. Analysis of calls by time of day failed to reveal any significant variation over the whole country, so it was decided to apply only one set of road speeds.

5.0 ROAD SPEEDS AND TIMES

5.1 Background

To optimise station location, it is necessary to use the risk map to determine the expected demand in terms of different types of fire incident. The time taken to attend each incident is then calculated on the basis of expected time of travel along the road network. The location of stations and/or appliances is then varied to achieve the optimum cover in terms of the shortest overall attendance times. A necessary component within the computer model is the assignment of road speeds that accurately reflect the average speeds of responding fire appliances. A number of previous studies have looked at this problem.

5.2 Christchurch Project 1997

In the Christchurch study the researchers obtained a computer map with four initial road classifications.

The project team assigned an initial speed of 40 km/hr to all the standard roads, and 20 km/hr to the other classes. All roads with faster travel times were selected and re-classified accordingly. This was done in consultation with operational personnel. The project report does not document the final road types/speeds selected, but clearly states that average rather than maximum speeds were used. Comparisons between the results they achieved, and those using the parameters of the current project show a very high level of compatibility.

5.3 Auckland Project 1998-99

After consultation with the Country Fire Authority in Victoria, Australia, where 13 classifications of Road type had been selected, the Auckland project selected 8 road type classifications. (The choice reflected the difference between an urban fire service and a predominantly rural fire service).

The road classifications selected were: -
Motorway
Major Urban Route
Major Urban Feeder
Minor Urban Route
Minor Urban Feeder
Suburban Link
Suburban Street
Environmental controlled street

After the computer map was modified to reflect these classifications, a series of workshops were set up to get input from operational staff, and to elicit feedback on the accuracy of the initial road types. These changes were incorporated in the map, and thematic maps displaying the road classification network were produced. It was immediately apparent that major variations of classification existed, particularly within suburban roads. Further workshops were held to allow a better integration of the whole road network.

A range of 8 road speeds were then assigned to these road types and the model run. Times were calculated from FIRS data for 1998 fire calls using 1st responding appliances. These calls were plotted on the map and the calculated response times displayed. The model times were then adjusted so that they coincided more accurately with the actual data.

Assignment of road speeds in the Auckland model have also been validated by using GPS data.

5.4 Current Project

Utilising the experience gained from the previous studies, and also reviewing other road network models, the decision was taken to use only 3 road classifications in the current model. Comparisons between a highly defined road network (8 classes of road) and a more simplistic one (3 classes) showed that virtually identical travel time results could be obtained.

When the NZ Aerial Mapping computer map was obtained, it had 5 road classes already defined. These are classified based on road type, ranging from accessway to motorway. The final decision was to utilise this database without modification. Speeds were assigned to these 5 classes that accurately reflected the average speed a fire appliance would achieve on the road type displayed. These speeds were ratified at workshops undertaken with operational crews. These speeds were then "fine tuned" to match those already obtained in the Auckland study.

6.0 ROAD SPEED VALIDATION

To ensure that the road speeds assigned to the model reflect actual response speeds; it is necessary to use real-time events as a comparison. This is done using four methods.

6.1 Historic Review

By re-running the problems from the three previous studies using current data, it was easy to make a comparison of variations. The results were almost identical, suggesting the current model's parameters were very close to those of earlier studies.

6.2 FIRS

Because the FIRS data contains the time that an appliance leaves the station and the time it arrives at an incident, it is possible to calculate the travel time. By comparing these times with those generated by the computer model, a measure of accuracy can be obtained.

6.3 GPS

The Global Positioning System (GPS) uses satellites to triangulate position and calculate speed. By installing a GPS unit and a Palm Pilot computer on a fire appliance an accurate track of both position and speed every 2 seconds was obtained. This was then plotted within the GIS mapping system to very accurately allow the average speed on any road sector to be gained. Currently 6 such units are deployed on Auckland Region appliances, supplying validation data.

6.4 Accident Data

A Land Transport Safety Authority database of all road traffic accidents for the last 20 years has a field containing the posted road speed. This was used to provide the legal speed of most road sectors, assisting with the allocation and validation of speed data. These speeds were compared with the assigned road speeds for Wellington and found to compare well.

6.5 Summary

Road speeds have been assigned to the 5 categories identified in the NZAM map. The assigned speeds have been checked in a number of ways, and are believed to reflect with reasonable accuracy the expected average travel speeds of appliances. The Fire Service Manual of Operations allows fire appliances to exceed posted road speeds by 25km/hr up to a maximum of 105km/hr, consistent of course with safety. The model does not however use this speed as an average speed as it seems unlikely that the excess speed would be achieved for the whole of a journey. In some cases however, the assigned travel speed to a road does exceed the posted road speeds.

7.0 NETWORK

After all travel information is entered into the database, it is then necessary to create a road network.

A network is defined as a set of nodes and links. Nodes are locations where flows start end or branch. Links are conduits that carry flow from node to node. In this study, a network is a representation of the road system. Nodes are typically located at intersections or changes of road direction and links are usually the section of road between them. TransCAD uses travel times or distance to create a simulated roading network by assigning values to each link. It is this network that is used for modelling purposes.

7.1 Tag to network

Although all the locations of structure fire incidents have been assigned a mapping co-ordinate, the demand points (fire call data) still have to be placed on the underlying road system. These are imported as a separate layer with nothing relating them to the road system layer. TransCAD links each demand point to the nearest node on the network.

8.0 COST MATRIX

In order to evaluate the cost of facility location solutions we first need to determine cost of service values for each demand point to every possible supply point. This is the amount of time or other cost, taken from each possible station location to every fire location on the map. These costs of service values are held in a cost matrix. (Figure 1) The rows are potential station locations and the columns relate to the fires. Note that "cost" in this sense does not refer to monetary value, but relates to the time to get to incidents. The time is the "cost" that we are trying to minimise.

Figure 1. Travel Time Matrix (seconds)

Matrix1 - Cost Matrix (TIME)

	9	75	80	109	136	181	202	278
37687	685.00	320.00	549.00	631.00	313.00	489.00	564.00	671.00
37688	693.00	328.00	557.00	639.00	321.00	497.00	572.00	679.00
37689	678.00	313.00	542.00	624.00	306.00	482.00	658.00	664.00
37690	674.00	309.00	538.00	620.00	302.00	478.00	654.00	660.00
37691	682.00	317.00	546.00	628.00	310.00	486.00	662.00	668.00
37692	1129.00	764.00	993.00	1075.00	757.00	933.00	1109.00	1115.00
37693	1124.00	759.00	988.00	1070.00	752.00	928.00	1104.00	1110.00
37694	1133.00	768.00	997.00	1079.00	761.00	937.00	1113.00	1119.00
37695	687.00	322.00	551.00	633.00	315.00	491.00	667.00	673.00
37696	686.00	321.00	550.00	632.00	314.00	490.00	666.00	672.00

9.0 FINAL MAPPING

Once all constraints and parameters are finalised, and the road speed data validated, the mapping model can then produce maps of the optimum fire station locations for each fire district.

The software operates by identifying demand points on the map and locating facilities to best serve the demand. In this case the historical fire incidents are the demand points and the fire stations are the facilities we are trying to locate. The software minimises the average time taken to serve all demand points from a facility or from a number of facilities.

It is possible to assess the advantages of the relocation of stations by comparing the number of incidents in each arrangement that fall outside of the target travel time, and also by comparing the average travel time for each arrangement.

There are several different ways in which the model may be run. The first is to start with an area under consideration for which the fire locations are known, but the station locations are, as yet, unknown. Starting with one station, the software locates the station in the best position to cover the risk. By applying network partitioning, using the station as the source it is easy to check to see if 90% or 95% (or whatever the agreed target is) of incidents fall within the target travel time. If not, the model is rerun, continuing to add stations until the target travel time is reached for an acceptable percentage of incidents.
Alternatively, it may be decided that for the area under consideration, one or more of the existing stations are not to be relocated from present positions. The model can be run to determine whether or

not this arrangement of stations can deliver the target attendance time to the accepted percentage of the incidents. If not, stations may be added until the target is achieved.

It is recognised that on many occasions when a fire appliance is summoned to an incident, it may already be off-station, carrying out fire safety work for example. On some occasions this will mean that the appliance has to travel further to the incident, but on others it will be closer than it does would have been at the station. It is assumed in the model that these two effects cancel out and that, on average, travel time is about the same, as it would have been from the station. It is recognised that this is something of a simplification, though not a serious one.

TransCAD may output two measures to assess its effectiveness. One is the proportion of fire incidents that fall outside of the target time. The second is the average time taken to attend all incidents. The optimisation routine is designed to minimise the latter, if the program can select all station locations. Where one or more stations have to be fixed, to existing locations for example, then the average time of attendance can be used to assess how far the proposed arrangement departs from the optimum.

9.1 PARTITIONING

Once the location of the facilities has been decided. This software allows the user to partition the network into various service or response areas. This allows the identification of coverage areas. This means that if the map says that a point can be reached in 5 minutes, it will be reached in 5 minutes every time. This is not the case in reality with any travel being that exact. This is only an issue along boundaries of coverage.

10.0 RESIDENTIAL RISK AND SOCIO-ECONOMIC INDICATORS

10.1 DepIndex96

The GIS coding of the FIRS data also allows incidents to be correlated with other data which is similarly coded such as census information. The latter is typically presented in geographical units known as meshblocks. Meshblocks are grouped into larger Area Units for some statistical purposes.

Studies in New Zealand and overseas have found relationships between the occurrence of fires and socio-economic indicators which suggest that fire incidence is more common in areas of low economic status. Accordingly a correlation was sought between the numbers of fires recorded in the FIRS system, allocated into mesh blocks, and the status of the residents of the meshblock as indicated by the Health Services Socio-Economic Index of Deprivation.

NZDep96 is an index of deprivation. The index combines 9 census variables from the 1996 census, which reflect aspects of material and social deprivation. NZDep96 provides a deprivation score for each meshblock in New Zealand. Meshblocks are geographical units defined by Statistics New Zealand, containing a median of about 90 people.

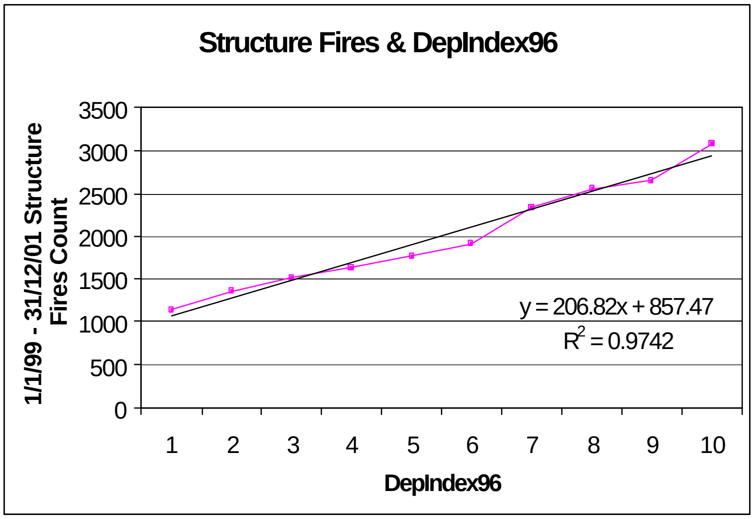
NzDep96 combines the following census variables (calculated as proportions for each small area);

1.	Communication	People with no access to a telephone
2.	Income	People aged 18-59 receiving a means tested benefit
3.	Employment	People aged 18-59 unemployed
4.	Income	People in households with equivalised* income below an income threshold
5.	Transport	People with no access to a car
6.	Support	People aged <60 living in a single parent family
7.	Qualifications	People aged 18-59 without any qualifications
8.	Owned Home	People not living in own home
9.	Living Space	People in households below equivalised* bedroom occupancy threshold

*Equivalisation: methods used to control for family composition

By plotting the occurrence of residential structure fires on a map layer containing the meshblocks with the deprivation index, a very strong correlation was obtained (Figure 2).

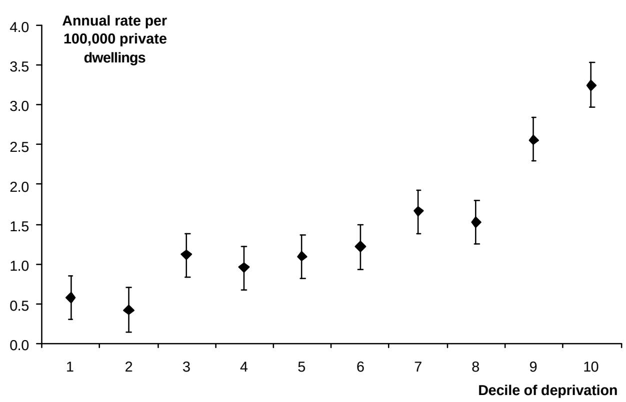
Figure 2. Structure Fires and the Deprivation Index



The 10 percent of New Zealanders in the lowest socio-economic category suffer nearly 2.5 times greater risk of experiencing a fire than the most affluent 10 percent and almost twice the risk of the average New Zealander.

Further research also established a correlation between fire deaths and a low socio-economic status (Figure 3). This suggested that those people in Decile 10 were 6 times more likely than those in Decile 1 to die in a residential fire.

Figure 3. Deprivation Index and the Fire Death Rate



The DepIndex has proved to be a reliable predictor of the likelihood of residential structure fires. Instead of using historical fire data to determine the location of fire stations, but using the socio-economic makeup of a community instead, the fire stations can be better placed to serve the greatest areas of risk.

Bas Cuthbert is a 27-year veteran of the New Zealand Fire Service. Working his way up through the ranks, his last operational appointment was as Fire Chief of Waitakere City.
His present rank is Assistant Fire Region Commander attached to the National HQ, developing, in conjunction with a multi-discipline team, a national Resource Allocation Model. He has been involved in the mapping aspects of the project, particularly, the station location modeling.