Models For Fire Station Location: A Review and Improved Distance Estimation Method Tested For Winnipeg

by

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A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

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ABSTRACT

Over the last two decades, researchers have developed several models which can be of help in determining how to locate and allocate fire fighting units in such a way as to best meet emergency service objectives. This thesis begins by reviewing these models.

The fire station location models measure performance in terms of response times to emergency incidents. The largest and most variable component of response time is the travel time from source to destination points. Various methods have been suggested and used for estimating travel times, but they tend to either be insufficiently accurate or require very large amounts of data. In this study, some simple methods for estimating travel time which have been used in models are tested for Winnipeg. A new algorithm is developed and tested which provides more accurate travel times for a city which has some major barriers to travel, while at the same time having small data requirements.

The review of available models revealed that most of the models developed for fire station location assumed that units are always available when an incident arises. In order to test the validity of this assumption for Winnipeg, incident data was studied to determine utilization rates for fire service units and the distribution of inter-arrival and service times for fire incidents. Finally, a model is suggested which would be helpful for fire service planning in Winnipeg, and the procedure for implementation is outlined.

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Chapter 1

INTRODUCTION

Providers of emergency service for a city have the responsibility of locating and deploying their emergency units in such a way as to provide the best possible service. In the case of a fire department, achieving optimum service means minimizing human injury and property loss by efficient allocation of limited resources.

Considerable effort has been made by researchers to develop models that can help in deciding how best to locate units. Since a way has not been found to directly predict life and property loss resulting from a certain allocation of fire units, response time to incidents has been generally accepted as a measure of performance. Researchers have attempted to find models which will suggest how to allocate available units to best meet response time objectives. Chapter 2 reviews the research that has been carried out with the objective of improving emergency service deployment.

A review of the literature on location modelling for emergency services results in the conclusion that, before a methodology can be chosen to help in locating emergency units in a particular city, the following questions must be answered:

1) What travel time estimation method can be used to provide accurate estimates of travel time from supply points to demand points?
2) Is it necessary to take into account the possibility of a unit being busy when needed?
3) What is the criterion to be used for measuring service provided? This criterion is usually stated in terms of desired response times, but can vary from minimizing average response time to providing equal response times to all areas of the city.

The third question can only be answered by policy-makers, who must weigh the importance of various, often conflicting, criteria, such as providing an efficient service as opposed to providing equal coverage to all. A great deal of insight into the other two questions can, however, be obtained for a particular city by studying the available information about demand for service and travel characteristics. This paper attempts to answer the first two questions for the City of Winnipeg. Chapters 3 to 5 discuss several methods that have been used in models to estimate travel times, and review data for Winnipeg to find an appropriate method for that city. A method is suggested that improves over those previously used. Chapter 6 looks at incident data in order to provide an answer to Question 2 for Winnipeg. In Chapter 7, findings are summarized, other implementation issues are discussed, and an appropriate model for Winnipeg is suggested.

Chapter 2

REVIEW OF LITERATURE

Researchers have advanced many models to try to shed light on the problem of how to locate emergency services in such a way as to minimize response times. Mirchandani and Reilly (1987) classified these models into two types: static models, which assume that all units are always available for dispatch to an emergency incident, and dynamic models, which allow for the possibility that some units will be unavailable if they are busy at other fires. These two types of models will be discussed separately below.

Models can also be classified (Mirchandani and Reilly) as evaluation and optimization models. Evaluation models give performance results for a configuration of company locations which the user suggests. Optimization models produce a configuration which is optimal, based on certain specified criteria. These terms will be used in the discussion of the models.

In general, the following procedure is followed in modelling an emergency service system involving mobile server units:

1. The area being studied is divided into small homogeneous sub-areas or zones. A central point

is chosen from which traffic will be assumed to originate or end. This point may be the geographical centre of the zone or the centre of gravity in terms of the number of demands for service.

2. A method of finding travel times between zones is determined. The travel times may either be calculated by the model or fed into the model.
3. The model then either evaluates a configuration of emergency service locations that is fed in, in the case of an evaluation model, or determines the optimum locations for units, in the case of an optimization model. In both cases the yardstick that is used is response time to emergency incidents.

STATIC MODELS

One of the first studies which specifically addressed the problem of locating fire services was carried out by Hogg (1968). She used a p-median type of model. This model locates "p" fire-fighting units in such a way as to minimize the total travel time to all fires. The study assumed that the rate of fire incidence was known or could be estimated from population densities. Travel times were estimated from run data and from the results of an experimental set of journeys, and were fed into the model. The total travel time was calculated as the sum for all zones of the travel time to the nearest station times the number of incidents in the time period being studied. The p-median model is formulated as:

$$\text{Min } Z = \sum_{j=1}^{n} \sum_{i=1}^{m} f_i t_{ij} x_{ij}$$

subject to

$$\sum_{j=1}^{n} y_j = p$$

$$\sum_{j=1}^{n} x_{ij} = 1 \qquad i=1,2,\ldots,m$$

$$y_j \geq x_{ij} \qquad i=1,2,\ldots,m; j=1,2,\ldots,n$$

$$y_j, x_{ij} \in \{1,0\} \quad i=1,2,\ldots,m; j=1,2,\ldots,n$$

where

y_j = 1 if a facility is located at site j, 0 otherwise,

x_{ij} = 1 if a facility at site j serves zone i, 0 otherwise,

f_i is the number of incidents in zone i for the time period,

t_{ij} is the travel time from zone i to site j.

The choice of minimizing total travel time is good in that it avoids locating too many stations in areas with very low demand. It can, however, result in poor coverage for the low-demand areas. The method used assumes a linear relationship between response time and fire damage, but Hogg suggested that a better knowledge of the actual relationship between these factors would improve the usefulness of the model.

In the late 1960's, a major study was undertaken by the Rand Institute for the U.S. Department of Housing and Urban Development and the New York City Fire Department. This project (see Ignall et al. 1975), which took about eight years to complete, was geared toward improving the delivery of New York City Fire Department services in the face of skyrocketing demand. Results were intended to be applicable to other large metropolitan areas as well.

At the time of the study, New York City had 375 fire companies and the most fires of any city in the world. The study looked at trying to improve effectiveness through changes in three areas: allocation of companies, dispatch policy and relocation. Relocation refers to temporarily moving companies to fill gaps caused by a busy period in a certain area.

The number of fires in New York was increasing constantly and it was found that the traditional solution of adding more companies was not keeping up with providing the desired service. The dispatch policy was to send the closest units to a fire and to send three pumpers and two ladders, if available, but at least one pumper and one ladder. When the situation was analyzed, it was found that since companies were so busy (at the busiest times it was not uncommon for half the companies in the City to be responding to incidents), in most cases three pumpers and two ladders were not available. Adding extra units merely filled out the number of units being dispatched to incidents without making more units available to wait for new incidents.

A model was developed (see Swersey 1982, Ignall 1982) to aid dispatchers in implementing an adaptive response to incidents based on the following three factors:

1. The probability of an alarm being serious;
2. The expected alarm rate in the area surrounding the alarm; and
3. The number of units available in the area surrounding the alarm.

By sending fewer pumpers and ladders out to some of the incidents, it was possible to increase the number of units available for future incidents.

In order to assess how many companies were needed and where they should be located, Rand developed a "square root model" (Kolesar and Blum 1973) which could predict average response times in the regions of a city by knowing the regional alarm rate, average service time, area and the number of companies in the region. The expected average travel time, t, is calculated simply as

$$t = c(A/(n-b))^a$$

where A is the area of the region, n is the number of companies allocated to the region, b is the average number of companies busy in the region, and c and a are empirical constants that depend on the street configuration. This model assisted in determining whether any regions were not adequately covered and whether any could have companies removed without reducing coverage unacceptably. It assumed that units did not travel outside of their regions, which might result in inaccuracies for some cities.

A discussion follows of two other models which were produced by the Rand study: the Parametric Model for the Allocation of Fire Companies and the Firehouse Site Evaluation Model. Two other models developed by Rand at that time, the Hypercube Queuing Model and the Simulation Model of Fire Department Operations, will be discussed in the section on dynamic models.

The Parametric Model for the Allocation of Fire Companies (Rider 1975) was developed as an aid in determining the number of fire companies needed in different parts of a city. It recognized that there may be two conflicting objectives: reducing average travel time, which would suggest locating companies in the areas of greatest alarm activity, and providing equal service to all parts of a city, which would imply spreading fire companies out evenly throughout the city.

The Parametric Allocation Model provides an explicit tradeoff parameter. It uses travel time as a measure of system performance and generates allocations satisfying criteria ranging from the minimization of city-wide travel times to the equalization of average regional travel times as the tradeoff parameter varies.

The measure of travel time used is average travel time in a region (as calculated by the "square root model" mentioned above), where a region is an area of the city which is relatively homogeneous with respect to fire hazards, potential firefighting problems and alarm incidence. This model is intended to help with the problem of how many fire companies to locate in each region of a city, but does not address the question of where to locate companies within the region. It assumes that fires in a region will be serviced by a company located in that region.

The Firehouse Site Evaluation Model (Dormont, Hausner and Walker 1975) was developed to assist in deciding how many fire companies should be on duty in a city and where they should be located. It provides a way to estimate fire protection levels, measured by response time, that would result from any given arrangement of fire companies. By comparing the fire protection levels resulting from various arrangements, a fire department can make rational decisions about the location of its fire companies. It is more detailed than the Parametric Allocation Model in that it evaluates exact locations of stations and finds the response time for each demand point in a city.

The model does not by itself generate alternative firehouse configurations. However, the information provided about the travel-time and workload characteristics of proposed configurations will suggest ways of changing the arrangement to improve performance.

Travel distance can be estimated in the Firehouse Site Evaluation Model as either the right-angle distance or the straight-line distance (or some fixed multiple of straight-line distance.) No consideration is given to barriers to travel. Travel distance is converted to travel time using algorithms developed by Kolesar and Walker (1973) from their study of the travel characteristics of New York City fire companies (see Chapter 5).

Toregas et al. (1971) viewed the location of emergency services as a set covering problem. The maximum time or distance that separates a user from his closest service is viewed as the crucial parameter. An upper limit is placed on the response time or distance to any user, and consideration is then given to determining the minimum-cost spatial arrangement of service facilities that adequately serves the entire user region. If costs are identical for all possible facility locations, then an equivalent problem is to minimize the total number of service facilities required to meet the response time or distance standards for each of the users. The solution to this problem will indicate both the number and location of the facilities that provide the desired service. It is assumed that the user demands can be represented as occurring at a finite set of points and that the potential locations for service facilities are also a finite set of points. It is also assumed that the minimum distance or minimum response time between any user-node and service-facility pair is known. The formulation of this problem is stated succinctly in Merchandani and Reilly (1987) as:

$$\text{Min } Z = \sum_{j=1}^{n} Y_i$$

Subject to

$$\sum_{j=1}^{n} a_{ij} y_i \geq 1 \qquad i=1,2,\ldots,m$$

$$y_j \in \{0,1\} \qquad j=1,2,\ldots,n$$

where

m is the number of zones,

n is the number of available sites,

a_{ij} = 1 if zone i can be served by a unit at zone j without violating constraints, 0 otherwise.

A drawback of this approach is that it ignores differences in the demand levels at various points, and since it also does not take into account the possibility of units being busy when needed, it will tend to locate too few units in high demand areas. This problem can be alleviated to some extent by requiring shorter response times for high-demand areas. This study was a precursor to the "Fire Station Location Package" (Public Technology Inc. 1974), a model developed under contract with the U.S. Department of Housing and Urban Development to evaluate firehouse locations.

The Fire Station Location Package estimates travel times using a street network. The city is broken down into "fire demand zones." A street map of the region being studied is converted into a computer-readable network description in which street intersections are represented as nodes, and streets are the connecting arcs between the nodes. An estimate is made of the average speed at which a fire company would travel along each arc. The speed of travel and the length of the arc determine the average time for a fire company to traverse it. The travel time from any firehouse to any fire demand zone is then estimated by finding the set of arcs that form the shortest time path. The model therefore explicitly accounts for barriers.

This model can be used either in "descriptive" or "optimization" mode. In its descriptive mode, reports are produced providing such information as the workload for each fire company and the covered and uncovered zones in the city. A covered zone is defined as one which can be responded to by at least one station within the specified desired response time. In its "prescriptive" or optimization mode, the Model will choose from a large set of potential firehouse locations the smallest subset that will provide certain required travel times to a set of points in the city. Public Technology Inc. reported in 1977 that 52 cities and counties had used the Fire Station Location Package (Chaiken 1978).

Hendrick et al. (1974) borrowed from Public Technology Inc. locator model concepts and data base requirements in their study of fire department operations in Denver, Colorado. One aspect of this study was the employment of various location methodologies to determine whether the level of service could be maintained while reducing the number of companies. Both evaluation and optimization methods were used. The optimizing method was formulated as a set-covering model. The objective was to determine the minimum number of stations out of 120 possible locations which would satisfy required response times. Demand areas were coded with various degrees of hazard, with associated required response times. One of the features of the Denver project was the development of new concepts to generate cost-effective station configurations which place special emphasis upon the use of existing fire stations.

The question of barriers was examined as part of a response time experiment which was carried out in order to verify the use of a right-angle distance calculation combined with a formula for travel time, none of which took into account barriers. About 1600 actual fire vehicle responses were timed and these were matched with the calculated response times. The team investigated several unusually long response times which had been identified to determine whether it had been necessary for the vehicle to cross a barrier. In only two cases from the nearly 1600 observations was it obvious that a barrier had substantially lengthened the response distance, and hence the response time. They concluded that in Denver a rectilinear calculation would be adequate without adjusting for barriers.

In order to overcome the problem of the set-covering model not taking into account differing demand rates between regions, Church and ReVelle (1974) formulated the maximum covering location model to maximize the total number of covered demands. They located a fixed number of emergency vehicles in such a way that the maximum number of demands for service were covered.

Schilling et al. (1980) also used a set-covering approach in a study conducted with the Baltimore Fire

Department. The model which was developed located a certain number of facilities in such a way that the largest number of people would have a facility within the maximum allowable service distance (or time). This model could be adjusted to take into account other criteria for allocating stations such as property value, number of fires and land area. Other models were also developed as part of this study. The "capital improvement" study assumed that K stations were to be relocated and then evaluated which K stations to move and to what locations. The "reallocation model" determined how the existing companies should be allocated to the new configuration of stations to ensure that each demand point has a pumper and a ladder within its response distance standard.

Mirchandani and Reilly (1987) suggested that using travel time as a proxy measure of the cost of a certain configuration of station locations may produce less than optimum results because this method assumes that there is a linear relationship between cost and travel time. They suggested a model which can take into account a nonlinear relationship between cost and travel time by incorporating utility functions for various response times of both first and second-due units. The model cannot be solved exactly, but a solution can be obtained through heuristic methods.

The model was applied to the Albany Fire Department, incorporating separate utility functions for low-risk, property-risk and high-risk fires and for first- and second-due pumpers (engines) and ladders. Travel distance was determined by dividing the city, with a population of 102,000, into thirty-eight zones and determining travel distance between each pair of zones as the rectilinear distance measured on a map. Travel time was obtained from distance using Kolesar and Walker's (1973) travel-time/distance model.

Several researchers have extended models to incorporate probabilistic travel times (see, for example, Mirchandani and Odoni 1979; Chelst and Jarvis 1979; Daskin 1987). They show that different optimum locations may be found if the distribution of travel times is considered, rather than using the mean travel time.

DYNAMIC MODELS

Models for fire station location that take into account the possibility of units being busy when needed are not as prevalent as those that do not. The reason for this is that fire companies in most cities are busy only a small percentage of the time (Dormont, Hausner and Walker 1975). Some of the models discussed in this section were developed for ambulance location; however aspects of them may be found useful for fire station location if the utilization rate is found to be high enough that the units cannot be assumed to be always available.

In some cases simulation models have been used to verify the findings from static models by introducing the possibility of the closest unit being unavailable when a demand occurs. Uyeno et al. (1981) created an ambulance location system for the British Columbia Provincial Ambulance Service. They found rough locations with a p-median model, which minimized average response time from p ambulance bases, and fine-tuned the results with a simulation model. This model has been applied to ambulance location in Vancouver, Victoria and Edmonton.

To determine travel time, the region is broken down into sub-regions with calls assumed to take place at the central point. A most-likely route is plotted between each pair of adjacent sub-nodes and the distances converted to travel time using average ambulance speeds over various classes of roads. The travel time between any pair of non-adjacent nodes is found by applying a shortest-route algorithm, using the travel times between adjacent nodes.

A simulation model was also used by Rand (Carter 1974) as part of their study of the New York City Fire Department. It was designed to examine the effect of modifications in any of the number of companies on duty, the location of fire stations or the rules used to dispatch and deploy the available companies. Travel distance is calculated based on a rectilinear or Euclidean distance obtained from the coordinates of the fire station and incident locations.

Travel time is calculated from distance using the algorithm developed by Kolesar and Walker (1973). Chaiken (1978) reports that although this model was tested and found useful in New York City and Denver, it had not at the time of his report been used by other cities. He suggests that the reason for this is that earlier applications validated the results of the Parametric Model and the Firehouse Site Evaluation Model which are less costly to implement.

Another model which resulted from the Rand study was the "Hypercube Queueing Model" (Larson 1974). It was intended for use by police and ambulance agencies for design and evaluation of fixed sites for their units and/or response areas for the units. It assumes that only one unit is dispatched to each incident. Larson suggests that it is suitable for use by agencies which often have ten percent or more of their units busy at one time. The standard estimate of travel distance is the right-angle distance. This assumption can be overridden and a matrix of travel times substituted. Alternatively, a few selected travel times can be put in to override the distance calculation for certain source-destination combinations.

The Hypercube model is an evaluative model which gives values of certain performance measures (such as workloads of units and travel times to emergency incidents) for various arrangements of patrol areas. Larson (1975) also developed an approximate procedure for computing selected performance characteristics of an urban emergency service system. This method provides results which are very close to those of the Hypercube Model without the investment of computer resources required by the Hypercube Model.

Fitzsimmons(1973) developed a model which was specifically intended for emergency ambulance deployment. His model, like the Hypercube Model, used a queueing model to account for the fact that the response time for a particular call depends on the state of the system when the call is received. He found in the course of his study, utilizing the experiences of the City of Los Angeles, that often when a medical emergency occurs the ambulance that would normally be assigned is busy; therefore an idle, but more distant, ambulance is dispatched. Fitzsimmons used a right-angle distance calculation, based on the (x,y) coordinates of the source and demand points. Travel time was calculated as a function of the distance travelled, taking into account a faster travel speed for longer trips. The objective was to minimize mean response time. Fitzsimmons stated that, if desired, a maximum response time to any demand point could be included as a constraint. A computer version of this model referred to as CALL (Computerized Ambulance Location Logic) was used successfully in the planning of emergency systems in the cities of Los Angeles and Melbourne.

Daskin (1982) extended the maximum covering location model (discussed in the section on static models) to allow for the possibility of a unit being busy when needed. His "maximum expected covering location model" incorporated a probability "p" that a randomly selected vehicle would be busy. He admits that certain assumptions which he makes may limit the accuracy of the model, but suggests that the results are a much closer approximation to reality for a system that has a large percentage of busy units than a model which ignores the possibility of a unit being busy when needed.

SUMMARY

There are several models and techniques which have been helpful in providing the types of information that can allow fire department planners to make better decisions. The problems of how many fire fighting units are needed and where they should be located are addressed by five main types of models:

1) Set covering models
2) P-median models
3) Queueing models
4) Simulation models
5) "Descriptive" models

The best type of model to be used in any particular study will depend on such factors as what type of objectives for response time are to be met and how busy the units generally are. It has been accepted by many researchers that if fire fighting units are busy less than about five percent of the time, it is not necessary to taken into account the possibility of the closest unit being unavailable. Chapter 6 discusses findings with regard to utilization rates in Winnipeg.

An issue that is often largely ignored in discussions of particular models is how travel times from fire stations to demand points are to be estimated. This is not a trivial problem. Objectives for models are stated in terms of response times, of which the biggest and most variable component is travel time. Therefore accurate estimates of travel time are essential in order that credible and useful results are produced.

Large numbers of travel time estimates are needed. It is usual to divide a city into zones for a study. If a city was divided into 100 zones, with travel assumed to begin and end at a zone centroid, 9900 estimates of travel time between centroids would be needed (or 4950 if it is assumed that $d_{ij}=d_{ji}$ for all points i and j, where d_{ij} is the distance from point i to point j.) An efficient method of estimating large numbers of travel times is needed.

Chapter 3 discusses some methods of travel time estimation that have been used and suggests an improvement to one of the most commonly used methods. Chapter 4 shows some results of applying these methods to Winnipeg. Chapter 5 looks at various functions which might be used to estimate travel time when distance is known and evaluates these for Winnipeg. Chapter 7 brings together all of the findings discussed in this paper and shows how they could be applied in choosing an appropriate model to be used in fire department locational planning for Winnipeg.

CHAPTER 3

ESTIMATING TRAVEL DISTANCE

Any model to be used as an aid in determining where to locate mobile emergency service units must have a method of estimating travel time from service points to demand points. There are two basic methods that have been used in location models. One is to calculate the Euclidean (straight-line) or rectilinear distance using x-y coordinates of the source and demand points. The other method is to create a network with streets and intersections as links and nodes, and then use a shortest path algorithm to calculate distance. These two methods will be described in more detail in the following two sections.

EUCLIDEAN OR RECTILINEAR DISTANCE ESTIMATE

Methods of estimating travel time which use Euclidean or rectilinear distance functions assume that travel time can be estimated reasonably accurately from the straight-line or rectilinear distance between points regardless of the region of the city or the actual routes available between the points. Once a distance is calculated, the distance is inserted into a formula to estimate the travel time. Chapter 5 discusses in detail the problem of estimating travel time from distance.

Distance estimation methods based on Cartesian coordinates were used in the Rand models developed to plan the location and deployment of emergency services (see Chapter 2 for a detailed discussion of these models). Their Firehouse Site Evaluation Model (Dormont et al. 1975) allows a choice of three alternative calculations to find the distance between two points with coordinates (X_1,X_2) and (Y_1,Y_2):

i) Straight-line or Euclidean distance, calculated as

$$\sqrt{(X_1-X_2)^2+(Y_1-Y_2)^2} \tag{3.1}$$

ii) Rectilinear distance, calculated as

$$|X_2-X_1| + |Y_2-Y_1| \tag{3.2}$$

This function was found to apply in cities where the streets follow a rectangular grid pattern.

iii) Straight-line distance times a factor, K, which is dependent upon the street patterns and geography of the city. This was found to be useful in many cities where the streets do not follow a rectangular pattern. Based on empirical data gathered

> in several cities, they found that the value of K varies only slightly from city to city, and that the value K=1.15 provided a good estimate for most cities.

The rectilinear calculation was also used by Fitzsimmons (1973) and Mirchandani and Reilly (1987).

Love and Morris (1979) evaluated the accuracy of several different distance-estimating functions using samples of urban and rural road data. They found that the Euclidean distance function estimated urban distances more accurately than the rectilinear function in most cases, unless the road network had a strong rectangular bias.

USE OF A NETWORK MODEL FOR CALCULATING TRAVEL DISTANCES

When estimates of travel times within a city or region are needed, a network approach is often used. A complete street network of a city has each intersection included as a node, with streets as the connecting links between the nodes. The links can be directed to account for one-way streets and estimates of the average travel speed along each link are also recorded. The travel time from any node in the network to any other node is then estimated by finding the set of links that form the shortest time path.

This approach is used in the Fire Station Location Package, which was developed by Public Technology Inc. (1974).

COMPARISON OF DISTANCE ESTIMATION METHODS

Each of the techniques discussed above has some advantages and some disadvantages. Choice of a method involves weighing these factors against the particular geographic characteristics of the region being studied as well as the purpose for which the travel times are to be used.

The distance calculation methods based on the Euclidean or rectilinear distance have the advantage of being relatively much easier and much less time-consuming to implement than the network methods. Some preliminary analysis should be done to determine the appropriate function to use, and then the required data is only the x-y coordinates of each zone for which service is required. A city can thus be divided into very small zones without resulting in data requirements being unmanageably large. This type of distance calculation can never, however, be exactly accurate for a city. Certain geographical factors which affect travel time can not be taken into account. For example, barriers such as parks, rivers and railway tracks can increase travel time, as can variations in speed and directness of available routes. A network, on the other hand, can be tailored to take all of these factors into account, but it requires a major commitment of time, both to create the network initially and to update it when changes occur. All nodes, their links to other nodes, the lengths of the links, and average travel speeds must be coded.

The use of a Euclidean or rectilinear distance estimate is the method that has most often been incorporated into models for locating fire stations. However the model that has most often been used by fire departments to aid in locational decisions is the Fire Station Location Package (Public Technology Inc. 1974), which requires a computer network. It is likely that a major reason for the success of this package is the fact that it does use a network, and can allow for irregularities of streets and barriers in a city. This inspires confidence in the user that accurate travel times can be obtained. However a great deal of data must be collected and, judging by the experience of the City of Winnipeg Fire Department, where this package has been used, a lengthy testing and "fine tuning" process is necessary to ensure the accuracy of results.

EUCLIDEAN OR RECTILINEAR FUNCTION WITH BARRIER ALGORITHM

Use of a Euclidean or rectilinear distance estimator can lead to some inaccuracies when barriers are involved, such as when two points being considered are on opposite sides of a river with no bridge along the Euclidean path between them. However the alternative of using the computer network is a costly one.

It is worthwhile to consider whether barriers can be taken into account with a variation of the Euclidean or rectilinear distance estimation method. One way to do this is to require that when distance is needed between two points separated by a barrier, the distance used is the sum of the distances from each point to the connecting bridge. If several bridges are available, the minimum distance path would be used. For example, in a city divided by one river with two bridges at points k and n, the distance, d_{ij}, between two points i and j on opposite sides of the river is expressed as:

$$d_{ij} = \min\ (d_{ik}+d_{kj},\ d_{in}+d_{nj}) \qquad (3.3)$$

A FORTRAN program to perform this calculation was developed for this study. To use this program, the city being studied must be divided into regions based on the locations of barriers. That is, if two points are separated by a barrier with a limited number of crossing points, they must be in separate regions. To find the distance between the points, the x and y coordinates for each point must be known, as well as in what region they lie. Then the program determines from a matrix the coordinates of the crossing points between the regions, finds the distance for each path, and selects the minimum of these distances as the distance between the two points.

Chapter 4 contains comparisons of actual travel distances in Winnipeg with estimates of distance obtained from this program, as well as with distances calculated without the barrier program.

Chapter 4

TESTING DISTANCE FUNCTIONS FOR WINNIPEG

Chapter 3 outlines several ways in which distances between points can be calculated from their x-y coordinates. In order to test the accuracy of some of these methods in estimating the travel distance between points in Winnipeg, data was collected including distance and time for 33 journeys within the City of Winnipeg. This information was obtained by driving along the routes and measuring distance and time.

Runs were chosen with the objective of getting representative travel distances for various types of trips within the City. The following criteria were used for choosing runs:

1. A range of distances travelled from about 1 to 11 kilometers were to be represented.
2. Some runs were to involve barrier crossings.
3. The fastest path between points was to be chosen.
4. Some runs were to involve main arteries only, while others were to leave the main arteries.
5. Runs were to be chosen from each major region of the City.

In the following two sections, actual distances measured will be compared to estimates obtained using the various estimating methods described in the previous chapter.

DISTANCE ESTIMATES NOT INVOLVING BARRIERS

Fourteen of the sample trips did not involve crossing a barrier. For these trips, a comparison was made of the actual distance travelled with the estimates that would be produced by both Euclidean and rectilinear distance formulas. The results obtained are illustrated in Figure 4.1, where the deviations of the estimates from the actual distances are plotted against actual distance. The deviation of the Euclidean estimate is represented by an "E" and the deviation of the rectilinear estimate is represented by an "R" for each run. It can be seen from the plot that the Euclidean estimates are always lower than the actual distance. The rectilinear estimates are generally higher than the actual distances, but in some cases are lower than or equal to the actual.

It would seem from the plot that Euclidean distance times a factor would provide a more reliable estimate of travel distance for Winnipeg than any estimate based on rectilinear distance. As mentioned in Chapter 3, the Rand studies (Dormont 1975) found that a factor of 1.15, when multiplied by Euclidean distance, provided a good estimate of distance in most cities. Figure 4.2 shows the deviations from actual distances for the sample runs of an estimate obtained by multiplying Euclidean distance by

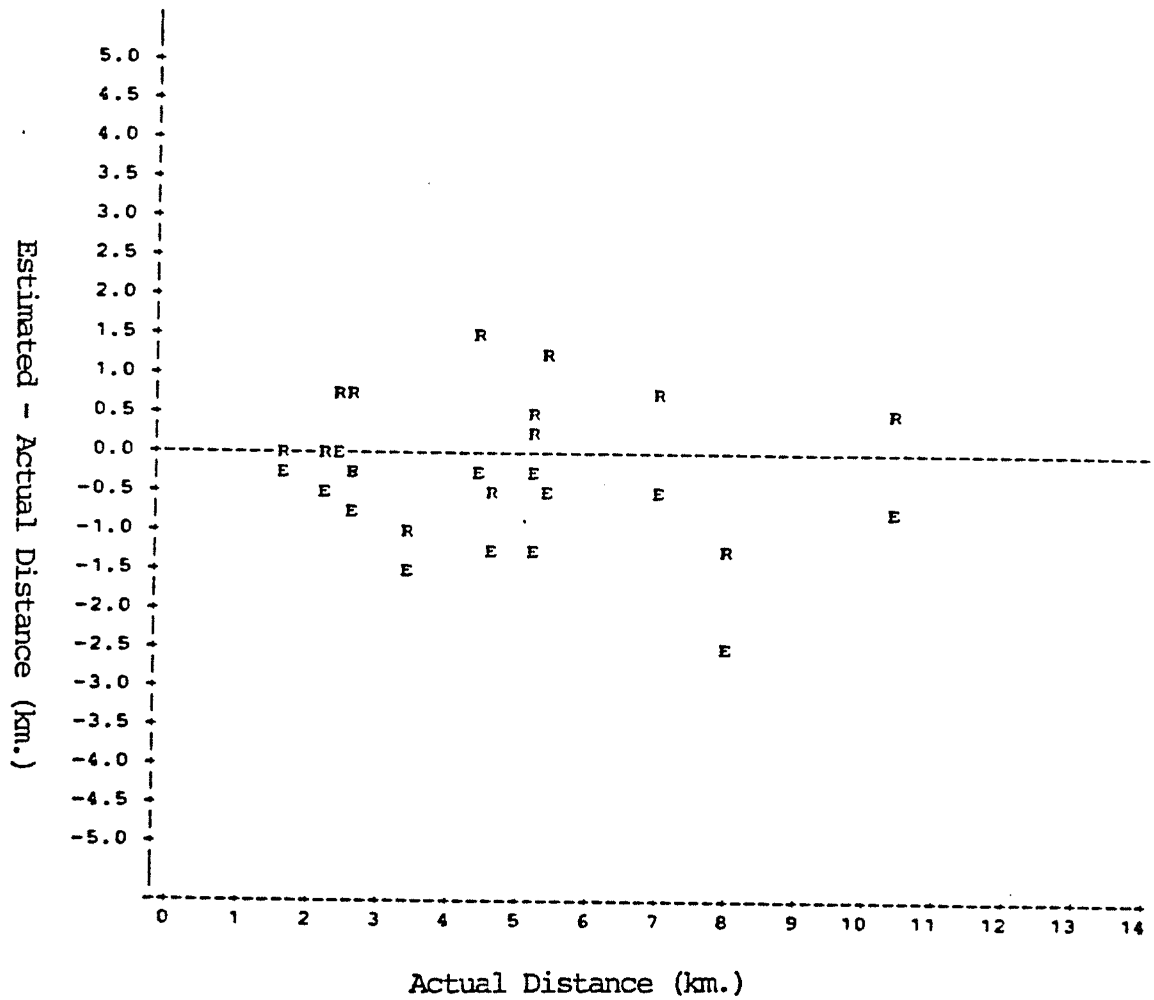

Figure 4.1 Deviations of Euclidean and Rectilinear Distance Estimates From Actual Distance For Trial Runs Not Involving Barriers

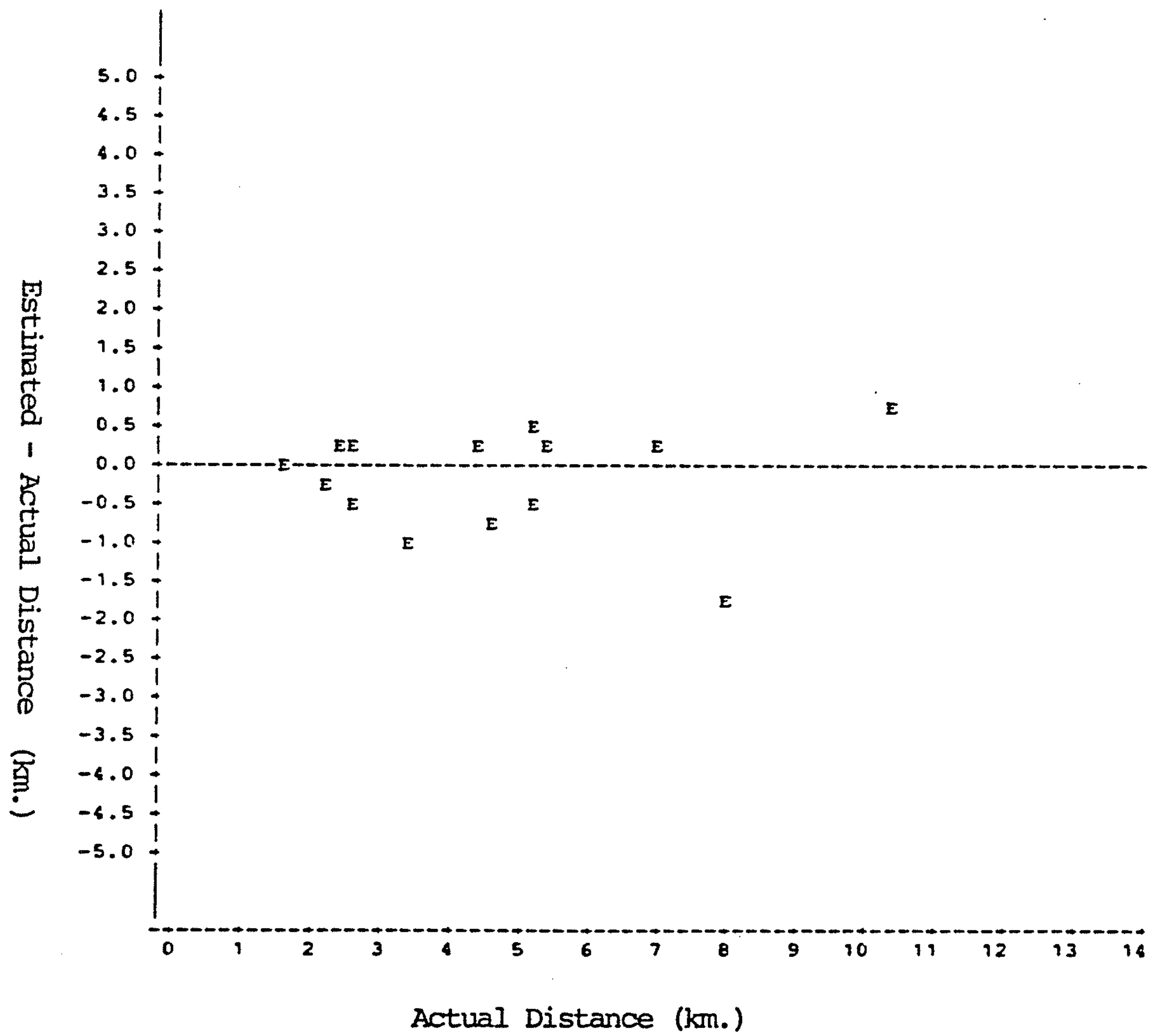

Figure 4.2 Deviations of "Euclidean Times 1.15" Estimates From Actual Distance For Trial Runs Not Involving Barriers

1.15. This result indicates that the factor 1.15 is an appropriate multiple for a Euclidean distance-estimating function for Winnipeg.

DISTANCE ESTIMATES WHEN BARRIERS ARE INVOLVED

When a barrier separates the source and demand points, with no crossing close by, the methods described above obviously will not provide a good estimate of the distance between the points. A straight-forward way of solving this problem is to estimate the distance between the points as the sum of the distances from each point to the nearest bridge.

Consider point i with coordinates (X_i, Y_i) and point j with coordinates (X_j, Y_j), separated by a river with a bridge at point k with coordinates (X_k, Y_k). The distance between them, D_{ij}, might be estimated, using a distance estimate based on 1.15 times straight-line distance, as

$$D_{ij}=1.15\sqrt{((X_i-X_k)^2+(Y_i-Y_k)^2)}+1.15\sqrt{((X_j-X_k)^2+(Y_j-Y_k)^2)} \quad 4.1$$

If more than one bridge is available, the minimum distance path can be chosen.

Figure 4.3 shows a comparison of actual distances for the 33 runs with the distance estimates obtained by multiplying 1.15 by the Euclidean distance. A forty-five degree line is drawn over the plot to represent where the plotted points would be if the distances were equal. It

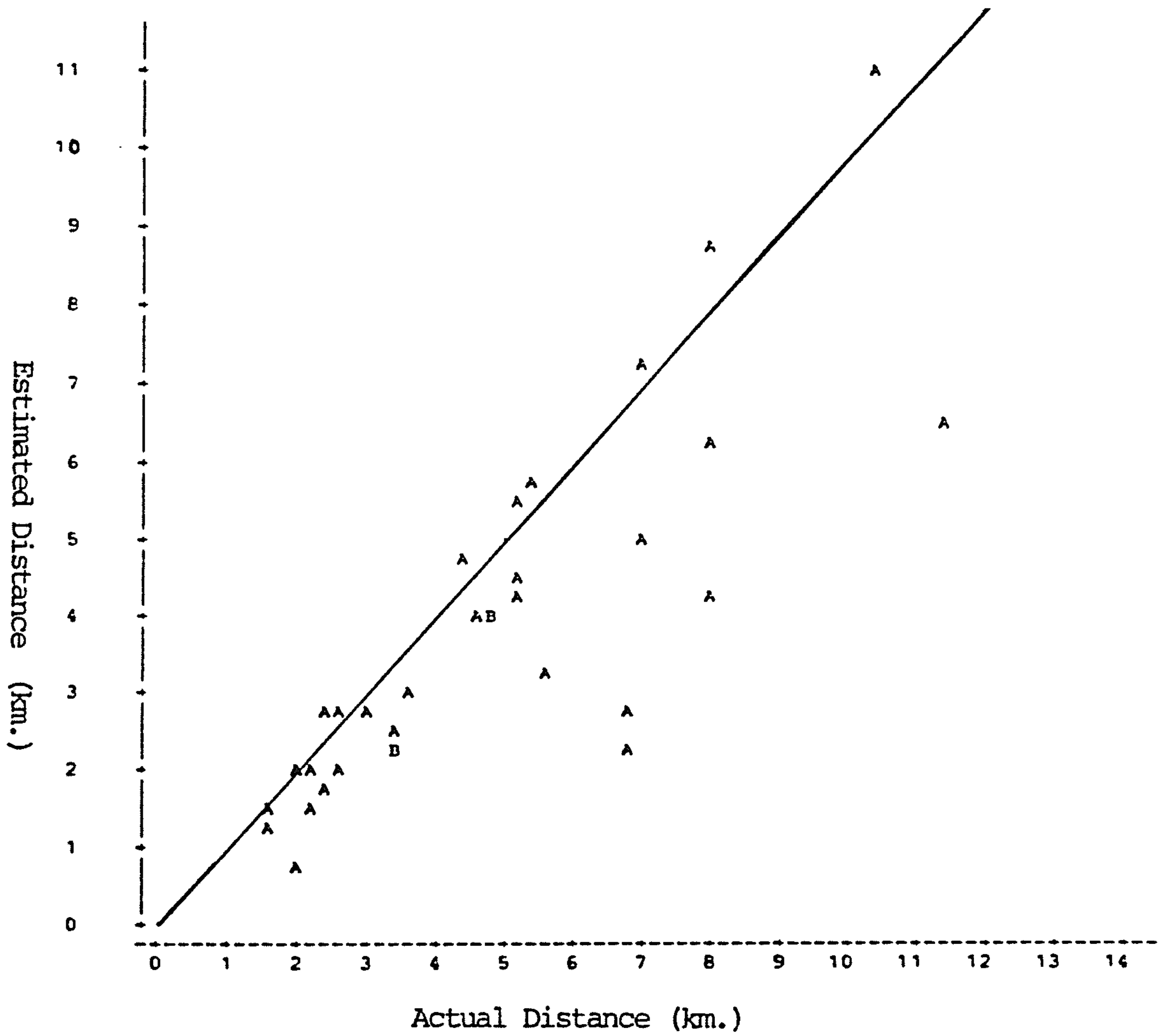

Figure 4.3 Comparison of Actual Distance With "Euclidean Times 1.15" Estimate For All Trial Runs. A Forty-five Degree Line is Drawn To Facilitate Comparison

can be seen that many of the estimates are very low in relation to the actual distance. Figure 4.4 is a similar graph except that the distance estimates for the 33 runs were obtained using the barrier algorithm of Equation 4.1. It is clear from comparing the two graphs that the barrier algorithm provides estimates that are much closer to the actual distances than the simple Euclidean estimate.

The least-squares regression function of actual distance on estimated distance was determined for each estimate. For the straight-line estimate, the least-squares function was

$$D_{ij}=1+DE_{ij}$$

where D_{ij} represents the actual distance and DE_{ij} the estimated distance. The R-square value for this estimate is .75. For the estimate obtained using the barrier algorithm, the least-squares function is

$$D_{ij}=.22+DE_{ij}$$

with an R-square value of .92. Again, it is evident that using the barrier algorithm provides a better distance estimate.

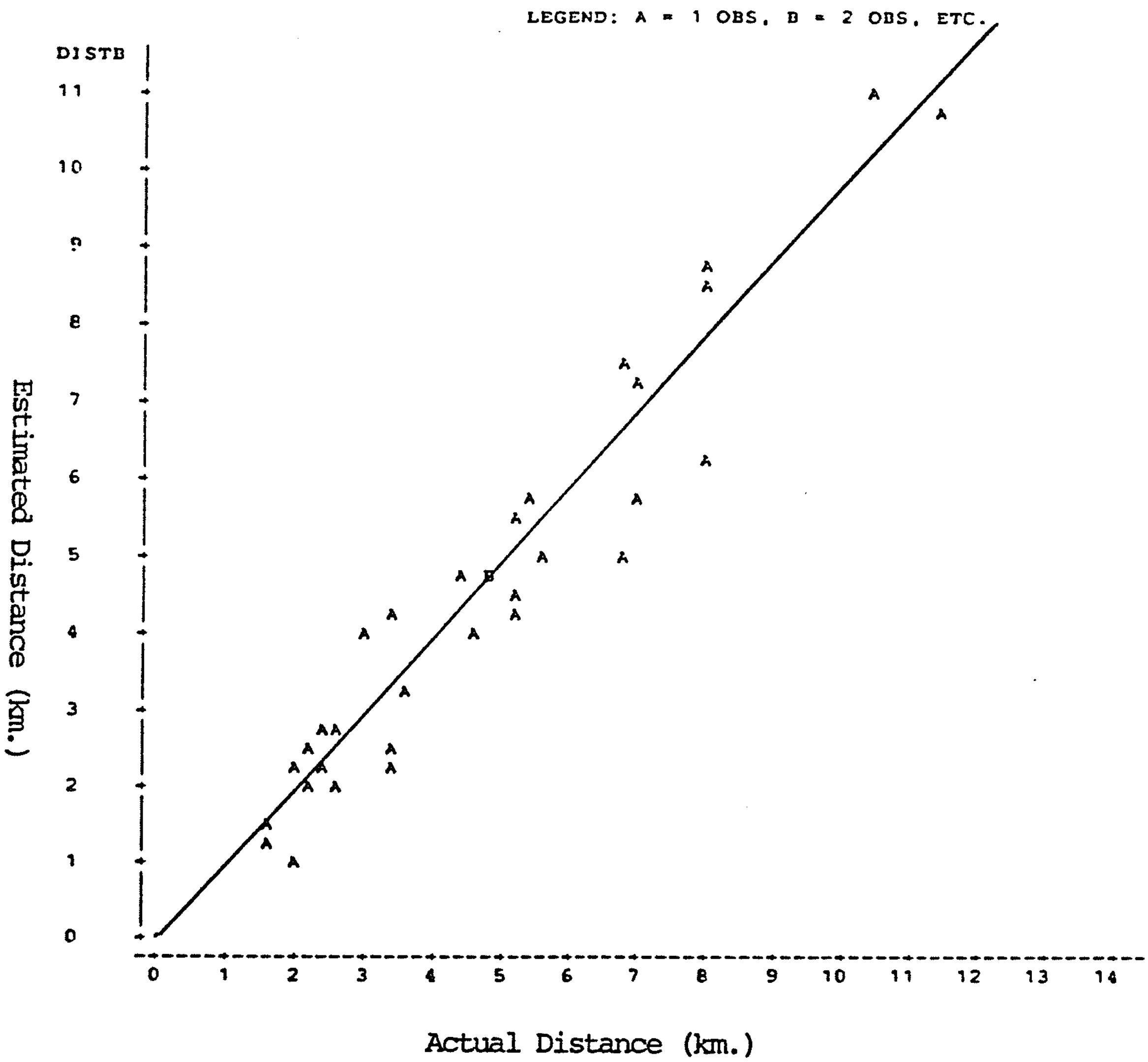

Figure 4.4 Comparison of Actual Distance With Distance Estimated By Barrier Algorithm For All Trial Runs. A Forty-five Degree Line Is Drawn To Facilitate Comparison

Chapter 5

ESTIMATING TRAVEL TIME FROM DISTANCE

RAND TRAVEL TIME EXPERIMENT

As part of the Rand study of the New York City Fire Department (see Chapter 2), Kolesar and Walker (1973) studied the relationship between travel distance and time in New York City (see also Kolesar 1975). They performed an experiment in which time and distance data for 2000 ladder runs in the City were recorded. They found that travel speed increased with the square root of distance for short runs and linearly for long runs, and that travel speed did not vary significantly according to time of day or region of the City. The following relationship between travel time and travel distance was found to hold:

$$T(D) = \begin{cases} 2.88\sqrt{D} & D \leq 0.88 \\ 1.35 + 1.53D & D > 0.88 \end{cases} \qquad (5.1)$$

where T is the travel time in minutes and D is the travel distance in miles.

Repetitions of this experiment in Trenton, New Jersey; Denver, Colorado; Wilmington, Delaware; and Yonkers, New York produced a slightly different relationship for those cities, that being:

$$T(D) = \begin{cases} 2.1\sqrt{D} & D \leq 0.38 \\ 0.65 + 1.7\,D & D > 0.38 \end{cases} \qquad (5.2)$$

TESTING THE RAND FORMULA FOR WINNIPEG

The Winnipeg Fire Department keeps comprehensive records of each incident to which the Department responds. Included in this data are the time that the fire company leaves the station and the time it arrives at the incident. The x-y coordinates of the incident and the number of the responding company are also recorded, and therefore it was possible to put together for this study a large amount of time/distance data. Distances were calculated as the Euclidean distance times a factor of 1.15, with no adjustment for barriers.

Figure 5.1 shows a plot of time vs. distance for a sample of 500 consecutive incidents which occurred in Winnipeg in 1984. Only first responses of pumper units are included. The graph is overlaid with a plot of relation 5.2 above. Converted to kilometers the relation becomes:

$$T(D) = \begin{cases} 1.66\sqrt{D} & D \leq 0.61 \\ 0.65+1.05D & D > 0.61 \end{cases} \qquad (5.3)$$

It was found in using the incident data that some of the travel time information was unrealistic. For example,

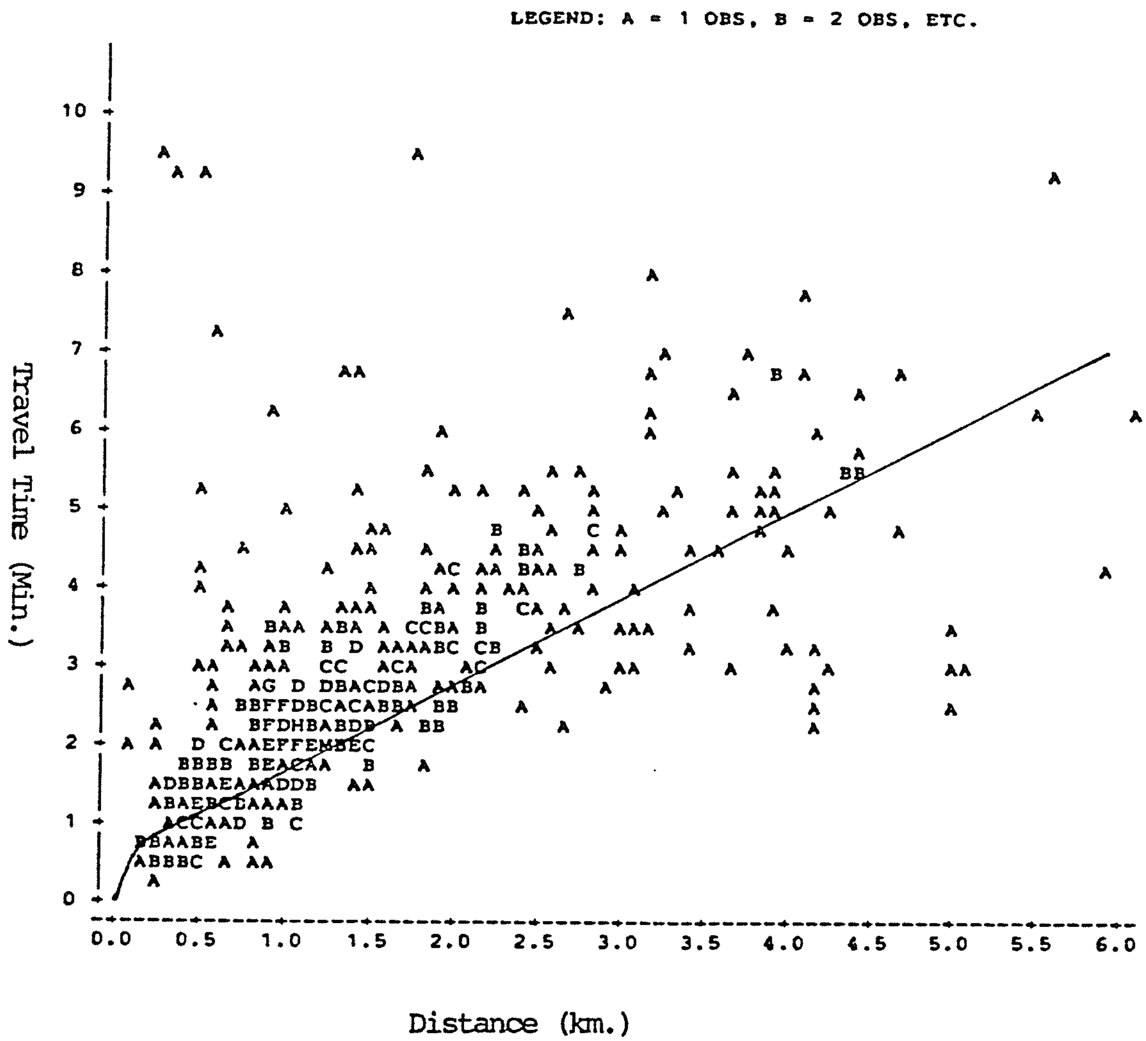

Figure 5.1 Plot Of 500 Runs By Pumper Units Showing Time and Distance, Overlaid With Equation 5.3

some response times were so high as to be very unlikely. Some response times were so low in relation to the distance travelled that it was evident that some element of the data had been recorded wrongly. Since the data is collected regularly during actual runs of pumpers, there are a few factors that can cause problems with its accuracy, such as if units are called back before reaching the incident or if an arrival is not recorded promptly. The author was assured by the Fire Department that the majority of the data is accurate, and so this has been relied upon.

The plot indicates that Equation 5.2 provides a fairly good estimation of travel time vs. distance for Winnipeg. The estimate, judging by the sample illustrated, appears to be somewhat low in the range from 0.5 to 3.5 minutes.

Testing Other Time/Distance Functions

This section describes analysis performed to determine whether a function could be found that fits the Winnipeg time/distance data better than the Rand "average city" function. Criteria used to evaluate the various functions tested were:

1. The value of correlation coefficients for the predicted travel time and the actual travel time.
2. Examination of the function being tested when imposed on the time/distance plots.

The first function tested was the linear regression function of time on distance, determined from the sample of 500 consecutive incidents by using the least squares procedure of the SAS computer program. The function is:

$$T(D) = 1.49 + 0.88D \qquad (5.4)$$

Table 5.1 shows the correlation coefficients of travel time, T, for the sample with the values of T(D) as predicted by this and other functions tested. Before computing the correlation coefficients and plotting the

Table 5.1 Correlation coefficients of predicted and actual travel times for various functions

Function		Correlation Coeff. With Actual Travel Time
Rand Function (Equation 5.3)		
$T = 1.66\sqrt{D}$	$D \leq 0.61$	0.62304
$0.65+1.05D$	$D > 0.61$	
Regression Line (Equation 5.4)		
$T = 1.49+0.88D$		0.63352
Nonlinear Estimate (Equation 5.5)		
$T = 2.5D^{0.4}$		0.63988
Combination Function (Equation 5.6)		
$T = 2.3\sqrt{D}$	$D \leq 2.0$	0.63405
$1.49+0.88D$	$D > 2.0$	

data, 52 incidents where the time/distance relationship was clearly unrealistic were deleted. The table shows a slightly improved correlation coefficient with actual time for the time estimates produced by the linear regression line estimate over the Rand function estimate.

Figure 5.2 shows the plot of the regression line on the time/distance data. From looking at the data points, it can be seen that there is a problem with this estimate in the range of distances from 0 to about 1 kilometer. The estimate is too high in this area.

Another function tested was the nonlinear function, $T(D)=aD^b$, where T(D) is the travel time, D is the travel distance and a and b are parameters of the function. Another procedure of the SAS package was used to determine the least-squares estimate of the parameters a and b for the function. The result was

$$T(D) = 2.5D^{0.4} \tag{5.5}$$

Figure 5.3 shows this function plotted against the actual data. The function looks like a good representation of the relationship suggested by the data. The correlation coefficient for the travel times predicted by this function with the actual travel times, from Table 5.1, is 0.640, indicating a slightly better fit than the Rand or least-squares regression line functions.

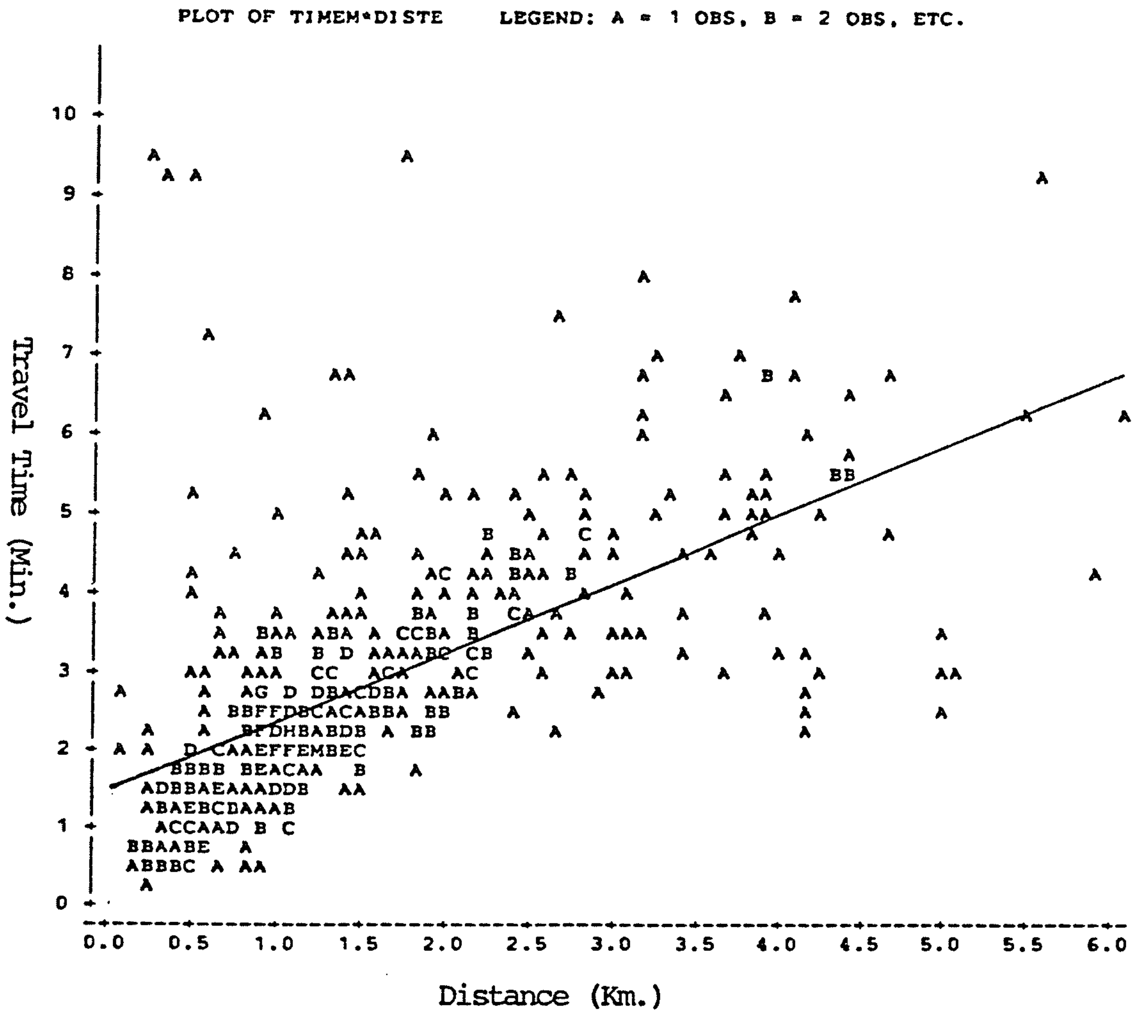

Figure 5.2 Plot Of 500 Runs By Pumper Units Showing Time and Distance, With Regression Line (Equation 5.4)

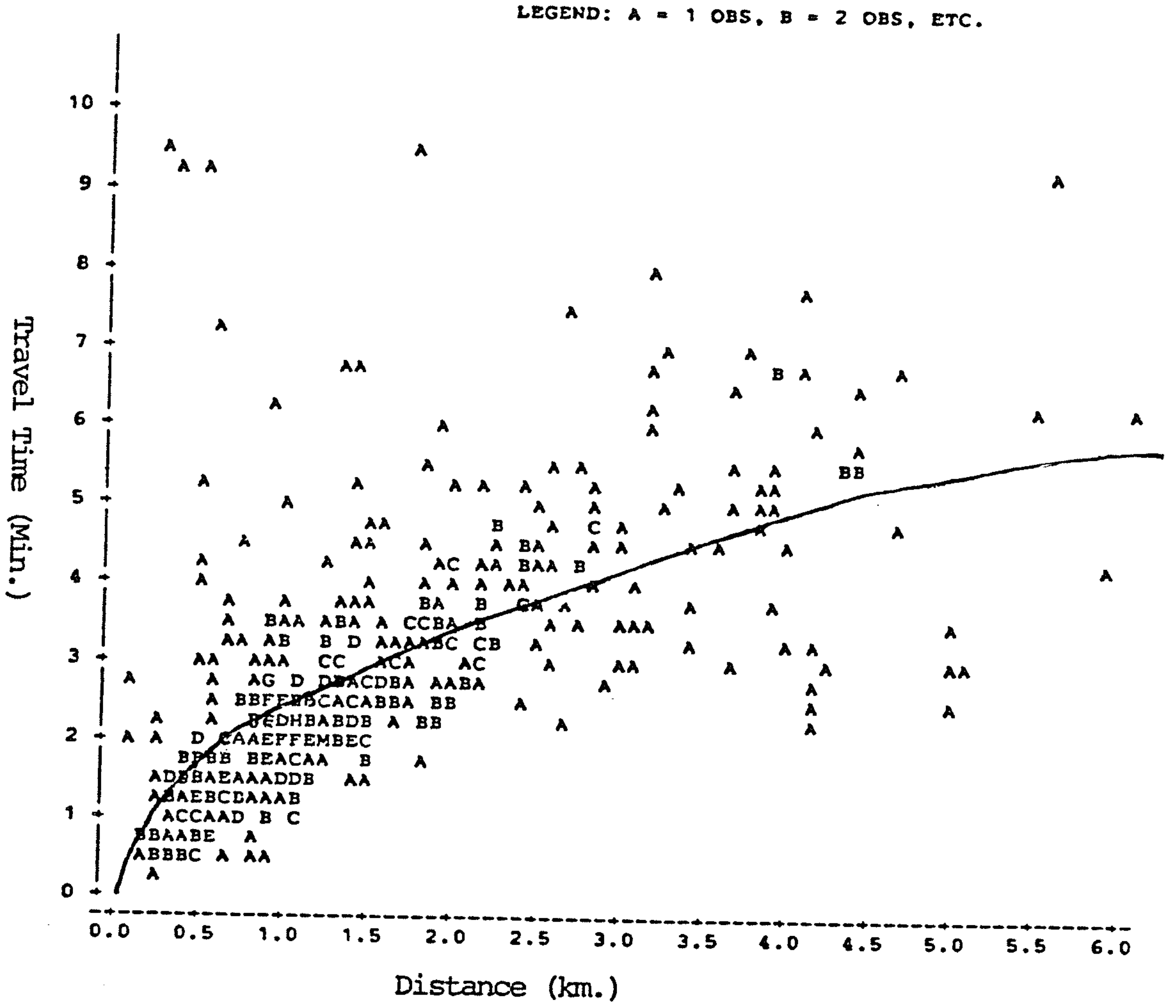

Figure 5.3 Plot of 500 Runs By Pumper Units Showing Time and Distance, Overlaid By Equation 5.5

The last function tested was the following:

$$T = \begin{cases} 2.3\sqrt{D} & D \leq 2 \\ 1.49 + .88D & D > 2 \end{cases} \qquad (5.6)$$

This function is a combination of the regression line for distances greater than two kilometers with a square root function for distances less than two kilometers. This function has a correlation coefficient of 0.634 and is shown in Figure 5.4. It also appears to fit the data fairly well.

CHOOSING THE BEST FUNCTION FOR WINNIPEG

The other models tested do not show any significant improvement over the Rand function for the Winnipeg data. The nonlinear estimate, which provides the best overall fit is not a good estimator for distances over five kilometers. This analysis indicates that the Rand function:

$$T(D) = \begin{cases} 1.66\sqrt{D} & D \leq 0.61 \\ 0.65 + 1.05D & D > 0.61 \end{cases}$$

can be used for Winnipeg to provide an estimate of travel time when distance is known.

It should be noted that the wide variation in travel times found in the data relating to any particular distance means that caution must be taken in drawing any conclusion,

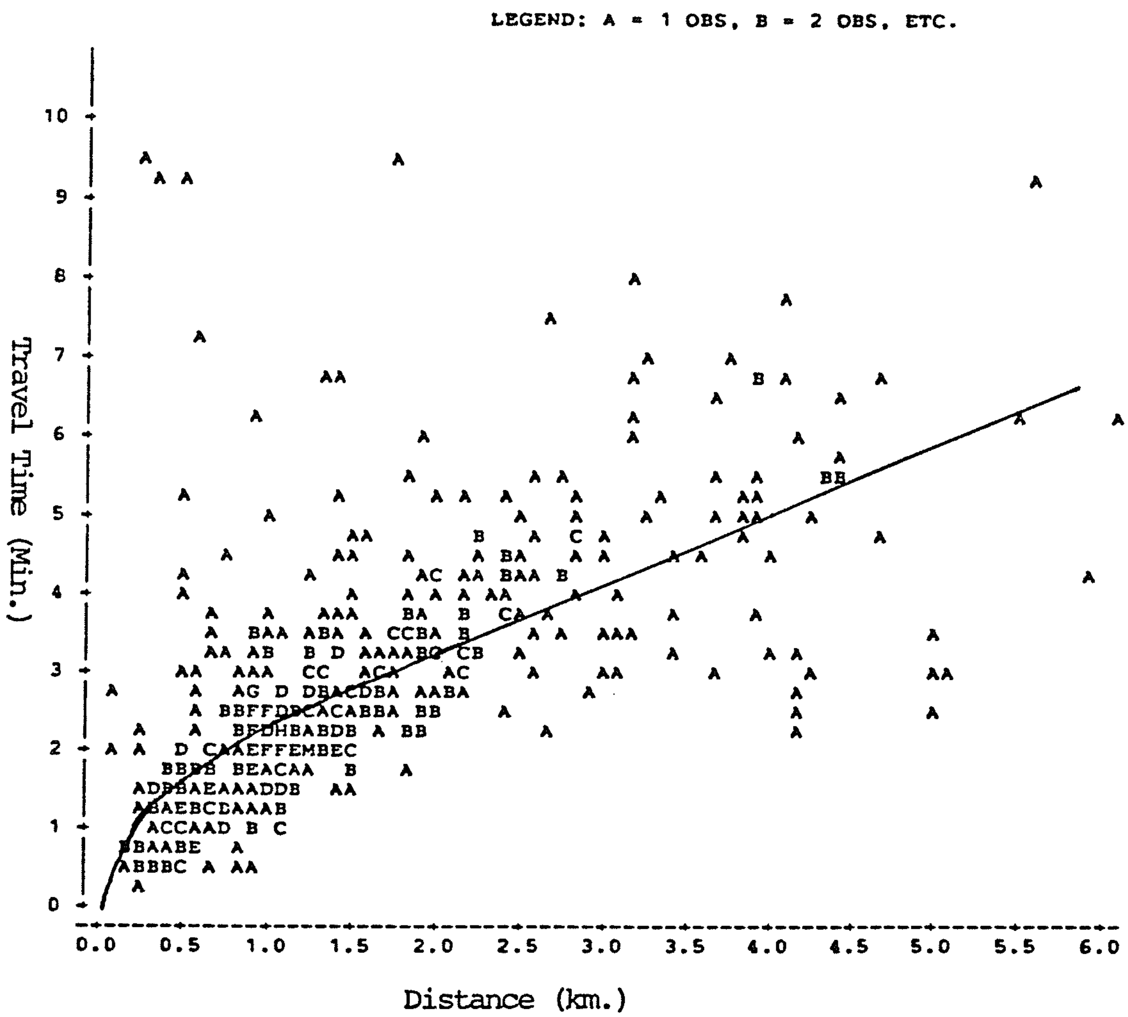

Figure 5.4 Plot of 500 Runs By Pumper Units Showing Time and Distance, Overlaid With Equation 5.6

based on this data, about the relationship between travel time and distance in Winnipeg. Further study in this area would be very valuable, particularly if data could be collected in a more controlled way.

Chapter 6

DETERMINING UTILIZATION RATES FOR WINNIPEG

Most techniques which have been used for locating fire stations have not taken into account the possibility of a unit not being available when needed. The traditional method used by fire departments in locating units is to ensure, to the greatest possible extent, that each area of the city has a station within a desired response distance or time. Appendix 1 contains a table which shows target response times for various classes of development in a city, the type of standard typically used by fire departments. This table was obtained from the "Fire Underwriters Survey" (1986).

The models which have most often been used to assist in determining how many fire stations are needed and where they should be located are the parametric, p-median and set covering models, which are discussed in Chapter 2. Although none of these models explicitly take into account the possibility of units not always being available, they all have some way of ensuring that the density of fire stations will be higher in areas with high alarm rates. In the case of the set covering model, this is usually accomplished by setting lower target response times for high-alarm areas. The p-median model, because its objective is to minimize total travel time, will tend to locate more units in high alarm areas. The "square root function" used by the parametric model to calculate travel distance, includes as one of its factors the average number of companies busy in a region. A high number of companies busy will increase the travel time estimate for a region and result in more companies being located there.

The p-median and set covering models will always underestimate travel time because they do not take into account the possibility of the closest unit not being available. Researchers have suggested that, at utilization rates of less than five percent, the assumption that units are always available is a reasonable one which will not significantly affect the results. For example Chaiken (1978) states that in a previous study he found that at low alarm rates the number of units needed to meet the requirements of his queueing model were well below the numbers needed to meet simple geographical requirements (to have units located within a certain travel time.)

In order to check whether this assumption holds up in Winnipeg, the fire incident data for the City for the period of a year was studied. It was found that the most busy unit spent five percent of its time responding to incidents, while the least busy unit was occupied two percent of the time. Table 6.1 shows the utilization rate

Table 6.1

UTILIZATION BY PUMPER IN 1984

Pumper No.	No. of Incidents	Mean Service Time	Utilization Rate
411	1846	15.07	.053
412	1160	12.46	.027
413	1309	12.03	.030
414	773	15.38	.023
415	595	14.51	.016
416	862	15.27	.025
417	1385	16.63	.044
418	783	19.27	.029
419	592	17.74	.020
421	574	19.66	.021
422	366	16.54	.012
423	318	16.50	.010
424	752	18.92	.027
425	561	19.33	.020
426	297	16.19	.009
428	539	18.41	.019
429	480	17.69	.016
431	218	17.26	.007
432	213	20.93	.008
433	367	23.73	.016
434	595	18.32	.021
435	519	20.21	.121
436	383	19.38	.014
437	459	22.70	.020
438	376	29.25	.021
439	594	18.78	.021
441	392	26.53	.020
442	359	20.46	.014
443	344	24.96	.016
444	543	18.52	.019
459	1094	10.01	.021

for each pumper unit in Winnipeg for 1984. An attempt was made to carry this analysis further by applying some queueing formulas to determine such information as the probability of a particular unit not being available when an incident occurs to which it is the closest responder. To this end, inter-arrival times for fire incidents and service times were analyzed in order to determine whether they fit into one of the statistical distributions for which standard formulas have been developed.

Previous studies have found or assumed that occurrences of fire emergencies follow a Poisson distribution. When actual occurrances for Winnipeg were examined, it was found that they did not fall within a Poisson distribution. The reason for this has not been found; further research would be necessary to determine why available data indicates that fire calls do not occur in a Poisson manner in Winnipeg.

The service times were tested as well, and it was found that they did not follow an exponential distribution. This agrees with the findings of other researchers. Berman (1987) suggests that it is because of the large travel time component in the service time figures. Even if the actual service time to put out a fire follows an exponential distribution, when travel time, which often represents a large percentage of service time, is added, the total does not follow an exponential distribution.

It can be concluded from the data available for

Winnipeg that, with the number of fire fighting units currently available in Winnipeg, the likelihood of the closest unit being unavailable is small enough that a model to assist in fire department locational planning for Winnipeg need not take this possibility into account.

Chapter 7

CHOOSING A MODEL FOR WINNIPEG

Winnipeg is a city of 650,000 people, spread over an area of 571.5 square kilometers. It is crossed by two major rivers, with few crossings in some areas, as well as by some railway lines with few crossings. Winnipeg has 25 fire stations. The locations of these stations go back, for the most part, to what they were 16 years ago, in 1972, when Winnipeg was made up of 12 independent municipalities, each with its own fire department. Appendix 2 contains a map of Winnipeg showing the major barriers to travel and the locations of fire stations. In Winnipeg, as in all cities, land use and population densities in many areas change over time. New housing and industrial development stretch the boundaries of the area requiring service. The fire department must continue to assess the service being provided to each area of the city and determine whether siting changes are needed to continue to provide emergency fire service to all areas of the city. In the preceding chapters, some techniques have been discussed which can be of use for this type of evaluation. In this chapter, the criteria for choosing a model, as outlined in Chapter 1, will be discussed in terms of the research findings for Winnipeg.

TRAVEL TIME ESTIMATION METHOD

An accurate method of obtaining large numbers of estimates of travel time between points is essential in order that any model can be used. A computer street network can provide accurate travel time estimates if it is set up properly. If a city has a good existing network that can be used this is an ideal source of travel time information. If such a network does not already exist, it must be considered that the creation of such a network involves a large investment of time and effort. It has been shown in this paper that Euclidean and rectilinear estimates, based on x-y coordinates, can provide reasonably accurate estimates of distance. These can be combined with one of the formulas described in Chapter 5 to come up with travel time estimates.

In a city where there are major barriers to travel, with limited crossing points, it would probably be necessary to use a special algorithm such as the one suggested in this paper to account for increases in travel time when barrier crossings are involved. Ideally, estimates of travel time obtained by applying functions should be compared to times obtained in actual runs by fire units to get an idea of the extent of natural variation that will be present. Because the standard functions cannot take into account directness of available routes and speed of travel for each different journey, the travel times obtained by applying the functions can never be exactly accurate. However, depending on the requirements of a particular model, distance and time functions should be able to be tailored to provide a sufficiently accurate estimate of travel time.

ACCOUNTING FOR BUSY UNITS

Models have been developed that take into account the fact that the closest unit may not be available to respond to an incident. Some of these models are discussed in the section titled "Dynamic Models" in Chapter 2. These models tend to be more complex and have larger data requirements than those which do not take into account vehicle busy periods. They have been used for ambulance siting and deployment, but rarely for fire station siting.

As shown in Chapter 6, fire service units in Winnipeg are busy only between one and five percent of the time. Therefore, a static model may be adequate for Winnipeg. It must be remembered, however, that if the application of a static model results in a recommendation to decrease the number of units or to relocate units, some assessment must be made of the utilization rates that would result if these actions were taken. This could be done by analyzing the data on past occurances of fires. If it is found that the resulting utilization rates are likely to be higher than about five percent in some areas, further analysis will be required using a technique that recognizes busy periods, such as a simulation or queueing model.

Some recognition of busy periods can be made by a static model if constraints are placed on second-due response times, as well as first-due. This could ensure that even if the first-due unit is busy, another unit will be available within an acceptable response time. At high utilization rates, however, this technique would probably not provide a very efficient solution.

CRITERIA FOR LEVEL OF SERVICE

As mentioned in Chapter 1, response time to incidents is generally accepted as an appropriate measure for the performance of an emergency service system. However, objectives for response time can vary. Some models, such as the p-median model, minimize the total travel time by all units to all incidents. However this approach can result in zones with few incidents being provided with very poor coverage.

Another objective commonly used in modelling is to provide service to all zones within a pre-set target response time. Target response times can vary for different zones based on such factors as alarm frequency, specific hazards, population densities, property values, combustability, probability of spreading and availability of alarm systems. The set covering class of models use this approach. The standard set covering formulation also can easily be modified to ensure that all zones are also covered within a certain time by the second-due unit. It may be found when the target response times are set and the model run that the number of units which are found to be needed is unacceptably large. Target times would then have to be relaxed on a zone-by-zone basis until it is possible to meet these targets with an acceptable number of units.

As mentioned in Chapter 2, variations of the set covering model use different objectives, such as

1) Satisfy required response times with the smallest number of stations, but use existing stations where possible (Hendrick 1974).
2) Maximize the total number of covered demands (Church and Revelle 1974).
3) Locate a certain number of facilities so the maximum number of people have a facility within the maximum allowable time (Schilling 1980).

Objectives for response times must be set by those who make policy decisions for the Fire Department. A model can then be chosen which can optimize in terms of those objectives. Use of models, when they are properly set up with accurate data, can help to structure and formalize the decision-making process and ensure that stated objectives are being met.

THE "RIGHT" MODEL FOR WINNIPEG

Consideration of the above mentioned criteria point to a set covering model as being a good choice for aiding with locational decisions for the Winnipeg Fire Department. It allows response times to be set by individual zone to take into account all of the various factors that determine risk for an area. Target response times can be set for each zone for both first and second response by pumper and ladder units. A configuration can then be found that meets these targets with the least number of units.

The version of the model (Hendrick 1974) which chooses existing station locations when possible would probably be a good choice. Changing of fire station locations involves capital cost and existing locations should be used where possible. The model will tend to eliminate poor locations while leaving the good locations.

CONSIDERATIONS FOR IMPLEMENTATION

There are several steps that must be taken in preparation for implementing a set covering type of model. The first step is to divide the city into zones. Since it would be impossible for a model to include each individual demand point (such as a house, an office building or a grassy field), these points must be aggregated into zones. Demand is then assumed to occur at a central point in the zone. This "zone centroid" may be the geographical center of the zone, or the center of gravity in terms of number of demands for service, or some other factor.

The question of how small the zones should be is an important one. The larger the zone is, the longer is the travel time from one end of the zone to the other, and the less accurate are the results obtained by a model using these zones. However, a very large number of zones results in a very large model which takes longer to set up and run. A tradeoff must be made between these two.

Goodchild (1979) researched the effect of degree of aggregation on accuracy of results for a p-median model. He found that solutions using aggregated data are open to extensive manipulation, depending on how the zones are drawn, and suggests that this finding casts some doubt on the use of location-allocation models. The problem would apply to any type of model which aggregates demand points. However error can be minimized by making the zones sufficiently small.

Once the zones are set out, it must be determined whether all of them or a subset will be considered as potential locations for stations. Then travel times must be determined from each demand zone to each supply zone. These can be found using either a street network or formulas based on the x-y coordinates of supply and demand points. Target response times must be set for each zone. Then for each zone, a set is created containing zone numbers of each other zone which is within the target response time. All of this information is then put into the model, which will come up with the list of zones in which stations should be located to meet all target response times with the least number of stations.

CONCLUSION

In this thesis, a review has been made of techniques for aiding in fire service unit location and deployment. A framework has been suggested for determining a model to use for a particular city. A new method of estimating travel times has been suggested. And, for the case of Winnipeg, a model has been recommended and steps for implementation outlined.

Further research in modelling for locational analysis will make available techniques which can allow many additional factors to be taken into account. For Winnipeg, further research in the following areas would be helpful:

1) Determining the size of zones to be used when applying the set covering model;
2) Comparing travel times determined by using distance and time formulas with actual run times; and
3) Analyzing interarrival times and service times for fire incidents to determine whether they follow any distribution for which queueing theory results are available.

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TABLE OF EFFECTIVE RESPONSE

The following table aids in the determination of Pumper and Ladder Company distribution and total members needed. It is based on availability within specified response travel times in accordance with the fire potential as determined by calculation of required fire flows, but requiring increases in availability for severe life hazard.

GROUP	DESCRIPTION EXAMPLES	FIRE FLOW		1ST DUE	2ND DUE	1ST DUE	TOTAL AVAILABILITY NEEDED			
		L/min X1000	Approx. gpm Range	Pumper Company, Minutes	Pumper Company, Minutes	Ladder Company, Minutes	Pumper Cos.		Ladder Cos.	
							No.	Min.	No.	Min.
1 (a) (b)	Very small buildings, widely detached. Scattered development (except where wood roof coverings)	2 3	400 600	7.5 6	- -	*9 *7.5	1 1	7.5 6	*1 *1	9 7.5
2	Typical modern, 1-2 storey residential subdivision 3-6 m (10-20 ft.) detached	4-5	800-1000	4	6	*6	2	6	*1	6
3 (a)	Close 3-4 storey residential and row housing small mercantile and industrial	6-9 10-13	1200-2000 2200-2800	3.5 3.5	5 5	*4 *4	2 3	5 6	*1 *1	4 4
3 (b)	Seriously exposed tenements. Institutional. Shopping Centres. Fairly large areas & fire loads, exposures	14-16 17-19	3000-3600 3800-4200	3.5 3.5	5 5	4 4	4 5	7 7	1 **1	4 4
4 (a)	Large combustible institutions, commercial buildings, multi-storey and with exposures	20-23 24-27	4400-5000 5200-6000	2.5 2.5	4 4	3.5 3.5	6 7	7.5 7.5	2 2	5 5
4 (b)	High fire load warehouses and buildings like 4(a)	28-31 32-35	6200-6800 7000-7600	2.5 2.5	3.5 3.5	3.5 3.5	8 9	8 8	3 3	7 7
5	Severe hazards in large area buildings usually with major exposures. Large congested frame districts	36-38 39-42 43-46	7800-8400 8600-9200 9400-10000	2.0 2.0 2.0	3.5 3.5 3.5	2.5 2.5 2.5	10 12 14	8 9 9	4 5 6	7.5 8 9

APPENDIX 2

Map of Winnipeg Showing
Fire Station Locations and Barriers