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Emergency Service Transport Models

by

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EMERGENCY SERVICE TRANSPORT MODELS

BY

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A thesis submitted to the Faculty of Graduate Studies of
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MASTER OF SCIENCE

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ABSTRACT

Police departments, fire departments, and emergency medical agencies are faced with the complex problem of allocating their resources to meet the demands for service. Over the past two decades, this allocation problem has been subject to considerable quantitative analysis. As a result, a variety of emergency service models have to been developed to assist policy makers and administrators analyze their deployment policies.

This thesis focuses on the validation and implementation of the Hypercube Queuing Model for the City of Winnipeg Fire Department. The Hypercube Queuing Model was run using two distinct sets of input data. The x and y coordinates of the response unit and the geographic atom and estimated travel times which were calculated based on Kolesar and Walker's methodology. The model was validated using historical data from the Computer Aided Dispatch System for the City of Winnipeg. Once validated, alternative deployment policies for the City of Winnipeg Fire Department were analyzed using the Hypercube Queuing Model.

Computations were performed to determine if there is a correlation between the demand for fire service and; 1) the time of day, 2) the month of the year, and 3) the day of the week.

The following conclusions were derived from the above analysis: 1) It was possible to implement the Hypercube Model for the City of Winnipeg. 2) The Hypercube can be used to analyze various deployment changes fire administrators are contemplating. 3) The average travel times generated by the Hypercube Model, using the estimated travel times as input, best fit the City of Winnipeg Fire Department Operations. 4) Statistical tests conducted did not conclude that the demand for service is independent of seasonality.

CHAPTER 1

PUBLIC FIRE PROTECTION

1.1 INTRODUCTION

Police departments, fire departments, and emergency medical agencies are faced with the complex problem of allocating their resources to meet the demands for service. Over the past two decades, this allocation problem has been subject to considerable quantitative analysis. As a result, a variety of emergency service models have to been developed to assist policy makers and administrators analyze their deployment policies

This thesis will deal specifically with the problems associated with the deployment and control of firefighting resources. Fire administrators are faced with many questions which are difficult to answer. How large a fire suppresion force does a city need and how should that force be deployed? There is no consistency from city to city. Clearly the more stations located in a city, and the more men assigned to each station the better the fire protection provided. However, there are limited resources which must be considered.

How many units should be dispatched to an alarm? Obviously the more units dispatched, the less likely significant losses will be realized. However, if a station dispatches all of its available units to an incident, any second alarms coming in may have to wait for service. This would be unacceptable![26]

Fire administrators must be able to answer these questions if they hope to balance their available resources with the demands for service. The safety of human lives and property has always been the most prominent concern. Additional pressures have been placed on administrators. Rising costs and tight budgets have forced fire department administrators to weigh the fire protection benefits against the cost of providing protection. Emergency service models would enable analysis of alternate deployment policies without risking lives or property.

1.2 PREVIOUS RESEARCH

The two types of analytical models for the location of fire stations which have advanced are static models, which assume that all units are always available for dispatch to a fire, and dynamic models, which allow for the possibility that some units may be unavailable if they are busy at other fires.

1.2.1 Static Models

Static models can be divided into two classifications, evaluation models and optimization models. The evaluation models compute performance measures such as response-time and work-load distribution for alternate siting plans. The Rand Firehouse Site Evaluation Model (Dormont, Hausner and Walker, 1975)[9] and the Public Technology Site Evaluation Program (Public Technology, Inc., 1974)[23] are the two best known.

The optimization models find the optimal location of sites according to some performance measure or measures. These models can be placed into two categories: set covering formulations and travel time (or damage) minimization formulations.

The set covering formulations seek to minimize the number of stations required to ensure that no area is more than a prespecified distance or time from a fire station. Toregas et al. (1971)[27] and Z. Hendrick et al. (1974)[11] have used a binary-integer-program to solve this type of problem.

Travel time minimization formulations locate a number of facilities so as to maximize some time- or distance-related utility function. Schilling et al.[25] formulated this problem for siting fire stations in Baltimore.

Hogg (1971b)[13] used a median approach to the problem of locating fire stations. The nominal objective of the optimization was to minimize the extent of fire damage for a given number of fire units. Due to the lack of available data, Hogg minimized the total travel time of all units to all fires. Hogg's paper is significant in that it considered average travel time as a siting criterion, rather than treating it as a coverage criteria as suggested by fire insurance rating organizations and set covering models.

Hirsch (1973)[12] used another family of location models, a minimax strategy, to locate facilities or units. The objective was to minimize the maximum cost that any demand point may incur.

Rider (1975)[24] has proposed a two-stage model referred to as a parametric allocation model which involves an assignment of the total number of fire fighting units to different homogenous regions of the city, each having a given demand rate. Using Kolesar's formulation (1973)[15], Rider related density of fire fighting units (units per square mile) with average travel time in order to allocate the units to the different regions.

1.2.2 Dynamic Models

Dynamic models were designed to allow for situations where there is a significant probability that some facilities may run out of available units. Between 1969 and 1975, the New York City Rand Institute was assigned to develop analytical tools to improve the delivery of fire protection service through more effective use of fire department resources (Walker, Chaiken, and Ignall, 1979)[28]. Besides their work on fire station placement, Rand researchers conducted analyses concerning decisions on how many units to send to each alarm, which units to send, and where to relocate available units during times of inordinately high demand for fire service. Rand researchers developed several models relevant to fire department operations analysis. The most significant are the Hypercube Queuing Model (Larson, 1974, 1975), and the Fire Operations Simulation Model (Carter, Ignall, and Walker, 1975).

Chapter Two discusses some of the more popular emergency models available.

1.3 SUCCESS FACTORS IN MODEL IMPLEMENTATION

Model designers field-test a model in several cities to ensure it meets the needs of local decision makers rather than needs perceived by the designer, and to validate the model by checking that outputs match reality. Despite these efforts, a field-tested model cannot necessarily be utilized by a city. Each city that uses a particular model must conduct their own field-test to ensure its appropriateness. The local analyst will not be able to persuade the fire chief, police chief, or city council to take action based on estimated performance measures that have not been shown to be trustworthy.

The degree of success of implementation of a model depends on a variety of factors. Model documentation should inform potential users of the cost and difficulty of running a model, the necessary compiler, as well as provide a program listing. Many emergency service agencies have difficulty finding a computer that will compile a program written in BASIC, PL/1, or especially SIMSCRIPT (the language simulation models are written in). As well, since no model is perfect, computer programmers must be available to modify the models written in these languages.

Data requirements influence whether a model is used since collecting the necessary data would require significant time and financial commitment. Most users do not come to grips with the problem of collecting data until the program is in hand.

Successful implementation of a model also depends on the potential user being aware of the benefits that will be realized from the use of a model. It is also very important to have an "advocate," a single person in the agency who sees the need for a model and pushes its implementation to a successful conclusion.

1.4 FIRE PROTECTION FOR THE CITY OF WINNIPEG

The City of Winnipeg Fire Department administration must control and deploy fire fighting resources for a city with geographic and climatic conditions which create traffic flow problems. The City of Winnipeg with a land area of 571.6 square kilometers has three rivers with a limited number of crossings, and a major railyard which bisects the city thereby limiting access to the north end. As well, many former suburban areas have one main arterial route, creating heavy traffic flow conditions during most of the day and almost impenetrable passage in rush hour periods.

For almost fifty percent of the year, Winnipeg fire fighters must contend with winter. Fire fighting conditions during the winter generally require greater responses of men and equipment. Other weather conditions such as rainstorms can cause underpasses on major arteries to flood.[8]

In an attempt to improve dispatching, a Fire/Ambulance Computer Aided Dispatch System was implemented in 1979 by the City of Winnipeg. All City of Winnipeg Fire Department responding appartus, except Chief's Autos, were equippd with status heads which report back to the C.A.D. System the current status of each unit during an emergency. The C.A.D. System permanently records detailed information about each call for service and the units dispatched. With this database of information it was possible to calculate performance characteristics such as demand for service for each Fire Alarm District, response times for apparatus, travel distances, etc. Given the deployment problems administrators must face and the detailed database of information available, it is quite feasible for an emergency service model to be implemented in the City of Winnipeg Fire Department.

Chapter Four provides an overview of the City of Winnipeg Fire Department operations.

1.5 HYPERCUBE QUEUING MODEL

This thesis focuses on the validation and implementation of the Hypercube Queuing Model for the City of Winnipeg Fire Department. The Hypercube Queuing Model (Larson. 1974, 1975),[18&19] an evaluative model, estimates the probability that each unit will be busy under varying dispatch policies, given the arrival rates for service and service time distributions for predefined zones in the city. The model is based on the representation of the queuing process that takes place when the preferred unit for an incident is unavailable. It is useful for locating units and districting a region into response areas for fire units, with the objective of minimizing response times as well as to more or less equalizing work loads.

The Hypercube Queuing Model is presented in detail in Chapter Three. A theoretical explanation of how the model works, model assumptions, model limitations, data requirements necessary to run the model, and the output generated from the execution of the model is given. Specific instuctions on how to use the model is presented.

The Hypercube Queuing Model requires part or all of a city to be divided into geographic atoms. The model documentation does not give the reader specific recommendations on how this task should be accomplished. Fortunately, the City of Winnnipeg was already divided into subareas. The City of Winnipeg was divided into two independent subareas called Fire Alarm Districts, and Fire Demand Zones. There are 64 Fire Alarm Districts and 1298 Fire Demand Zones. The City of Winnipeg Fire Department referrs to sections of the city as Fire Alarm Districts for dispatching purposes, and Fire Demand Zones in historical analysis. The dillema was that some of the information needed to run the Hypercube Model related to the Fire Demand Zones, while other information related to Fire Alarm Distircts. To resolve this problem, the relationship between Fire Alarm Districts and Fire Demand Zones was determined by cross referencing various sources of Fire Department data. Once this relationship was determined, geographic atoms were equated to Fire Demand Zones.

Chapter Five details the data collection and preparation which was necessary to perform the analysis of the Fire Department.

The Hypercube Queuing Model was run using two distinct sets of input data.

1. The x and y coordinates of the response unit and the geographic atom were input into the Hypercube Model. The computer model uses this location information when estimating travel times between atoms. The model assumes the responding unit will travel the sum of the east-west distance and the north-south distance between its initial location and the location of the incident. This is referred to the Manhattan metric assumption.

2. Kolesar and Walker conducted a stopwatch experiment for New York City to determine the relationship between travel time and distance. They concluded that in most parts of New York City travel time increases with the square root of the distance for short runs, and linearly for long runs.[16]

   This experiment was repeated for the City of Winnipeg, using historical data from the C.A.D. System. A single continuous function was fitted to City of Winnipeg data. Response times were calculated using using this relationship. These times were input into the Hypercube Model.

Using historical data from the Computer Aided Dispatch System for the City of Winnipeg, performance characteristics for response units were calculated. To determine which data option, if any, better represents reality, a comparison was made between the computed performance characteristics from the Hypercube Queuing Model runs and the actual performance characteristics for the City of Winnipeg. Chapter Six details the results of the analysis.

Alternative deployment policies for the City of Winnipeg Fire Department were analyzed using the Hypercube Queuing Model.

1) The Hypercube Model was used to determine the effect removal of fire stations would have on the response times of units and the work load distribution.

2) Analysis was done to determine if the Fire Department would be able to meet the future demands for service given the population growth projections.

The implementation of the Hypercube Queuing Model is given in Chapter Seven.

1.6 TIME RELATED DEPENDENCIES FOR FIRE DEMAND

Using a computer program called Statistical Analysis System (S.A.S.), computations were performed to determine if there is a correlation between the demand for fire service and:

1) the time of day,
2) the month of the year, and
3) the day of the week.

Chapter Eight presents the sensitivity analysis conducted.

The conclusions of this thesis as well as future research which could be conducted is given in Chapter Nine.

CHAPTER 2

EMERGENCY SERVICE MODELS

2.1 INTRODUCTION

In this chapter we will examine some of the operational research models that are used in emergency services. We will study the reasons for using these models as well as identifying some of the major models. Some large systems, such as the systems that represent emergency department operations (fire, police, ambulance), contain many interacting elements which make it difficult to determine the consequences of policy changes. Deployment analysis is the application of systems analysis to the problem of allocating emergency service resources. Systems analysis is used to make better deployment decisions because it provides an objective framework for comparing alternate policies.

How can alternate policies be evaluated to see which best meets the objectives? Each alternative policy could be tried out in a city for a period of time to see which is best. However, experimenting with emergency systems can be impractical, expensive, time-consuming, and/or dangerous. No emergency service agency would likely consider operating a few weeks at a time with different numbers of emergency units on duty to determine the appropriate number to deploy.

For these reasons, models are used to analyze deployment policy alternatives without the real world costs. A large number of methods have been developed to analyze deployment problems. The choice of which model to use usually depends on a trade off between the simiplicity of the model and the accuracy of the results. The more complex the model, the closer it represents the real world and the more accurate its predictions about the consequences of a change in policy. A complex model generally costs more to operate and requires considerably more data than a simple model. The simpler the model, the easier it is to explain it to the policymaker; and the more a policymaker knows and understands about a model, the more likely he or she is to accept its results in evaluating policies.

2.2 MODEL DESCRIPTIONS

Below are brief descriptions of some of the models that have been developed to analyze deployment problems in emergency services. Two common features of models are that they are partial representations of reality and they are used to approximate performance measures of a real world system. Models are used to relate factors of the system that are under the control of the policymaker to the measures of performance that are being used to evaluate alternative policies.

2.2.1 Parametric Allocation Model (PAM)

The Parametric Allocation Model was developed to provide a rough analysis of the number of firehouses or garages needed in each of several large sub-regions of fire departments or ambulance agencies. With very modest data requirements, the model will generate descriptive information about the travel time and workload characteristics of any allocation of firehouses or garages proposed by the user, and prescriptive output which suggests the number of firehouses or garages to be allocated to each region. The objective of the model is to minimize a function that incorporates aspects of efficiency and equity.[6]

2.2.2 Firehouse Site Evaluation Model (FHSEM)

Designed for use by fire departments, this model evaluates specific proposed locations of firehouses. Ordinarily, the Parametric Allocation Model would be used prior to using FHSEM. A geographically detailed database is required. The model was developed under the assumption that fire companies are always available to respond to incidents from their assigned firehouses. This is a reasonable approximation for most cities. In the FHSEM, several fire companies may respond to each incident, and performance statistics are provided for each of them. The model does not attempt to recommend any locations of firehouses as better than others. Such a decision is left up to the policy makers.[6]

2.2.3 Simulation Model of Fire Department Operations (FIRESIM)

FIRESIM is a detailed simulation model requiring an elaborate database as well as personnel with programming to set up the computer program and statistical skills to interpret the output. Practically any deployment policy, including firehouse locations and dispatching practices can be evaluated using this model. Unlike the FHSEM, the simulation mdoel takes into account the unavailability of fire companies. It is more accurate than either PAM or FHSEM.[6]

2.2.4 Patrol Car Allocation Model (PCAM)

The Patrol Car Allocation Model was designed for use by police departments. It is similar in purpose to the PAM. Output generated describes the number of patrol cars to be allocated to each of several large geographical regions at various times of the day. Its data requirements are fairly modest but more elaborate than for the PAM. With PCAM the allocation is envisioned to vary on different days of the week or at different times of the day (rarely the case for fire departments).[6]

2.2.5 Hypercube Queuing Model

The Hypercube Queuing Model was designed for use by police, fire, and ambulance agencies to help them design and evaluation fixed sites and response areas for the units. A geographically detailed database is required. The model is dynamic, and its calculations assume that only one response unit is dispatched to each incident. The Hypercube Model does not suggest any kind of change as being desirable. It simply helps the agency evaluate alternate plans that personnel create themselves.[5]

2.2.6 Simulation Model of Police Patrol Operations (PATROLSIM)

This model is similar to FIRESIM in its design, data requirements, and applications, however, it is intended for use by police departments.[6]

2.2.7 PTI Fire Station Location Package (PTI)

The PTI methodology is very similar to FHSEM. Both models calculate the values of a set of measures that characterize a given configuration of fire companies. The calculations are made assuming that every unit is always available to respond to an alarm, a reasonable approximation in most cities. The primary difference between the two methods are PTI's use of a road network, FHSEM's explicit weighting of travel times by expected incidence rates, and FHSEM's aggregation of travel times by fairly homogenous subareas larger than PTI's fire demand zones and smaller than the whole city.[26]

2.3 MODEL UTILIZATION

These are only some of the models available for use by fire departments, police departments, and medical emergency agencies. The objective of the above mentioned models is to help plan the locations and response district of mobile units. They help the agency evaluate alternative plans that agency personnel create themselves by providing detailed quantitative information about each of the designs. This permits the administrators to carefully analyze the alternative plans and determine which ones appears best.[6]

Police departments, fire departments and emergency medical agencies all use performance measures such as travel times and workloads distribution when evaluating alternate deployment policies. The ambulance system planner needs assistance in determining good locations for the ambulance and reasonable areas of primary responsibility for each. The police system planner needs assistance in designing beats or sectors. The fire system planner needs assistance in determining fire station locations. The objective of all three areas is to minimize the travel times and balance the workloads. As a result most models reveal the trade-offs one must accept in attempting to reach acceptable performance in travel times and workloads. Using the output the planner can simultaneously consider travel time reduction, workload balancing, and preventive measures.

Models that are used in ambulance location problems can also be applied to analysis of fire operations. The delivery of ambulance service and fire protection both relate the quality of service to response time. Savas (1969), Gordon and Zelin (1970), Volz (1971), Fitzsimmons (1973), and Daberkow and King (1977) are some relevant ambulance location studies.[22]

Despite the similarities between the agencies, it is not always appropriate to use a model developed specifically for police departments to analyze deployment policies for fire departments. Fire departments, police departments and ambulance agencies do not operate in the same way. For example, fire departments and ambulance agencies have fixed home locations, fire stations and garages, for their units when they are not responding to a call for service. Police departments have beats or sectors, in which their units patrol. Police units are mobile when they are not servicing a call.

CHAPTER 3

HYPERCUBE QUEUING MODEL

3.1 INTRODUCTION TO THE HYPERCUBE QUEUING MODEL

In this chapter we will examine the Hypercube Queuing Model. The Hypercube Queuing Model was designed to help police departments, fire departments, and emergency medical agencies plan the locations and response districts of their mobile units. By implementing this model, an agency could analyze alternative deployment policies without risking lives or property.

Changes in the operations of the agency that might be considered include:

- Adding new units;
- Eliminating an existing unit;
- Moving units from one location to another;
- Redrawing the boundaries of patrol areas;
- Changing response district without moving any units;
- Moving the overlays representing special units.

The Hypercube Model assists in the planning process by describing the consequences of a proposed change in terms of performance measures such as workloads of units and travel times to emergency incidents. If several possible changes are under consideration, the output from the computer program may indicate that one of them is best. More commonly, the information generated by the model shows that no one proposal is best in regard to all performance measures. This leads the planner to suggest new proposals that may achieve a better balance among conflicting objectives than any of the ones originally presented.

The value of the model lies in the fact that most agencies' operations involve sufficient complications that it is nearly impossible for a planner to look at a map and make accurate "guesses" regarding the workloads of the units or the parts of the city where travel times may be high. In many cases, when the existing configuration is described to the model, the resulting output is illuminating. The agency may never have collected data necessary to calculate the performance measures generated by the model.

It should be noted that the Hypercube Model does not suggest any kind of change as being desirable. It simply helps the agency evaluate alternative plans that agency personnel create themselves. The model provides detailed quantitative information about each of the designs they create, thereby permitting careful analysis of which ones appear best.[5]

3.2 MODEL ASSUMPTIONS, DATA REQUIREMENTS, AND OUTPUTS

3.2.1 Model Assumptions

The Hypercube Queuing Model has two versions: an "exact" model and an "approximate" model. With the exact model, queuing equations are solved exactly, thus there are no errors of approximation introduced. The exact model is only practical for up to 15 units. A unit is a vehicle (firetruck, police car, ambulance) that needs to be deployed. The approximate model can be used for any number of units. For 15 units or less, the approximate model is less expensive to operate on the computer than the exact model. For more than 15 units it is necessary to use the approximate model. The errors introduced by using the approximate model are almost always under five percent, and typically under two percent.[5]

Each of the models, the exact hypercube model and the approximate hypercube model, require the same data and produce the same outputs. The models differ when describing program options.

The hypercube model can be used to estimate certain performance measures of any spatially distributed emergency service system which has the following characteristics:[20]

1. The region, which is the area in which the system provides service, can be broken down into a number of "reporting areas" or "geographical atoms." Typically no more than a few city blocks in size, the atom is the smallest geographical unit for aggregating statistics on the spatial distributions of calls for service and positions of the response units.

2. Calls for emergency service are generated independently from each of the reporting areas. Although the exact time and location of any particular call cannot be predicted in advance, long-term statistical averages are available

to predict the relative workload generated from each of the reporting areas.

3. Data are available to estimate the travel time from each reporting area to every other reporting area.

4. There are M spatially distributed response units, each of which may travel of any to the reporting areas in the serviced region.

5. The location of each response unit when not servicing a call is known (at least statistically). For instance, a patrolling police car may allocate fifty percent of its patrol time to reporting area seven and twenty-five percent each to reporting areas eight and eleven. A fixed-position unit, such as an ambulance, would always be located in one particular reporting area when not providing emergency medical service.

6. Geographical atoms are collected together to form a "district." For mobile units, such as police cars, any atom in which the unit spends some of its available time must be included in its district. In addition, other atoms in which no available time is spent may be assigned to a units' district. Distrits may overlap. In police applications these districts are usually called beats, sectors, or patrol areas. For fixed-position units, such as fire units or ambulances, the atom containing the fixed position must be included in the unit's district. Any other atoms may be specified to be within the fixed unit's district. Often for fixed units its district is defined to be all points closer to that unit than to any other unit. The district is used in

determining preventive patrol assignments, in determining dispatch strategies, and in computing output performance measures.

7. In response to each call for service, exactly one response unit is dispatched to the scene of the call, provided at least one unit is available within the service region. If no unit is available, the call either enters a queue with other backlogged calls or it is serviced by some backup system. A backup system might be that police provide backup to an ambulance service or a neighboring community by dispatching units into the temporarily saturated community. If the call enters a queue, it is later dispatched on a first-come, first-served basis. Since the model only dispatches exactly one unit to a call, it does not accurately portray the performance of those fire departments that send many units to the scene of a fire alarm.

8. The service time for a call, which is the total travel time and on-scene time, has a known average value. Generally speaking, each response unit may have its own average service time. There is considerable variability about the average value(s) due to the unpreditability of service times in actual systems. As one measure of variability, the standard deviation of the service time is assumed to approximately equal to the mean. The exact model assumes negative exponential service times. Slight deviations in this assumption do not markedly alter the predictive accuracy of the model.

9. Variations in the service time that are due solely to variations in travel time

are assumed to be of minor significance compared to variations of on-scene service time. This assumption, which limits the applicability of the model, is most nearly satisfied by urban police departments and least nearly satisfied by rural emergency services (especially rural ambulance services).

In practice, no emergency service system will ever conform to all of the model's assumptions exactly. In applying the model, the user must weigh the extent to which the actual system does not fit the rigidities of the model and the associated loss in predictive accuracy against alternative methods. This comparison is useful when selecting the method which best suits the resource allocation purposes at hand.[20]

3.2.2 Data Requirements

1. The region of the city under investigation must be divided into sub-regions called geographic atoms. Once this task is completed, it is necessary to establish which atoms will be in a unit's district, and the relative amount of nonbusy time each unit spends in each of its atoms. Districts may overlap. That is, one or more geographic atoms can be contained in two or more districts. For example, unit one from district one may spend ten percent of its time in atom three, while unit two from district two may spend thirty percent of its time in atom three. In police applications, every geographic atom must be contained in at least one unit's district. If for example, there is a geographic atom in which no nonbusy time is spent by any response unit, it still must be "in" a district.

2. For each geographical atom, the relative workload distribution (in number of calls for service) must be determined. Additionally, the average workload per hour experienced by the emergency response system under study is needed.

3. The average speed of response of the response units (in miles per hour) is required.

4. The x and y coordinates of each geographic atom (measured in units of 100 feet) is needed. The computer program uses this information when estimating travel times between atoms. Assuming a street grid structure for the city, the computer model requires that the responding unit travel the sum of the east-west distance and the north-south distance between its initial location and the location of the incident. Administrators in some cities may be fortunate enough to have an empirically devised table of travel times from point to point. If this is the case, the x and y coordinates are not required.

5. The average total serivce time (in minutes), which includes travel time to an incident and on-scene time, is required.

6. The type of position and response time estimation procedure the dispatcher employs when making a dispatch assignment must be known. The four options available with the hypercube are as follows:

SCM	Strict Centre of Mass
MCM	Modified Centre of Mass
EMCM	Expected Modified Centre of Mass
ESCM	Expected Strict Centre of Mass

A brief description of the four options available is given in Chapter 7.

7. How the response system functions when all units are simulataneously busy and additional calls for service that arrive are needed. Two options are available. There could be limitless (or unlimited) queuing capacity where backlogged calls are held in queue and dispatched on a first-come, first-served manner. The other option is a zero queue capacity. That is, no queuing is to occur and calls which arrive when all units are busy are to be handled by a backup response system. The model does not compute performance measures for the backup systems other than the total fraction of call that are handled by that system.[20]

Since the purpose of the Hypercube Model is to compare configurations, the user might want to prepare descriptions of several alternative configurations. Alternatively, one configuration can be entered and then later changed in response to the ouput information provided by the model.

3.2.3 Model Output

The Hypercube Model will describe all the following characteristics of a trial confuiguration:

For the entire city or part of the city under study:

- average travel time to an incident;
- the difference in workload between the busiest and least busy unit;
- percent of dispatches that take units outside their response district (for units with fixed locations) or patrol areas (for mobile units).

For each emergency unit:

- average travel travel time to the incident it responds to;
- its workload;
- percent of its dispatches that are outside its response district or patrol area.

For each response district or patrol area:

- average travel time to incidents in the district;
- percent of incidents handled by a unit assigned to the district.

For each reporting area:

- average travel time to incidents in the area;
- percent of incidents there are handled by each of the units;
- in the case of patrol cars, the average number of times per hour that a car passes a randomly chosen point in the area while on patrol.

3.3 HOW THE HYPERCUBE MODEL WORKS

The Hypercube Queuing Model maintains the status of the entire collection of emergency response units so that it may perform dispatch functions and calculate performance characteristics. This is accomplished by assigning a condition of availabilty to each unit and tracking the activities of that unit for a specific time frame.

Emergency response units are either available for dispatch or unavailable for dispatch. The state of the entire collection of emergency units is described by specifying the condition, available or unavailable, of each unit. For example, if there are three units, one possible state is that all three units are available, another is that unit one is unavailable and units two and three are available. With a total of three units there are a total of 2^3 states, corresponding to the eight corners of the cube, ((0,0,0),(1,0,0),...,(1,1,1)). With n emergency units there are 2^n possible states, each corresponding to a vertex of an n-dimensional hypercube. Hence the name Hypercube Queuing Model.

When an incident occurs, the unit that is the dispatcher's first choice to respond to the location of the incident will be dispatched if it is available. The expected travel time of the unit to the emergency can be calculated since the computer program knows the patrol area or location of the unit. If the first-choice unit is unavailable when an emergency occurs, based on information provided by the user, the program determines which unit will respond and calculates the expected travel time. If all units are unavailable, the user has a choice of having the program assume either that the incident will wait until a unit is available or that some unit from another agency will handle the incident. Typically police and ambulance agencies will not dispatch a unit from another agency to handle calls for service that cannot be immediately handled. Instead a queue of calls is developed and the agencies will respond to them when units are available to do so. Fire departments on the other hand, will assign calls for service to another agency to handle and not allow a queue to develop.[20]

3.4 MODEL DESCRIPTION AND TERMINOLOGY

A geographical description of the region under study is the central concept behind the model. To use the model, the city or part of the city to be studied must be divided into small "reporting areas" called geogrpahic atoms. The region is assumed to be partitioned into K geographic atoms of any geometric shape. Atoms are about the size of several city blocks or can correspond to the area covered by a single alarm box. A reporting area must be considerably smaller than a unit's response district. The atoms can be as small as necessary to avoid unreasonable quantization error. For each atom k ($1 \leq k \leq K$) the fraction of region wide workload f_k generated from within the atom is input into the model, where,

$$\sum_{k=1}^{k} f_k = 1.$$

Travel-time statistics also plays a major role in the model. The program needs to know the travel time between reporting areas. Some or all of the travel times can be determined by methods such as by experiment or use a computerized road network. Entered into the program is a travel-time matrix whose generic element is τ_{ij}, which is the mean travel time from atom i to atom j. In general, $\tau_{ij} \neq \tau_{ji}$. Means travel times are calculated using this matrix. The numerical values of the τ_{ij}'s may refelect complications in travel such as one-way streets, bariers, traffic conditions, etc. Alternatively, the location of the center (the centroid) of each atom (x'_i, y'_i) and the travel speed of the units may be specified. Based on this information the program will estimate the travel times. As a default, τ_{ij} is assumed to be $(|x'_i - x'_j| + |y'_i - y'_j|)/v$, where v is the effective response speed. In the computer program, one can selectively override this default for the case of intra-atom travel (involving τ_{ii}'s).

The geographic depiction of the "location" of a response unit is general enough to model the fixed locations of fire units and ambulances and the mobile locations of police patrol units. This is accomplished by specifying a location matrix $L = (l_{ij})$, where l_{ij} is the probability that response unit i is located in cell j while available or idle. In other words, the matrix specifies the fraction of available or idle time that response unit i spends in atom j. Here "idle" is a convenient queuing-theory term for reflecting the activity between responses to calls for services. In actuality, the unit may be far from idle, perhaps performing crime-preventive patrol in the case of police units or performing equipment maintenance or field inspections in the case of fire units.

It is required that L be a stochastic matrix, that is, for all i, $\Sigma\, l_{ij} = 1$, for j=1 to K. A fixed-location unit would have $l_{ij} = 1$ for some atom j, and $l_{ik} = 0$ for $k \neq j$.

For fixed location units, the atom j could be defined as a point atom, that is, an atom of zero area. A mobile-location unit would most likely have several nonzero l_{ij}'s. Within this structure it is very natural to allow mobile units to have overlapping districts or areas of responsibility. For instance, atom k would belong to overlapping district if $l_{ik} \neq 0$ and $l_{jk} \neq 0$ for some i and $j \neq 1$.

Entered into the program is λ, the number of emergencies per hour that are expected to occur in each atom. From a queuing point of view, it is assumed that calls for service are generated from within the region in a Poisson manner at a mean rate λ per hour, with each atom k acting as an independent Poisson generator with mean rate λf_k. As well, there are N servers, which are the response units located within the region.

If the identity of busy servers is not a concern, the queuing system is simply the M/M/N system. The user can specify whether the system has zero-line capacity or infinite-line capacity. The following assumptions characterize the M/M/N model:

1. The interarrival times of calls have a negative exponential distribution and exactly one of the N response units is assigned to every call that is serviced;

2. The service time of any response unit for any call for service has a negative exponential distribution with mean $1/\mu$, thus variations in service time that are due to variations in travel times are ignored;

3. The service time is independent of the identity of the server, the location of the customer, and the history of the system;

4. For the zero-line capacity case, any call for service that arrives while all N response units are busy is either lost or (more likely in practice) serviced from outside the region or by special reserve units from within the region;

5. For the infinite-line capacity case, any call for service that arrives while all N response units are busy is entered at the end of a queue of calls that is depleted on a first-come, first-served manner.

To describe the more complicated state space in which the identities of busy (unavailable) and idle (available) response units are retained, definitions and operations pertaining to binary numbers are required. A generic, one-digit binary number is denoted as b. A generic ordered set of N one-digit binary numbers is denoted as B. A generic ordered set of N one-digit binnary numbers is given by $B \equiv \{b_N, b_{N-1}, \ldots, b_1\}$. The weight of B, denoted w(B), is equal to $\Sigma\, b_i$, which is the number of binary "ones" in the set B. For each set B there is a corresponding unique numerical value v(B), given in decimal form by:

$$v(B) = b_N \cdot 2^{N-1} + b_{N-1} \cdot 2^{N-2} + \ldots + b_1$$

Conversely, for each positive integer k, there is a corresponding, unique set B(k), such that v[B(k)] = k. Where the meaning is clear we shall occasionally perform "arithmetic" operations on the set B, recognizing that v(B) is implied.

For each set $B = \{b_N, b_{N-1}, \ldots, b_1\}$, there is a corresponding unique point or vertex R^N with the ith coordinate equal to b_i $(i = 1,\ldots,N)$. The set C_N of all these 2^N vertices is an N-dimensional unit hypercube. The ith hyperplane from the origin (or simply the ith hyperplane) is the set

$$H_i = \{B \in C_N : w(B) = i\}, \quad i = 1,\ldots,N.$$

Binary set operations are defined as follows:

Or: $B_1 \bigcup B_2 = \{1\}$ if $B_1 = \{1\}$ or $B_2 = \{1\}$.

And: $B_1 \bigcap B_2 = \{0\}$ if $B_1 = \{0\}$ or $B_2 = \{0\}$.

Complement:
$$B' = \begin{cases} \{0\} & \text{if } B = \{1\}, \\ \{1\} & \text{if } B = \{0\}. \end{cases}$$

These definitions carry over in the obvious way to sets having more than one digit.

The Hamming distance between two vertices, B_i and B_j, is the weight of the symmetric set difference,

$$d_{ij} \equiv w[(B_i \bigcap B_j') \bigcup (B_i' \bigcap B_j)].$$

Thus d_{ij} is equal to the number of elements (binary digits) of the set B_i, which differ from the corresponding elements in the set B_j. Geometrically, the Hamming distance is simply the rectilinear of "right-angle" distance between two points in R^N. We also find it convenient to define the "upward" Hamming distance,

$$d^+_{ij} \equiv w(B'_i \bigcap B_j),,$$

and the "downward" Hamming distance,

$$d^-_{ij} \equiv w(B_i \bigcup B'_j).$$

Clearly,

$$d_{ij} = d^+_{ij} + d^-_{ij}.$$

3.4.1 State Transition Matrix

The state space of the zero-line capacity queuing model is the N-dimensional hypercube C_N, where each vertex (state) corresponds to a particular combination of response units, busy and idle.

State Space

Given: $B = \{b_N, b_{N-1}, \ldots b_1\}$

Where: Unit i is busy, if $b_i = 1$

Unit i is idle, if $b_i = 0$

This state space is augmented by an "infinite tail," to accomodate the infinite-line capacity model. The two models, zero-line capacity and infinite-line capacity, are governed by the same equations for unsaturated states, that is states with at least one available response unit. As a result the focus will be on the development of the zero-line capacity model.

State Transition Matrix

To convert the geographical data into a queuing framework, a state transition matrix is defined as:.

$$\Lambda = (\lambda_{ij})$$

where,

λ_{ij} = infinitesimal mean rate at which transitions are made from state i to state j, given that the system is in state i;

$i,j = 0,1,\ldots\ldots,2^N - 1,\ i \neq j,$

$\lambda_{ii} = -\Sigma_{j \neq i} \lambda_{ij}$

For convenience, the states (vertices) are indexed according to their numerical values. For example, i is selected so that $v(B_i) = i$, $i = 0,1,\ldots,2^N-1$. Note that Λ is a differential matrix, therefore $\Sigma_j \lambda_{ij} = 0$.

3.4.2 Classes of Transitions

The two classes of transitions on the hypercube are upward and downward. Upward transitions change a unit's status from available to unavailable. Downward transitions change a unit's status from unavailable to available. For a given vertex $B_i = \{b_N, b_{N-1}, \ldots, b_1\}$, upward transitions can occur in all "adjacent" vertices B_j for which $d^+_{ij} = 1$. If unit l is the unit whose status is changed from idle to busy, then $B_i = \{b_N, b_{N-1}, \ldots, 0_l, \ldots, b_1\}$ and $B_j = \{b_N, b_{N-1}, \ldots, 1_l, \ldots, b_1\}$. Downward transitions can occur to all adjacent vertices B_j for which $d^-_{ij} = 1$. No transitions occur to vertices that are more than unit-Hamming distance from B_i. This is due to the fact that only one unit is assigned to each call.

Since the service times are all distributed as negative exponential random variables with a mean of μ^{-1}, the transition rate associated with each downward transition is equal to μ. Thus, for all (i,j) for which $d^-_{ij} = 1$, $\lambda_{ij} = \mu$. For convenience, μ is set equal to 1, thereby equating the unit of time to the mean rate of service time.

The upward transition rates depend on the region's geography, the system state, and the dispatching selection critierion. A recursive method to generate the set of upward transition rates was developed.[20] First the geographical atom of the call was fixed, then the hypercube was toured in a unit-step fashion. The entire matrix is considered completed as soon as the hypercube has been toured once for every atom.

Since the model assumes Poisson input and negative exponential service times, thereby making knowledge of past system history irrelevant, the state of the system is fully specified by B_i. The knowledge of past system history is irrelevant because of the model assumptions. The model is a finite-state, continous-time Markov process, whose steady-state probabilities are determined from the equations of detailed balance,

$$P\{B_j\}[\lambda_j + w(B_j)] = \sum_{\{B_j \varepsilon C_N : d^{+}{}_{ij} = 1\}} P\{B_i\}\lambda_{ij}$$

$$+ \sum_{\{B_j \varepsilon C_N : d^{-}{}_{ij} = 1\}} P\{B_i\}, \quad j = 0,1,\ldots,2^N-1$$

where $P\{B_j\}$ = Prob{system is occupying state j under steady-state conditions},

$B_j \varepsilon C_N$, $j = 0,1,\ldots,2^N-1$,

$$\lambda_j = \begin{cases} 0 \text{ for } j = 2^N-1, \\ \lambda \text{ otherwise.} \end{cases}$$

Heuristically, these equations require that the steady-state rate of transitions out of state B_j, the left hand side of the equation, be equal to the steady-state rate of transition into state B_j, the right hand side of the equation. The latter transitions include $w(B_j)$ upward transitions to B_j, which result in a new unit becoming busy, and $(N - w(B_j))$ downward transitions to B_j, which result in a new unit becoming idle. To guarantee a probability distribution and thereby eliminate a degenerate solution, the probability must sum to one.

$$\sum_{i=0}^{2^N-1} P\{B_i\} = 1,$$

This condition forces any one of the balance equations to be redundant and therefore removable from the set of equations.

Theoretically, the solution to this set of equations requires only a matrix inversion, and should be relatively straightforward. However, the size of the matrix Λ is equal to 2^{2N} elements. This is large for even moderate values of N. For instance for N=10, the matrix contains 1,048,576 elements. Clearly both computational and storage problems of large magnitude are realized.

3.4.3 Generating The Upward Transition Rates

Generating upward transitions rates requires the optimal unit to dispatch be known, and a tour of the hypercube is constructed. Once the tour is constucted and the optimal units to dispatch are known the upward λ_{ij} can be calculated by first initializing the matrix Λ to zero. Then, at the point on the tour associated with atom k and vertex $B_i = \{b_N, b_{N-1}, \ldots, b_1\}$, exactly η_{ik} transition rates will be incremented by $\lambda f_k/\eta_{ik}$. In particular,

$$\lambda_{ij} \leftarrow \lambda_{ij} + \lambda f_k / \eta_{ik}$$

for all adjacent states $B_j = \{b_N, b_{N-1}, \ldots, b'_{rl}, \ldots, b_1\}$ such that $d+_{ij} = 1$ and $b'_{rl} = 1 \neq b_{rl}$. Very frequently there are no ties, that is $\eta_{ik} = 1$. In this case only one addition is performed for every vertex for each geographical atom.

3.4.4 Generating a Unit-Hamming-Distance Binary Sequence

To develop an efficient method for generating the upward transition rates, for each geographical atom k ($1 \leq k \leq K$), the hypercube is toured in a unit-step fashion. From one step to the next, the status of only one response unit changes, either from busy to idle or from idle to busy.

In order to tour the hypercube in a unit-step manner, a complete sequence, $S_1 S_2, \ldots$, of N-digit binary numbers, with 2^N unique number members in the sequence and adjacent members being exactly unit-Hamming distance apart must be generated. Such a sequence represents a complete unit-step tour of the hypercube.

When the binary numbers are identified with their values, the following algorithm generates such a sequence $S_1, S_2, \ldots\ldots, S_2N$:

```
Step 1:    Set $S_i = 0$, $S_2 = 1$, $M2 = 2$, $J = 2$.
Step 2:    If $J > N$, STOP, binary sequence completed.
Step 3:    $M1 = M2$, $M2 = 2*M1$, $I = M1$.
Step 4:    $S_{I+1} = M1 + S_{M2-I}$.
Step 5:    $I \leftarrow I + 1$.
Step 6:    If $I < M2$, go to step 4.
Step 7:    $J \leftarrow J + 1$.
Step 8:    Go to step 2.
```

As an example, the following sequence was generated for N =3:

Step 1:

Initialization

Steps 3-6:

Add "one" in 2nd

position and

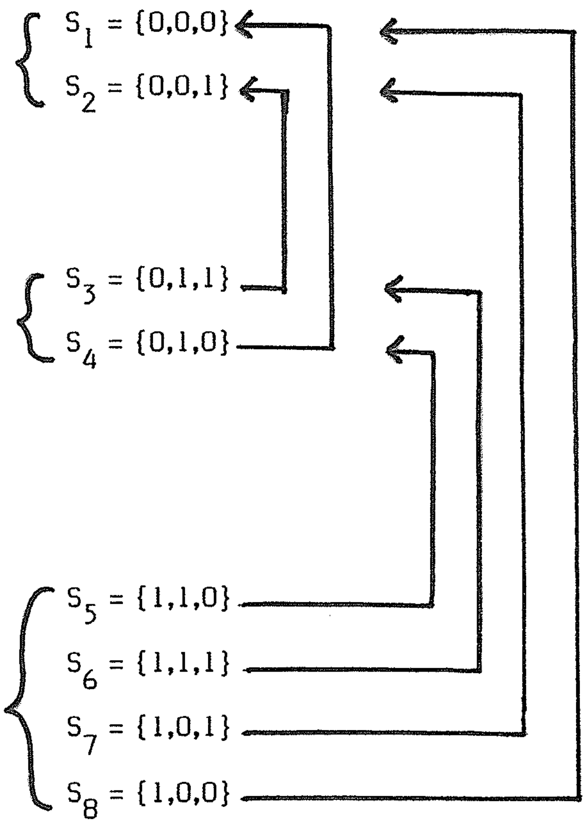
step backwards

Steps 3-6 again:

Add "one" in 3rd

position and

step backwards



STOP.

This generated tour is only one of many possible unit-Hamming distance complete tours of the hypercube.

3.4.5 Determining the Optimal Unit(s)

The optimal unit to dispatch in the current state on a tour is likely either the same unit that was optimal in the state considered just prior to the current one, or the unit whose status just changed, provided it has switched from busy to idle.

At each vertex the identities of the optimal units to dispatch must be computed. In particular, the following variables must be calculated:

η_{ik} = total number of response units that are optimal, given state B_i and geographic atom k,

r_l = the number of the lth optimal response unit,

where

$r_l = 1,2,\ldots,N,$

$l = 1,2,\ldots,n_{ik}.$

If $\eta_{ik} > 1$, it is assumed that the unit dispatched to atom k when the state is B_i is to be chosen randomly from among the units $r_1, r_2, \ldots, r_{\eta ik}$.

For a certain class of dispatch policies, determining the identity of the best available unit(s) to dispatch at each vertex, can be accomplished very efficiently by exploiting the "unit-step" property. This class includes any policy that allows determination of dispatch preferences for units to calls from any particular atom without references to system state. In other words, for such a policy, one can always say that some unit i, if available, would be the first preference for dispatch to atom k, unit j would be the second preference, unit l the third preference, etc. For such fixed-preference policies, the dispatcher always selects the most preferred available unit, given the system state. Thus, for instance, the dispatch selection criterion may be strict centre of mass (SCM), modified centre of mass (MCM), expected strict centre of mass (ESCM), or expected modified centre of mass (EMCM). The policy may include additional complications, such as giving the district's "own" unit first preference regardless of estimated travel times.

More complicated dispatch policies, such as time-average minimization of system-wide travel time, as illustrated by Carter, Chaiken, and Ignall,[3] are not included in the class of policies considered by the hypercube. For such policies, the determination of the optimal unit may be a very difficult task that involves many calculations. However, the results of such calculations can be fed directly into the hypercube model, thereby facilitating the computation of steady-state probabilities and system-performance measures.

In order to be concrete (and brief) in the following discussion, the dispatch selection algorithm was developed in the context of one particular fixed-preferences policy, namely the expected modified centre of mass (EMCM) policy. With this strategy, the dispatcher takes into account the geographical atom of the call and correctly utilizes all the information he has available regarding locations of units. Defining q_{ik} and t_{ik} as

q_{ik} = the number of the ith closest unit to geographic atom k, given that all units are available,

t_{ik} = mean travel time from district i to geographic atom $k = \Sigma_j l_{ij} \tau_{jk}$.

The dispatcher using an EMCM policy would select the available unit with minimum τ_{ik}. If there was a tie, it would be broken by random choice.

As an example, suppose the hypercube is in the process of being toured and a step from vertex S_{i-1} to vertex S_i is being considered. Already determined, are the identities of the $n_{(i-1)k}$ units that are optimal units at vertex S_{i-1}, assuming a call from geographical atom k. Now, this step can cause any one of the N units to change status. The particular unit whose status is changed is

$$n_0 = \log_2[v(\{S_{i-1} \bigcap S'_i\} \bigcup \{S'_{i-1} \bigcap S_i\})] + 1$$

If $v(S_{i-1}) > v(S_i)$, then unit n_0 is now available; otherwise it is unavailable.

Consider the former case first. There are three possibilities:

(1) Unit n_0 is now the unique optimal unit.
(2) Unit n_0 is additional optimal unit.
(3) Unit n_0 is not an optimal unit.

Given the EMCM dispatching criterion, the possibility that applies is readily determined by comparing the travel time of the new unit, t_{nok}, to t_{r_1k}, the travel time of a previously optimal unit. If either (1) or (2) applies, no further computations are required. This completes operations at vertex S_i if unit n_0 is now available.

Now consider the case in which unit n_0 is unavailable. There are also three possibilities here:

(1) Unit n_0 was the unique optimal unit.
(2) Unit n_0 was one of the two or more optimal unit.
(3) Unit n_0 was not an optimal unit.

Again, the situation that applies is determined by comparing t_{nok} to t_{r_1k}. If (3) applies, nothing further happens. If (2) applies, unit n_0 is removed from the list $r_1, r_2, \ldots, r_{nik}$, and the value of n_{ik} is decreased by one. If (1) applies, another optimal unit (or set of optimal units) must be found. This is done by searching the list q_{ik}, starting immediately after the entry for which $q_{ik} = n_0$. The first available unit that is found from this list is an optimal unit for vertex S_i. This unit now becomes r_i. Additional units in the list of q_{ik} must be examined since the possiblility of a tie exists. This additonal search is teminated as soon as a t_{ik} is found that is stricIty greater than $t_{r_i k}$. At this point all the r_i's and n_{ik}'s have been computed, and the job is finished.

There exists one further complication for situation (1) above where unit n_0 is unavailable, and that involves the case for which B_i is $\{1,1,1,....,1,1\}$. Occuring once each tour, this is the state in which all N units are simultaneously unavailable. Obviously, any search for available units will be fruitless. But we want to preserve the generality of the algorithm and avoid a situation in which we would have to test continually for state $\{1,1,1,...,1,1\}$ and invoke special procedures once it is incurred. The problem is solved by defining an artificial unit that is designated as unit N + 1, which is always available for an N-unit problem. We make unit N + 1 particularly unattractive to dispatch by setting $t_{(N+1)k} = +\infty$ for all k. In actuality, "+∞" in a computer program corresponds to a very large yet infinte number. Thus, if the algorithm finds $B_i = \{1,1,1,...,1,1\}$, it reluctantly selects unit N + 1 as the optimal unit. One step later, when it finds that unit N + 1 was the optimal unit and that some other unit i (i = 1,...,N) is available, it immediately designates unit i as the optimal unit for the new vertex.

Regarding the generality of the TOUR algorithm, the dispatch criterion enters only at the point of determining which of the three possibilities applies, given either the availability or unavailability of the unit n_0. Thus the general structure of the algorithm remains invariant within the large class of fixed-preference dispatch policies. To adapt the algorithm to another dispatch policy with this class, the comparison of t_{nok} with t_{r1k} need only be replaced by the analogous comparison or other procedure associated with the new criterion.

3.5 LIMITATIONS OF THE HYPERCUBE MODEL

1. The computer program for the Hypercube Queuing Model was written in a language called PL/1 and was designed to run on a mainframe computer. An agency wishing to use the program must have access to a mainframe computer with a compiler for this language. This is a reasonable requirement for larger agencies, however, smaller agencies may not have access to such a mainframe computer system. Many emergency service agencies have difficulty finding a computer system that they can use that will compile a program written in BASIC, PL/1, or especially in SIMSCRIPT. Nearly all agencies can compile a COBOL program.

2. It is not necessary for any of an agency's staff to understand the PL/1 language. All options available with the program are chosen by means of input cards described in the user's manual.[20] However, in study of emergency service model utilization by agencies (Chaiken 1978)[6], it was found that in trying to implement models, errors in the programs and/or user's manuals were found. Aside from the difficulties with bugs in the programs and errors in the user's manuals, over half of the users had to

change the programs in some way before operating them. Some of the changes were very minor and were already anticipated in the user's manual as possibly desirable. Others were more substantial and involved changes to make the program compatible with the user's compiler. An unexpected development was the complete rewriting of two programs into other languages. For example, there are at least four versions of the Parametric Allocation Model and a Cobol version of the Hypercube model.

Based on this study, it would be beneficial if an agency's staff understood the program language a model was written in. It is quite likely smaller agencies would not have employees skilled in the language a program is written in.

3. The cost of using the Hypercube Model could result in some significant mainframe computer charges since the user pays for the time connected to the computer as well as the runs. The cost for each run of the program on a mainframe computer system varies from installation to installation. The primary inflences on cost are:

   - Whether the user chooses the exact hypercube model, which can be quite expensive or the approximate model which is inexpensive.
   - The number of emergency units to be considered.
   - The number of reporting areas in the city of part of the city to be modeled.[5]

4. In the exact model, the maximum number of emergency units is limited to

15. If the entire City were under study, this is a very low limit. Winnipeg, which is certainly not the largest city in the North America, has 25 stations. Thus it is reasonable to assume there are a number of cities which have significantly more units.

5. The model requires a significant amount of data. The length of time required to collect data for use in the model depends on the following:

   - Whether the agency has previously recorded the reporting area for each incident in computer-readable form. If an agency has not collected any data, they would require about four man-months for data collection. Data preparation would require approximately two man-weeks.
   - Whether the coordinates of reporting areas on a grid map of the city are known, or the time required to travel between each pair of reporting areas is known.[5]

   - The cost of data collection and preparation would be a major factor that should be considered when deciding to implement the Hypercube Model.

3.6 HOW TO USE THE HYPERCUBE MODEL

The number of emergencies per hour that are expect to occur in each reporting area must be estimated by the user from past data. Also, the average length of time it takes for a unit to handle an incident must be estimated for the part of the city being studied. (The exact hypercube model permits this service time to vary according to which unit responds to the incident.) For police patrol cars, the user must determine, in addition, the speed of units while on patrol and the number of partollable street-miles in each reporting area.

The user specifies a possible configuration of the emergency units by telling the progam how many units there are, the patrol areas of locations for each one, and the relative amounts of time the unit patrols each reporting area when not otherwise busy. (If the unit has a fixed location, it stays in one reporting area 100 percent of the time when not busy.) To do this, the user simply draws on a map the patrol areas to be tried out and sees which reporting areas fall in each one.

The program also needs to know which unit will be the dispatcher's first choice to respond into each reporting area, which will be his second choice if that unit is busy, and so on. The user can input this information for each reporting area or let the program calculate the dispatcher's choices according to the length of time it would take each unit to travel to the incident. (The general idea is that the program assumes the dispatcher will choose the closest available unit, closest in the sense of travel time. There are several variations permitted.)

Since the purpose of the Hypercube Model is to compare configurations, the user might want to prepare descriptions of several alternative configurations. Or, he can just enter one configuration and then later make changes to it, in response to the output information provided to him by the model.

From this information it might be found, for example, that the busiest unit in a trial configuration will be unavailable 80 percent of the time and will be able to respond to only 20 percent of the calls in its district. This would suggest that its response district should be made smaller. A new trial configuration would then be designed, and the model would indicate whether an adequate improvement has been made. This process is continued until the user is satisfied with the results and has found an acceptable allocation of resources.

CHAPTER 4

HISTORY OF FIRE PROTECTION FOR THE CITY OF WINNIPEG

4.1 STAFFING AND ORGANIZATION OF THE FIRE DEPARTMENT

The City of Winnipeg, or "unicity," represents the unification of 12 formerly independent municipalities reorganized by the Province of Manitoba in 1972. To meet the needs of the City of Winnipeg, a single fire department was created in 1974 by amalgamating the formerly independently operated civic fire departments.

The staffing and deployment of the Fire Forces of the Amalgamated Winnipeg Fire Department was established by a Committee chaired by the Provincial Fire Commissioner and composed of all the area Fire Chiefs, the Director of Personnel of the City of Winnipeg, the Deputy City Treasurer of Winnipeg, the Chief Engineer of the Canadian Underwriters Association and a representative of the Manitoba Fire Fighters Association. This Committee established a staffing and deployment plan which utilized existing personnel and stations. This plan, which became the basis for the present Department, allocated 200 men in 24 Fire Stations, operating 32 Pumper Companies, 10 Ladder companies, 4 Rescue Companies, 5 District Chiefs and 1 Assistant Deputy Chief per Platoon.[11] Today, the City of Winnipeg Fire Department has 959 authorized positions, all full-time. The distribution of positions by function is as follows:

Function	Authorized Positions
Fire Fighting	892
Fire Prevention	22
Administration	17
Communications	13
Repair Shop	9
Training	6

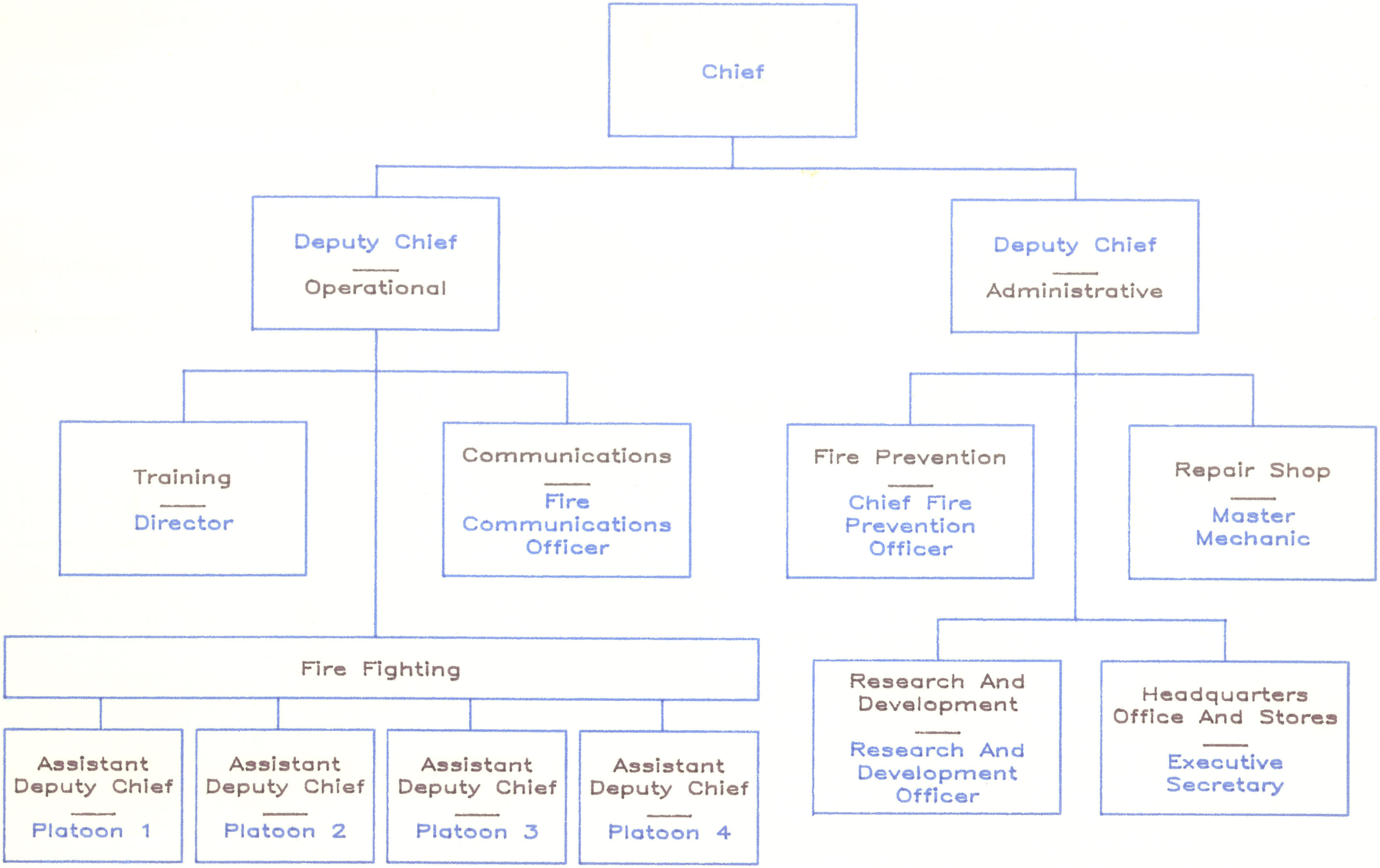
An additional ten personnel are responsible for the operation and maintenance of the high pressure plant (these staff are not supervised by the Fire Department.) The organizational structure of the Winnipeg Fire Department is given in Figure 1.[8]

The cost of operating the Winnipeg Fire Department has been growing at slightly above the rate of inflation in recent years. Budgeted expenditures in 1986 were almost $10 million over the actual expenditures of $33 million in 1980, or an increase of 30 percent over a six-year period. Fire Department expenditures in recent years are summarized as follows:

Year	Fire Department Expenditures	Per Cent Increase From Previous Years
1986	43,086,262	10.0
1985	39,177,211	3.2
1984	37,950,788	3.7
1983	36,562,834	9.5
1982	33,395,631	-

The City of Winniepg is currently experiencing a period of sustained population growth. The Department of Environmental Planning projects that total Winnipeg population will increase to 635,200 by 1996 and 645,300 by the year 2001, or .5 per cent a year. This growth is expected to be outstripped by the growth in dwelling units: It is forecast that between 1986 and 2001 some 34,000 new dwelling units will be created, for a growth rate of 1 per cent a year. While

FIGURE 1
WINNIPEG FIRE DEPARTMENT
CURRENT PLAN OF ORGANIZATION



apartment buildings (five or more stories) currently account for just under 15 per cent of the total Winnipeg housing stock, this proportion is anticapted to increase.[8]

4.2 MAJOR IMPROVEMENTS

The Winnipeg Fire Department has been undergoing improvements since the amalgamation of the eight separate Fire Departments in 1974. One of the improvements has been its provision of better coverage through its closing of old Fire Stations and opening new Fire Stations. The following changes have been made:[1]

FIRE STATION CLOSURES

Station	Community	Year	Reason
St. Mathews & Sanford	City Centre	1972	Amalgamation
William & Cecil	Weston	1974	Amalgamation
Talbot & Stadacona	Chalmers	1974	Amalgamation
Dorchester & Wilton	Cresentwood	1974	Amalgamation
Westminister & Lipton	Westminister	1974	Amalgamation
Arnold & Osborne	River View	1974	Amalgamation
St. Mary & St. Annes Rd.	Elm Park	1974	Amalgamation

FIRE STATION RELOCATIONS

Station	Year	Reason
Henderson & Essar (now at Rothesay & McIvor #24 Stn)	1975	Recommended
Pembina & Waller (now at Beresford & Lilac)	1978	Recommended

NEW FIRE STATIONS

Station	Year	Reason
Waverly & Chevrier	1979	Recommended

RENOVATED FIRE STATIONS

Station	Year	Reason
Sargent & Burnell	1983	Inadequate space

After the 1974 amalgamation, it was clear the dispatching methods utilized by the smaller independent municipal fire departments would not be appropriate for the large unified City of Winnipeg Fire Department. To improve dispatching of police, fire and ambulance emergency units, a Computer Aided Dispatch System was implemented. By 1980, the system was fully operational.[14]

In 1983 a Fire Station Location Steering Committee composed of the Commissioner of Finance, Chairman of Committe on Finance and one other member of the City Council, the Director of Civic Properties, the Fire Chief, two Deputy Fire Chiefs, and a representative of the United Fire Fighters Union, met on an ongoing basis to assess the fire demand requirement of the City and how to best define fire Station locations to provide an adequate protection for the citizens of Winnipeg. Using the Public Technology Incorporated of Wahsington, D.C. (P.T.I.) process, this committee together with a Project Team conducted a thorough review of the Fire Protection Services provided by the City. The Committee met usually once a month and has approved and set standards for the delivery of Fire Service in Winnipeg.[1]

In July 1987 a comprehensive operational audit of the City of Winnipeg Fire Department was conducted. The report sited several opportunities to significantly reduce Department costs and improve services to citizens. To achieve these cost savings and service improvements, the Department was advised to:[8]

- Reduce the existing duplication of pumpers and stations.
- Relocate one station in the area west of Transcona.
- Add one rescue unit, and move one aerial ladder truck.
- Not add driver aides for District Chiefs.
- Make more productive use of the time when fire crews are not responding to emergency alarms.
- Increase the frequency of commercial and industrial fire inspections.
- Reduce the overstaffing in the Communications Centre.

In response, Fire Department Officials are investigating the implications the recommendations would have on fire protection for the City of Winnipeg.[2]

CHAPTER 5

THE DATA PROBLEM

One of the essential questions examined in this thesis is whether the data base developed by a typical city such as Winnipeg is robust enough to be used in emergency service models. An emergency service model such as the Hypercube has very specific data requirements. The various data bases for the City of Winnipeg were developed for internal use. This chapter describes the sources of data available and the necessary preparation of the data for use in the model.

5.1 SOURCES OF DATA

There were a number of sources of data for this project. They were on different media and in different locations.

5.1.1 Master Area File

The Master Area File, which is stored on the mainframe computer facility of the City of Winnipeg, contains the x and y coordiantes of every street intersection for the City of Winnipeg. It was created by the City at Winnipeg and is utilized by various City departments such as Transport, Works and Operations, Fire Department, Police Department, and Ambulance Services. For each roadway the file contains the intersecting roadway, and the x and y coordintes at the intersecting point. Each coordinate is measured in meters. The (0,0) position is the Public Safety Building.

The Master area file was downloaded from the City of Winnipeg's mainframe computer to a microcomputer ASCII file. The ASCII file was converted into a fixed length file for use with PCFile release 4.0.

5.1.2 Computer Aided Dispatch (C.A.D.) System

In an attempt to improve dispatching, a Fire/Ambulance Computer Aided Dispatch System was implemented in 1979 by the City of Winnipeg. A Computer Aided Dispatch System which has been operational since 1980, stores emergency incident and dispatch information on magnetic tape at the mainframe computer facility at the City of Winnipeg.

The 1984 data generated by the Computer Aided Dispatch System was made available on the mainframe computer at the University of Manitoba. The C.A.D. dataset at the University of Manitoba contains two type of records: incident records and dispatch records. An incident record describes the facts about each call for service, such as the time of an incident, the location of an incident, and the type of incident. Each incident record is followed by one or more dispatch records. A dispatch record is created for each unit dispatched to an incident. To create a dispatch record all Fire Department responding apparatus, except Chief's Autos, were equiped with status heads. The purpose of these heads were to generate back to the C.A.D. System the current status of any apparatus responding to an emergency. The heads have five push buttons, each of which, when activated, indicate the apparatus status. They were numbered as follows:[11]

10-10 - Responding to Emergency
10-13 - Arrived at Emergency
10-8 - Leaving Emergency Scene
10-5 - ON Air/On Duty
10-6 - In Fire Station

Tables 1 and 2 describe the variables that are included in the incident and dispatch records, respectively.

TABLE 1

COMPUTER AIDED DISPATCH SYSTEM
INCIDENT RECORD

VARIABLE	DESCRIPTION
RECTYPE	I for incident record.
INCIDNO	Master incident number used on all fire reocrds.
DATEINC	YYMMDD
TIMEINC	HHMMSS - This time is after successful entry, an "entered" is visible on the top corner of screen, and an incident number is attached.
RECBY	ADT, AMPL, PROT, HQ, PREV, MESS, OBS, WAS, & preset to 911.
FALSE	F = false alarm, b = other.
X-COOD	X-Cood of intersection.
Y-COOD	Y-Cood of intersection.
FAD	Fire Alarm District.
DISTYPE	Type of dispatch made by dispatcher, STEL, TEL, NSO, OD/A, --- FESS
FARRIVED	Time HHMMSS of arrival of first unit.
FARRUNIT	Unit number of first arrived unit.
INTERDEPT	Interdepartmental incident.
OPERID	Operator ID or "from" ID, i.e., "PP" for Police, "AA" for Ambulance.
ADDRESS	Address information (first 12 char of field).

TABLE 2

COMPUTER AIDED DISPATCH SYSTEM
DISPTACH RECORD
(repeated for each unit dispatched)

VARIABLE	DESCRIPTION
RECTYPE	D = Dispatch Record.
INCIDNO	Incident number.
DATEDISP	Date of dispatch, YYMMDD.
TIMEDISP	Time of dispatch, HHMMSS.
DISPTYPE	Dispatch type, S(Still), T(Tel), B(Box), N(NSO).
UNIT NO	Unit Number.
TIMERESP	Time of responding HHMMSS.
TIMEARR	Time of arrival at scene HHMMSS.
TIMECLEAR	Time "cleared" of incident HHMMSS.
TIMEAVAIL	Time "available" HHMMSS.

5.1.3 Public Technology Incorporated Model (P.T.I.)

In 1983, the P.T.I. Fire Station Location Package was puchased by the City of Winnipeg to assist in the evaluation of Fire Station proposals contained in the Fire Department's five year Capital Plan, to review existing Fire Station Locations throughout the City, and evaluate the need for new stations or station relocations, to review the adequacy of total response, including aerial ladders, rescue companies and District Chiefs. The function of the model was to allow for relatively easy comparisons between alternative Fire Station location proposals. The model does not make any decisions, but by showing how well the community is serviced by each proposal, it acts as a aide to decision making.[1]

The P.T.I. methodology required considerable detail about the distribution of the fire risks in the city. To provide the detail, a research team from the Fire Department divided the City up into 1298 small areas, called Fire Demand Zones (FDZ). Each FDZ was assigned a hazard level. Additionally, the P.T.I. model required that the City's street network, including bridges, be entered into it. This network was assigned speeds for the responding pumper units. The input data created as a result of implementing the P.T.I. model was utilized in the implementation of the Hypercube Model.

Additionally, the computer printout from the P.T.I. methodology provided valuable information for analysis of the Hypercube Model. One such printout provided a list of all the Fire Demand Zones, the corresponding neighborhood numbers, and the names of the intersecting roadways at the centre of each Fire Demand Zone.

5.1.4 Map of Fire Alarm Districts, Fire Demand Zones and Neighborhood Boundaries

A map of all the Fire Demand Zone and Neigbourhood boundaries was acquired from the City of Winnipeg Fire Department.

When creating the Fire Demand Zones required for the P.T.I. model, each neighborhood in the City was divided into small sub-regions comprizing of a few city blocks. The numbers assigned to the Fire Demand Zones cooresponded to the neighborhood numbering system. For example, Sargent Park, whose neighborhood number is 135, was divided into eleven Fire Demand Zones numbered 135-1,135-2,....,135-11. The Fire Demand Zone numbers had been re-ordered sequentially from 1 to 1298 for input into the P.T.I. process. However, the map provided by the Fire Department did not display the new numbering sequence.

The boundaries of the Fire Alarm Districts were displayed on the map. From this map it was easy to determine the Fire Demand Zones contained in each Fire Alarm District.

Finally, the map had plotted onto it the location of Fire Stations. The Fire Demand Zone a station was located in could be determined by reading the map.

5.2 PREPARING THE DATA

Prior to data prepartion, a region of the City of Winnipeg was selected for analysis. It was decided that the region of the City to be selected should have a high level of demand for service. This decision was made because there would be more incidents involved in the anlaysis, as well as a higher probability of a queue forming. Additionally, the Hypercube Model was designed for analysis of a city where often more than 10 percent of its units are busy at one time.[5] The distribution of demand for service for 1984 is given in Table 3. This table was developed the 1984 C.A.D. dataset and a computer software program called Statistical Analysis System (S.A.S.).

TABLE 3
DISTRIBUTION OF DEMAND FOR PUMPERS

FIRE ALARM DISTRICT	TOTAL DEMAND
01	868
02	205
03	191
04	213
05	261
06	222
07	150
08	82
09	318
10	159
11	75
12	390
13	3
14	1
15	22
15	120
17	204
18	126
19	88
20	185
21	225
22	3
23	324
24	20
25	324
26	111
27	261
28	1
29	192
30	0
31	258
32	196
33	118
34	129
35	393
36	116
37	126
38	13
39	109
40	109
41	273
42	374
43	20
42	374
43	20
44	46
45	149
46	567
47	249
48	129
49	113
50	154
51	323
52	59
53	34
54	10
55	47
56	12
57	2
58	1
59	1
60	2
61	59
62	142
63	110
70	12

Since Station 1 has the highest demand for service in the City, it was selected for the analysis. Using the map of Fire Alarm Districts and Station Locations provided by the City of Winnipeg, Fire Stations 2, 5, 6 and 7 were then selected because their regions of primary concern were adjacent to Fire Station's 1 region of primary concern. The Fire Stations selected for analysis and their corresponding addresses and areas are given in table 4.

TABLE 4

SELECTED FIRE STATIONS AND THEIR LOCATIONS

STATION #	LOCATION	AREA
1	65 Ellen Street	Downtown
2	56 Maple Street	Downtown
5	845 Sargent Avenue	Inner City
6	349 Burrows Avenue	North End
7	180 Sinclair Street	North End

A Fire Department has a variety of different types of units available for fire fighting. The City of Winnipeg Fire Department has pumpers, aerial ladders, cheif's automobiles, rescue units, tankers, and emergency support units. The response characteristics of each type of unit must be analyzed separately due to the differences in their maximum speeds and their manoverability. Only pumpers were included in the implemenation and validation of the Hypercube Model.

The Hypercube Queuing Model assumes that only one unit from each station is dispatched to an incident therefore only first arriving units were included in this analysis. The response time of the first arriving unit is the most critical since it is the job of the crew on this unit to assess and gain control of the situation as quickly as possible. A first arriving unit is a unit which arrives first on the scene of an incident.

Given a region of the city is selected, all of the necessary data needed to run and validate the Hypercube Model had to be compiled. Specifically,

- the selected region of the city had to be divided into geographic atoms;
- the relative workload distribution (in numbers of calls for service) among geographic atoms had to be determined;
- the location of a response unit when not servicing calls was required;
- the x and y coordinates (100 ft units) of each atom, or empirically derived travel times from point to point had to be established;
- the average service time had to be calculated;
- the average workload per hour had to be calculated.

The first task was to divide the selected region of the City into goegraphical atoms. A geographical atom consists of a few city blocks. The boundaries of each of the areas a fire station is responsible for are called Fire Alarm Districts. A Fire Alarm District is comprised of several city blocks. A station may be responsible for one or more Fire Alarm Districts, as given in Table 5.

TABLE 5

FIRE ALARM DISTRICTS FOR SELECTED STATIONS

STATION NUMBER	1st DUE FIRE ALARM DISTRICT
1	01 64
2	03 39
5	04 05 06
6	31 62
7	32 63

A Fire Alarm District is too large a subarea to be considered a geographical atom for input into the Hypercube Queuing Model. However, each Fire Alarm District is made up of several Fire Demand Zones. A Fire Demand Zone is typically no more than a few city blocks in size, therefore, can be considered equivalent to a geographic atom.

Unfortunately, all incident and dispatch information was recorded with respect to Fire Alarm Districts. It was thus necessary to establish the relationship between FADS and FDZs so that the C.A.D. data could be used in the analysis. Ouput from the P.T.I. model listed the Fire Demand Zones each Fire Station was responsible for. A second output from the P.T.I. model execution listed the sequential Fire Demand Zone numbers, the neighborhood Fire Demand Zone numbers, and the names of the two intersecting roadways at the centre of the corresponding Fire Demand Zone. Given the roadway names at the centre of each Fire Demand Zone, the x and y coordinates were extracted from the Area Master File. The x and y coordinates were then converted into 100 foot units.

The Fire Alarm Districts each Fire Station was primarily responsible for is presented in Tables 6, 7, 8, 9, and 10. It was thus possible to draw the relationship between Fire Alarm Districts and Fire Demand Zones. Table 4 summarizes the compilation of the various sources of data.

The Fire Demand Zone for each of the selected Fire Stations was plotted onto a map. The Fire Stations locations were marked onto the map and their areas of primary responsibility were color coded for each Fire Station. (See Figure 2)

Using the map in Figure 2 and the Master Area File, the Fire Demand Zone each station was located in and the x and y coordinates of the Fire Station Location was determined. Table 11 provides a summary. The Fire Demand Zone each station was located in represents the atom a response unit is located in when not servicing a call.


383
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412
321
135
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318
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504
505
324
125
123
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317
307
513
514
506
308
112
113
119
313
516
517
92
126
114
115
110
120
309
310
121
518
311
116
111
3
1
2
585
153
154
93
94
95
58
59
60
107
117
4
5
108
109
138
96
97
98
61
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63
18
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99
100
101
64
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74

FIGURE 2

FIRE DEMAND ZONES

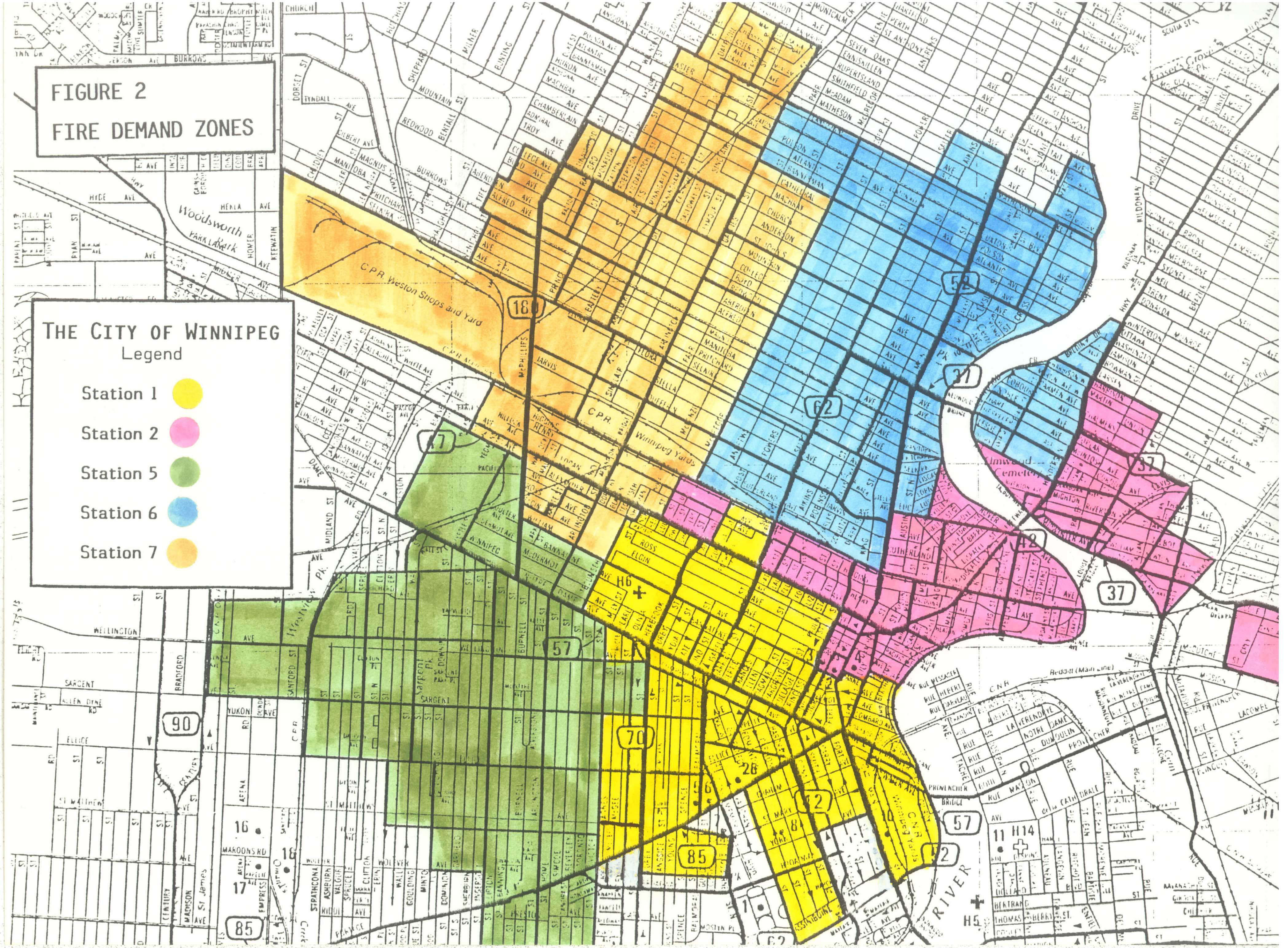

FIGURE 2

FIRE DEMAND ZONES

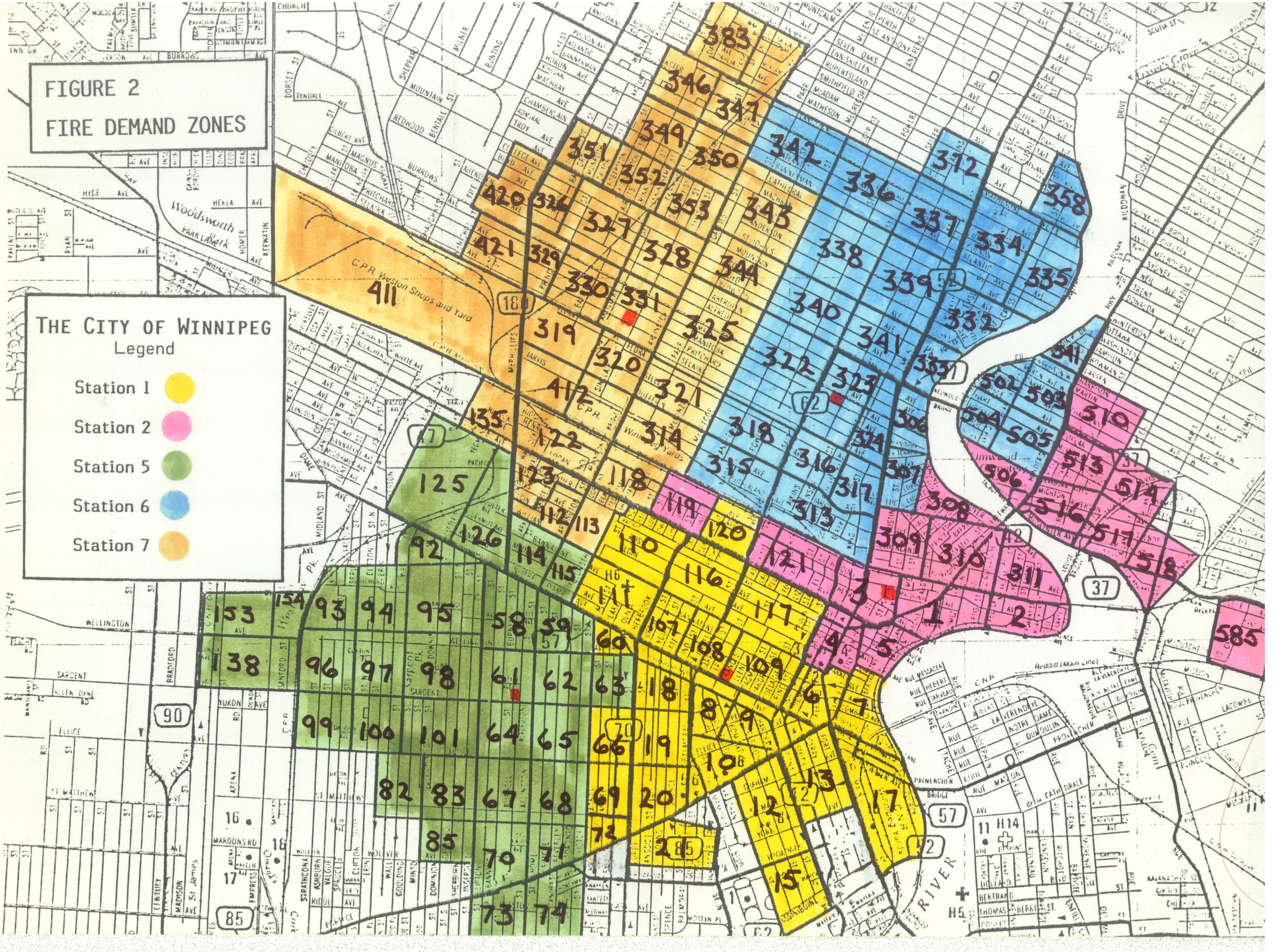

TABLE 6

STATION 1, FIRE ALARM DISTRICTS 01 & 64

FIRE DEMAND ZONE	INTERSECTING ROADWAYS AT CENTER OF FDZ	COORDINATES (100 foot units) X	Y
6	McDermont/Albert	1.35	-11.16
7	Lombard/Westbrook	14.50	-16.50
8	Sargent/Balmoral	-26.48	-15.58
9	Ellice/Donald	-7.78	-19.00
10	Portage/Vaughan	-19.95	-32.88
12	Carlton/St. Mary	-7.94	-37.44
13	St. Mary/Gary	4.27	-32.68
15	Broadway/Carlton	-3.84	-48.13
17	Gilroy/Water	25.99	-30.94
18	Cumberland/Langside	-34.42	-5.35
19	Ellice/Langside	-35.17	-28.12
20	Furby Pl/Langside	-35.27	-36.16
21	Langside/Portage	-35.17	-41.64
60	Maryland/Wellington	-44.52	-2.10
66	Maryland/Ellice	-44.79	-27.79
69	St. Mathews/Maryland	-45.05	-39.57
72	McGee/Portage	-48.39	-47.61
107	McDermont/Lydia	-32.58	4.23
108	McDermont/Isabel	-23.56	0.13
109	McDermont/Dagmar	-11.81	-5.32
110	Ross/Tecumseh	-48.00	26.12
111	Pearl/McDermont	-44.92	9.78
117	Ellen/Ross	-9.48	8.56
120	Gunnel/Logan	-18.37	12.66
116	Roos/Isabel	-23.59	25.07

TABLE 7

STATION 2, FIRE ALARM DISTRICTS 03 & 39

FIRE DEMAND ZONE	INTERSECTING ROADWAYS AT CENTER OF FDZ	COORDINATES X (100 foot units)	COORDINATES Y (100 foot units)
1	Higgons/May	32.42	13.75
2	Higgons/Mordount	53.64	8.30
3	Henry/Main	12.76	12.70
4	Main/Rupert	7.51	1.87
5	Rupert/Lily	13.32	-0.46
119	Sherbrook/Henry	-27.20	31.24
121	Ellen/Henry	-5.45	20.90
308	Rover/Grove	35.66	33.76
309	Jarvis/Austin	19.85	27.33
310	Sutherland/Gomez	37.80	19.88
311	Sutherland/Stephens	52.63	15.36
312	Sutherland/Higgons	60.37	14.08
506	Riverton/Talbot	43.11	40.55
510	Martin/Brazier	71.39	57.94
513	Gordon/Brazier	64.64	43.11
514	Gorndon/Stadacona	76.25	37.50
516	Riverton/Brazier	62.14	35.50
517	Talbot/Stadacona	68.74	30.38
518	Watt/WM Newton	84.85	23.20
585	Grey/Tyne	104.07	8.27

TABLE 8

STATION 5, FIRE ALARM DISTRICTS 04, 05 & 06

FIRE DEMAND ZONE	INTERSECTING ROADWAYS AT CENTER OF FDZ	COORDINATES X (100 foot units)	Y
58	Banning/Wellington	-72.25	-1.67
59	Simcoe/Wellington	-59.58	-1.87
61	Banning/McIntyre	-73.13	-9.94
62	Beverly/Wellington	-56.93	-1.74
63	Sargent/Maryland	-44.52	-14.63
64	Burnell/Ellice	-69.56	-27.46
65	Beverly/Ellice	-57.38	-27.33
67	Banning/Ellice	-73.23	-27.33
68	Beverly/St. Mathews	-57.52	-39.34
70	Einarson/Banning	-73.95	-49.97
71	Beverly/Portage	-57.75	-51.74
73	Ruby/Preston	-74.15	-62.31
74	Canora/Honeyman	-59.12	-52.59
82	Wall/St. Mathews	-97.22	-38.72
83	Dominion/Armoury	-86.95	34.81
85	Dominion/Wolever	-86.91	-51.41
92	Wall/Wall East	94.66	23.03
93	Ashburn/Richard	-112.93	12.11
94	Erin/Richard	-101.05	10.70
95	Dominion/Yarwood	-85.37	6.86
96	Ashburn/Sargent	-113.65	-13.58
97	Erin/Sargent	-37.86	-14.90
98	Dominion/Sargent	-86.29	-14.08
99	Ashburn/Ellice	-113.92	-26.51
100	Wall/Sargent	-96.66	-13.98
101	Dominion/Ellice	-86.59	-27.04
114	McDermont/McPhillips	-72.54	22.51
115	McDermont/Arlington	-62.17	17.85
125	Myrtle/Notre Dame	-86.55	23.13
126	Coulter/Dead End	-75.46	30.05
138	Empress/Sargent	-128.19	-0.69
153	Empress/Welington	-128.19	-0.69
154	Wellington/Sanford	-124.09	-0.75

TABLE 9

STATION 6, FIRE ALARM DISTRICTS 31, & 62

FIRE DEMAND ZONE	INTERSECTING ROADWAYS AT CENTER OF FDZ	COORDINATES (100 foot units) X	Y
306	Burrows/Main	19.78	54.69
307	Selkirk/Austin	21.98	42.52
313	Sutherland/Robinson	-1.57	30.97
315	Jarvis/Powers	-15.13	41.24
316	Stella/Aikins	0.33	42.85
317	Flora/King	12.83	41.21
318	Powers/Stella	-12.07	48.49
322	Magnus/Powers	-5.12	63.22
323	Aikins/Magnus	30.32	111.09
324	Magnus/Charles	13.03	55.02
332	Anderson/O'Meara	32.06	76.38
333	Main/Redwood	21.75	63.82
334	Inkster/Cochrane	44.25	97.22
335	Luxton/St. Cross	51.25	51.87
336	Inkster/Andrews	10.63	113.00
337	Inkster/Aikins	28.41	104.47
338	Church/Powers	7.78	91.08
339	Church/Aikins	19.59	85.60
340	College/Powers	1.87	78.22
341	College/Aikins	13.75	72.81
342	Polson/McKenzie	-3.51	114.05
358	Smithfield/St. Cross	60.08	104.80
372	McAdam/Aikins	32.81	113.62
502	Carmen/Glenwood	43.93	66.41
503	Martin/Beatrice	51.02	66.18
504	Glenwood/Hespler	36.75	57.68
505	Hespler/Beatrice	45.18	53.81
541	Breden/Roosevelt	61.75	73.33

TABLE 10

STATION 7, FIRE ALARM DISTRICTS 32, & 63

FIRE DEMAND ZONE	INTERSECTING ROADWAYS AT CENTER OF FDZ	COORDINATES (100 foot units)	
		X	Y
112	Elgin/Xante	-64.41	30.64
113	Ross/Arlington	-56.79	30.38
118	Tecumseh/Logan	-45.74	35.17
122	Maude/Henry	-63.03	47.80
123	Maude/Alexander	-66.14	40.13
135	Logan/Yeomans	-77.60	49.71
314	Jarvis/Parr	-39.34	52.50
319	Battery/Flora	-57.75	74.51
320	Stella/Sinclair	-47.90	64.87
321	Stella/McKenzie	-29.82	56.70
325	Magnus/Parr	-29.43	74.25
326	Radford/Redwood	-61.85	102.04
327	Redwood/Prince	-56.66	99.74
328	Sinclair/Redwood	-36.39	90.39
329	Manitoba/McPhillips	-69.98	89.14
330	Battery/Manitoba	-54.04	82.19
331	Manitoba/Sinclair	-42.62	77.04
343	Church/McKenzie	-10.37	99.35
344	Boyd/McKenzie	-17.36	84.19
346	Inkster/Airlies	-31.07	132.49
347	Inkster/Sinclair	-19.16	126.75
349	Machray/Airlies	-38.29	116.61
350	Cathedral/Sinclair	-25.26	114.08
351	Radford/Mountain	-56.40	109.13
352	Airlies/Mountain	-44.23	103.45
353	Mountain/Galloway	-34.32	98.92
383	Daffidol/Aster	-24.08	140.92
384	McAdam/Sinclair	-14.47	135.47
412	Right Part CPR Yards	51.38	58.11
420	Redwood/McPhillips	-68.44	105.19
421	Manitoba/McNicol	-83.21	95.44

TABLE 11

FIRE STATION LOCATION INFORMATION

STATION NUMBER	FIRE DEMAND ZONE	INTERSECTING ROADWAYS	COORDINATES X (100 foot units)	Y
1	109	Ellen & McDermont	-14.24	-4.27
2	3	Maple & McDoanld	21.26	12.24
5	61	Sargent & Burnell	-70.73	-14.47
6	323	Burrows & Aikins	8.04	59.98
7	331	Sinclair & Pritchard	-44.10	74.05

The relative workload distribution among geographic atoms was determined by plotting the number of times a unit was dispatched to a particular x and y coordinate. This information was then summarized for each Fire Station and is presented in Tables 12, 13, 14, 15, 16, and 17.

TABLE 12

STATION 1, FIRE ALARM DISTRICTS 01 & 64 RELATIVE WORKLOAD AMONG GEOGRAPHIC ATOMS

ATOM	FIRE DEMAND ZONE	CALLS FOR SERVICE
1	6	108
2	7	58
3	8	129
4	9	67
5	10	108
6	12	102
7	13	116
8	15	7
9	17	29
10	18	15
11	19	55
12	20	27
13	21	53
14	60	8
15	66	19
16	69	28
17	72	20
18	107	4
19	108	18
20	109	27
21	110	0
22	111	75
23	116	4
24	117	0
25	120	3

TABLE 13

STATION 2, FIRE ALARM DISTRICTS 03 & 39 RELATIVE WORKLOAD AMONG GEOGRAPHIC ATOMS

ATOM	FIRE DEMAND ZONE	CALLS FOR SERVICE
26	1	19
27	2	10
28	3	24
29	4	98
30	5	12
31	119	0
32	121	17
33	308	0
34	309	28
35	310	15
36	311	8
37	312	7
38	506	0
39	510	29
40	513	26
41	514	3
42	516	7
43	517	14
44	518	18
45	585	0

TABLE 14

STATION 5, FIRE ALARM DISTRICTS 04, 05 & 06
RELATIVE WORKLOAD AMONG GEOGRAPHIC ATOMS

ATOM	FIRE DEMAND ZONE	CALLS FOR SERVICE
46	58	9
47	59	11
48	61	6
49	62	18
50	63	27
51	64	9
52	65	31
53	67	8
54	68	15
55	70	11
56	71	24
57	73	23
58	74	33
59	82	0
60	83	0
61	85	0
62	92	6
63	93	4
64	94	6
65	95	5
66	96	1
67	97	6
68	98	2
69	99	0
70	100	3
71	101	5
72	114	3
73	115	52
74	125	4
75	126	2
76	138	0
77	153	0
78	154	0

TABLE 15

STATION 6, FIRE ALARM DISTRICTS 31, & 62
RELATIVE WORKLOAD AMONG GEOGRAPHIC ATOMS

ATOM	FIRE DEMAND ZONE	CALLS FOR SERVICE
79	306	19
80	307	21
81	313	22
82	315	4
83	316	26
84	317	27
85	318	1
86	322	7
87	323	6
88	324	50
89	332	3
90	333	4
91	334	12
92	335	27
93	336	5
94	337	17
95	338	33
96	339	25
97	340	27
98	341	12
99	342	5
100	358	0
101	372	7
102	502	0
103	503	0
104	504	0
105	505	0
106	541	0

TABLE 16

STATION 7, FIRE ALARM DISTRICTS 32, & 63
RELATIVE WORKLOAD AMONG GEOGRAPHIC ATOMS

ATOM	FIRE DEMAND ZONE	CALLS FOR SERVICE
107	112	6
108	113	14
109	118	5
110	122	17
111	123	9
112	135	0
113	314	7
114	319	0
115	320	3
116	321	29
117	325	121
118	326	8
119	327	5
120	328	8
121	329	0
122	330	7
123	331	9
124	343	15
125	344	15
126	346	3
127	347	2
128	349	7
129	350	1
130	351	6
131	352	2
132	353	2
133	383	0
134	384	0
135	412	6
136	420	0
137	421	0

To perform time calculations using the C.A.D. dataset, tests were done to determine if the time a unit was dispatched was later than the time that unit was cleared from the incident. This situation occurs when a call for service comes in just before midnight and the unit returns back to the Fire Station early the next morning. Any dispatch records that fell into this situation were adjusted using time and date built-in functions avaialable in S.A.S.

The total average service time for each station was calculated using the PROC MEANS procedure available in SAS. Service time is the sum of the time it takes a unit to travel from a fire station to an incident, the total time spent on the scene, and a handling time of 10 seconds. The total service time of each dispatch record of a first-arriving unit from the C.A.D. dataset was used in the calculation. The total service time for pumpers of each station is given in Table 17 below.

TABLE 17

TOTAL SERVICE TIME FOR PUMPERS IN EACH STATION

STATION NUMBER	TOTAL SERVICE TIME (minutes)
1	15.0
2	17.2
5	16.7
6	18.3
7	17.2

To determine the average workload per hour experienced by the pumpers, only those records which represented first-arriving pumpers were counted. The total number of times each first-arriving pumper was dispatched was counted. This was divided by the total number of hours in a year.

The average workload was calculated as the total calls for service divided by the number of hours in a year. The total calls for service is the total number of incident records for the selected area from the C.A.D. database. An average workload of 0.28 calls per hour was experienced by the Winnipeg Fire Department pumpers.

5.3 EDITING THE DATA FOR FALSE ALARMS

Any unit whose total service time was less than 30 seconds was eliminated from the analysis. A less than 30 second service time indicated that a unit was sent back to the station before it arrived at the scene. In other words, if the AT SCENE TIME is within 30 seconds of the TIME CLEARED, the dispatch record was deleted. This occured if the incident did not require that unit's services and the dispatcher sent the unit back to its Fire Station before it arrived at the scene.

CHAPTER 6

ESTIMATING TRAVEL TIMES

6.1 INTRODUCTION

The time it takes for emergency vehicles, such as fire units, police cars, and ambulances, to respond to calls for service is a generally recognized measure of performance of emergency service agencies, since time is the key factor in minimizing property damange and casualty loss. Travel time is implicitely or explicitely included in most of the models developed for analysis of the deployment of emergency vehicles. Yet when these models were developed, little was known about actual travel times and how they vary with distance, by time of day, with weather, etc.

Kolesar and Walker[16] derived a single continuous function which adequately represents the relationship between travel time and travel distances at all times of the day in all parts of New York City. The motivation for the study was that travel time information was needed to run mathematical models which were being used to analyze deployment policies of the Fire Department of New York City. No empirical data on travel times and travel distances were available.

In order to obtain quantitative information about the relationship between travel times and travel distances in various regions of the City at different times of the day, during the summer of 1971 the Fire Department of New York City conducted a stopwatch experiment. Selected units were instructed to measure their travel times with stopwatches, their response distances with vehicle odometers, and record their travel speeds. Data on over 2000 responses made by 15 units were collected and analyzed.

The time/distance relationship normally employed assumes that a unit makes an entire trip at a constant velocity and, therefore, that travel time increases proportionally with the distance travelled.

They hypothesized that for short runs, a pumper never reaches a cruising velocity, but rather increases its speed for the first half of the trip, and then decelerates for the last half of the trip as it approaches its destination. For longer runs, there is a similar initial acceleration phase, but that the unit then runs a cruising speed for some distance before decelerating as it nears its destination. These hypotheses can be expressed mathematically as follows:

Let:

a = acceleration

D = length of the run

D_c = distance required to achieve cruising velocity

v_c = cruising velocity

T = travel time.

Using basic physics relations, and assuming constant acceleration and deceleration, a, during the initial and final phase of travel, and a constant cruising velocity, V_c, during the middle phase, travel time as a function of distance is expressed:

$$T(D) = \begin{cases} 2\sqrt{D}/\sqrt{a}, & \text{if } D \leq 2D_c, \\ V_c/a + D/V_c, & \text{if } D > 2D_c \end{cases}$$

A generalization of these relationship are:

$$T(D) = c\sqrt{D},$$
$$T(D) = a + bD.$$

Least squares regressions fits were made using the above relationships.

Based on the results of the experiment, Kolesar and Walker concluded that in most parts of New York City, travel time increases with the square root of distance for short runs, and linearly for long runs. They concluded that a single continuous function can adequately represent the relationship between travel time and travel distance at all times of the day in all parts of the city. This function is a square-root relationship for response distances up to some point d; and linear for response distances greater than d; at the point d, the two functions intersect and have the same slope. When such a function was fitted to the New York City data, the best value of d was 0.88 miles, and the time/distance relationship was:

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

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

6.2 CITY OF WINNIPEG ANALYSIS

This experiment was repeated to determine whether the relationship between travel times and distances for the City of Winnipeg can be respresented by a single continuous function. Travel times and approximate travel distances for each call for service was available through a Computer Aided Dispatch System maintained by the City of Winnipeg Fire Department. Therefore, it was not necessary to conduct a stopwatch experiment.

Six fire stations from the downtown, inner city, and north end of the City were included in the analysis. The fire demand zones each of these stations were primarily responsible for constituted a relatively large section of the city that was moderately busy. Details of the fire stations are given in Table 18, and their locations are shown in Figure 2.

TABLE 18

PUMPERS SELECTED FOR THE ANALYSIS

STATION NUMBER	AREA	PUMPER NUMBER	LOCATION	1984 OPERATIONS NUMBER OF RUNS (All Runs)
1	Downtown	411	65 Ellen Street	1411
		412		862
		413		1077
		459		934
2	Downtown	414	56 Maple Street	613
5	Inner City	417	845 Sargent Avenue	1062
6	North End	418	349 Burrows Avenue	659
7	North End	419	180 Siclair Street	934

Using the 1984 incident and dispatch information from the C.A.D. System, actual travel times for each pumper was calculated. Travel time is the time between a unit responding to an incident and when it arrives at the scene. The C.A.D. System maintains the time of responding and the time or arrival at the scene for each unit dispatched. As a result, travel time calculations were relatively straight forward and highly accurate. The travel distance calculation was not as obvious due to the lack of detailed data. The C.A.D. System records the x and y coordinates of each incident. Given the x and y coordinate of each pumper (i.e. station), the travel distance was considered the sum of the east-west distance and the north-south distance, from the pumper's station to the incident. Travel distance calculations were considered only an approximation because vehicles do not travel exactly east-west and north-south. Exact travel distance calculations would require that the C.A.D. System recorded the specific streets travelled by a unit for each incident. This information is not maintained by the system.

The relationship between the selected fire stations, fire alarm districts, and pumpers is given in Table 19. The summary statistics of the data analysis is given in Table 20.

TABLE 19

REGION UNDER STUDY

STATION NUMBER	FIRE ALARM DISTRICT
1	01 64
2	03 39
5	04 05 06
6	31 62
7	32 63

TABLE 20

SUMMARY STATISTICS

	RESPONSE DISTANCE MILES		RESPONSE TIME MILES		NUMBER OF RUNS	
	AVERAGE		AVERAGE		AVERAGE	
UNIT #	1ST-DUE	ALL	1ST-DUE	ALL	1-ST DUE	ALL
411	0.77	0.86	2.94	3.29	619	1411
412	0.57	0.65	2.73	3.28	195	862
412	0.66	0.70	3.16	3.42	177	1077
459	0.63	0.67	2.83	3.31	89	934
414	0.80	0.91	3.51	4.01	236	613
417	0.99	0.97	3.77	3.78	455	1062
418	1.41	1.48	3.05	3.27	442	659
419	0.71	0.82	3.61	4.12	201	360
ALL	0.86	0.86	4.06	3.49	2412	6978

Records were eliminated from the anlaysis in which the calculated travel time was less than 30 seconds. This indicated the pumper dispatched to an incident had been ordered to return back to the station while on-route.

6.3 REGRESSION ANALYSIS

Regressions were done separately for each selected pumper. Separate regressions were done; (1) for runs (responses) to alarms to which the company was the first-due pumper, and (2) for all runs, including second-due, third-due and so on. The purpose of these separate analysis was to determine how the travel time patterns varied among pumpers, and how they differed, if at all, for short runs and for longer runs. The results are summarized in Table 21.

TABLE 21

SUMMARY OF SQUARE-ROOT MODEL REGRESSION RESULTS

	1ST-DUE RUNS					ALL RUNS				
UNIT	c	σ_c	S1	S2	S1/S2	c	σ_c	S1	S2	S1/S2
411	1.20	0.11	1.10	1.79	0.62	1.34	0.09	0.95	1.66	0.57
412	1.16	0.10	1.01	1.79	0.57	1.37	0.19	1.89	2.74	0.69
413	1.17	0.16	1.67	2.50	0.67	1.34	0.10	1.04	1.84	0.57
459	1.01	0.03	0.31	0.70	0.44	1.29	0.18	1.82	2.73	0.67
414	1.29	0.08	0.81	1.49	0.54	1.41	0.09	0.94	1.68	0.56
417	1.19	0.08	0.80	1.32	0.61	1.22	0.08	0.80	1.47	0.54
418	1.28	0.09	0.90	1.10	0.82	1.43	0.07	0.73	1.04	0.69
419	1.21	0.09	0.94	1.56	0.60	1.37	0.13	1.37	2.22	0.62
ALL	1.43	0.08	0.82	0.81	1.01	1.52	0.07	0.75	0.41	1.83

Table 21 contains for each participating pumper the following information for first-due runs, and all runs resulting from regressions of $T(D) = c\sqrt{D}$ and $T(D) = a + bD$:

c - the estimated value of the coefficient c of the square-root function,

σ_c - its standard error,

S1 - the sum of the squared errors of the original data from the model T(D) = c/D,

S2 - the sum of the squared errors of the original data from the model T(D) = a + bD.

If S1 < S2, then the square-root model was a better fit. Using this measure to determine which model was better, it was clear that the square-root model fits first-due runs and all-runs equally well. This was to be expected since the average travel distances for both groups were somewhat equal.

Again, using S1/S2 as a measure of which model was better, it appears that pumper 418's preference for the square-root model was not as strong as the other units. This was a reflection of pumper 418 having a longer average response distance than the other pumpers.

6.4 FITTING THE PIECEWISE SQUARE ROOT-LINEAR FUNCTION

Since the previous analysis indicates, broadly speaking, that a square-root function fits the data well for short responses and a linear function fits better for long responses, a piecewise square root-linear function with a continuous first derivative to all of the data was fit. Such a function was consistent with the original hypothesis, about time/distance relationships. It is of the form:

$$T(D) = \begin{cases} c\sqrt{D}, & D \leq d \\ a + bD, & D > d \end{cases}$$

The data for all pumper runs and 1st-due pumper runs was used separately to fit a square-root function for short runs and a linear function for long runs simultaneously. The fit of this piecewise function was made using least squares. Mathematically, the problem is:

Find a, b, c, d to

Minimize $\sum (T_i - c\sqrt{D_i})^2 + \sum (T_i - a - bD_i)^2$,

Subject to:

$$c\sqrt{d} = a + bd,$$

And

$$c/(2\sqrt{d}) = b.$$

Where,

(T_i,d_i) - for i = 1,2,...., N are the observed travel time/travel distance pairs ordered by increasing distance.

c - is the parameter of the square-root portion of the function

a & b - are the parameters of the linear portion of the function

d - is the distance at which the two segments of th function are tangent

For any given d, N_d is the number of observed distances that are less than or equal to d. The constraints specify the tangency conditions.

Lotus 1-2-3, a microcomputer software program, was utilized to develop an interative method for solving this constrained minimization problem for estimation of the non-linear parameters.

The problem of fitting a continuous piecewise square root-linear travel-time curve to the experimental data can be expressed mathematically as follows:

Given N sets of observations (T_i, D_i, M_i), 1 = 1,2,..., N

Where T_i - denotes the average travel time (in minutes)
M_i - number of responses
D_i - reesponse distance (in miles)

Find the values of the parameters a, b, c, and d to

$$\text{Minimize} \quad \sum M_i(T_i - f(D_i))^2$$

Subject To:

$$f(D) = \begin{cases} c\sqrt{D}, & \text{if } D \leq d, \\ a + bD, & \text{if } D > d, \end{cases}$$

And

$$a + bD = c\sqrt{d}$$

$$b = c/(2\sqrt{d}).$$

The first two contraints specify the form of the piecewise function to be fitted. The second two constraints specify that the two pieces of the curve are to be tangent at the break point d. After eliminating a and c by solving them in terms of b and d, the problem can be written as:

Find b and d to minimize

$$q(b,d) = \sum M_i(T_i - 2b\sqrt{dD_i})^2 + \sum M_i(T_i - bd - bD_i)^2$$

where N_d is the largest value of i such that $D_i \leq d$, assuming the sets of observations are ordered by increasing value of D_i.

By fixing the value of d, the optimal value of b, $b^*(d)$, for that value of d, can be determined by differentiating the above function with respect to b and equating the derviative to zero. The result is:

$$b^*(d) = \frac{2\sqrt{d} \sum_{i=1}^{N_d} M_i T_i \sqrt{D_i} + \sum_{i=N_d+1}^{N} M_i T_i(d + D_i)}{4d \sum_{i=1}^{N_d} M_i D_i + \sum_{i=N_d+1}^{N} M_i(d + D_i)^2}$$

By varying d, an optimal pair of values b^* and d^* can be determined. An interactive computer program was developed which computed $b^*(d)$ and $q(b^*(d))$ for a given d.

The results of this procedure produced the estimates

ALL RUNS

$$T(D) = \begin{cases} 2.59\sqrt{D}, & D \leq 2.03 \\ 1.85 + 0.91D, & D > 2.03 \end{cases}$$

FIRST DUE RUNS

$$T(D) = \begin{cases} 2.38\sqrt{D} & D \leq 1.78 \\ 1.59 + 0.89D & D > 1.78 \end{cases}$$

Table 22 and Table 23 presents a summary of the data used for these fits for all runs and first-due runs respectively.

6.5 MATRIX GENERATION

Using the first arriving pumper runs of the peicewise square root-linear function, a FORTRAN program was written to generate the travel time matrix necesary to run the Hypercube Queuing Model. The 137 row by 137 column matrix is a complete inter-atom travel time matrix. This matrix was input into the Hypercube Model instead of x and y coordinates.

TABLE 22

FIRST ARRIVING PUMPERS

Distance (miles) Di	Numver of Responses Mi	Mean Travel Time Ti
0.10	28.00	1.15
0.20	65.00	1.10
0.30	125.00	1.70
0.40	228.00	1.63
0.50	302.00	1.60
0.60	173.00	2.10
0.70	243.00	2.01
0.80	199.00	2.24
0.90	149.00	2.37
1.00	142.00	2.78
1.10	158.00	2.42
1.20	96.00	2.68
1.30	71.00	3.30
1.40	76.00	2.68
1.50	81.00	2.59
1.60	47.00	2.92
1.70	53.00	2.78
1.80	49.00	2.02
1.90	53.00	2.24
2.00	24.00	3.05
2.10	19.00	2.95
2.20	8.00	5.10
2.30	2.00	2.60
2.40	8.00	4.82
2.50	1.00	2.98
2.60	1.00	3.07
2.70	1.00	4.70
2.80	2.00	5.44
2.90	3.00	4.73
3.00	0.00	0.00
3.10	1.00	3.67

TABLE 23
ALL PUMPERS

Distance (miles) Di	Number of Responses Mi	Mean Travel Time Ti
0.10	57.00	1.82
0.20	141.00	1.26
0.30	318.00	1.48
0.40	639.00	1.81
0.50	973.00	1.71
0.60	441.00	2.12
0.70	758.00	2.17
0.80	607.00	2.37
0.90	446.00	2.46
1.00	426.00	2.71
1.10	620.00	2.62
1.20	315.00	3.20
1.30	222.00	3.43
1.40	181.00	3.04
1.50	173.00	3.26
1.60	101.00	2.90
1.70	123.00	3.23
1.80	106.00	2.97
1.90	95.00	2.58
2.00	54.00	3.64
2.10	73.00	3.30
2.20	32.00	4.42
2.30	16.00	3.99
2.40	25.00	3.91
2.50	6.00	3.46
2.60	6.00	4.22
2.70	5.00	4.45
2.80	4.00	5.19
2.90	3.00	4.73
3.00	2.00	4.47
3.10	1.00	3.67

CHAPTER 7

IMPLEMENTATION OF THE HYPERCUBE MODEL

7.1 PROGRAM DESCRIPTION

The version of the Hypercube Queuing Model used for the analysis of the City of Winnipeg Fire Department is a batch program which was issued in 1975. An interactive version of the program is currently under development at the Massachusetts Institute of Technology.[18]

The program is written in the programming language PL/1 and can only operate on mainframe computer systems which have a PL/1 compiler. The PL/1 Optimizing Compiler, version 1, release 4.0 was used to run the Hypercube Queuing Model. Slight modifications were necessary to run the Hypercube Queuing Model on this compiler..

Information required by the program is contained on data cards, which must be prepared in accordance with the instructions in the Hypercube Queuing Model: User's Manual.[19] System control cards to compile, link-edit, and execute the program must appear before the source deck, and the source deck is followed directly by the data cards.

The Computer Aided Disptach database is stored on 9600 bpi magnetic tape at the University of Manitoba Computer Services Department, 6th floor

Engineering Building. Using Statistical Analysis System (SAS), the 1984 incident and dispatch records were copied from the magnetic tape to a temporary disk pack and stored in a SAS dataset. This procedure was repeated on a weekly basis since it was not possible to store the selected records of the database on a permanent disk pack. This was due to the large space requirements of the database.

The Hypercube Queuing Model source deck was stored on 9600 bpi magnetic tape at the University of Manitoba Computer Services Department, 6th floor, Engineering Building. Using a copy procedure available through Job Control Language the program was copied from magnetic tape to a permanent disk pack and stored in a Mantes file located in a personally owned Mantes group. Two Mantes files were created to store the data cards; one for the initial run involving x and y coordinates of response units and the second for the empirically calculated travel times. A third Mantes file was created which contained the Job Control Language necessary to run the Hypercube Queuing Model on the Unversity of Manitoba mainframe computer.

7.2 PROGRAM EXECUTION

The first attempt at executing the Hypercube Model was unsuccessful. The problem was due to the different versions of PL/1. The Hypercube Model is written in an early version of PL/1 while the Unversity compiles a later version of the program language. After modifications were made to the program source the model was successfully run on the Unversity of Manitoba mainframe computer.

Several runs of the model were made due to key punch errors in the data cards. The RAND Hypercube Queuing Model Package is not at all "user friendly." If errors were made in the data cards, the model does not give meaningful error messages to assist the user with the data debugging process. If errors are made in the data cards, the model does not give the user the output and error messages related to the input cards. The error messges given to the user are located in the program source and would require the user to understand the PL/1 programming language.

7.3 PROGRAM OUTPUT

The Hypercube Queuing Model was run using two distinct set of input data; x and y coordinates of the pumpers and their geographic atoms, and response times for pumpers using the relationships derived from Kolesar and Walker's experiment. All information pertaining to the x and y coordinates can be found in Chapter 5. The results of the Kolesar and Walker experiment conducted using the City of Winnipeg data can be found in Chapter 6.

The following two sections will present the output generated by the Hypercube Model for the two distinct sets of input data as well as give the interpretation of the results.

7.3.1 X & Y Coordinates of The Centre of FDZ

The x and y coordinates of the centre of each Fire Demand Zone were input into the Hypercube Queuing Model. The model was executed and the computed performance measures generated have been listed below. Three groups of performance meassures generated by the model are included in this paper. The measures that relate to the average performance of all fire stations combined is presented first. Each line of output is listed separately followed by a brief interpretation. Subsections 7.3.1.2 and 7.3.1.3 detail the unit-specific and district specific performance measures.

7.3.1.1 Performance Measures For All Stations Combined

```
AVERAGE SERVICE TIME = 16.81 MINUTES
```

This is the average service time for all units, that is, the average of (15+17.20+16.70+18.3+17.2)/5.

```
AVERAGE NUMBER PER HOUR OF CALLS FOR SERVICE = 0.280
AVERAGE NUMBER PER 16.81 MINUTES OF CALLS FOR SERVICE = 0.078
```

Since there are 0.28 calls for service generated per hour (on average), there are 0.28 x (16.81/60) = 0.078 calls for service generated each 16.81 minutes (on average).

AVERAGE UTILIZATION FACTOR (IN CASE OF UNLIMITED LINE CAPACITY) = 0.016

Since 0.078 calls for service arrive (on average) each 16.81 minutes and all (eventually) are assigned to a unit, then on average 0.078 x (1/5) = 0.016 calls are assigned to any particular pumper every 16.81 minutes. But each such assignment requires (on average) 16.81 minutes to service, thus the "average pumper" is busy servicing calls 1.6 percent of the time. This figure is called the average utilization factor (referring to the fraction or percent of time that pumpers are servicing calls).[19]

REGION-WIDE AVERAGE TRAVEL TIME = 4.882 MINUTES

This indicates that the average travel time to a call for service, averaged over all the Fire Demand Zones in the region, is 4.882 minutes. Since the travel speed is 26 mph (or 13/30 miles/minute), this implies that the average distance traveled per response is (13/30) x (4.882) = 2.115 miles.

AVERAGE TRAVEL TIME FOR QUEUED CALLS = 10.775 MINUTES

Here the program is showing that a significantly larger average travel time incurred by calls that are delayed in queue (averaged over all calls delayed in queue, reguardless of Fire Demand Zone).

PROBABILITY OF SATURATION = 0

Saturation is said to occur when all units are simultaneously busy. If this occurs X percent of the time, then (due to the random arrival patterns of calls for service) X percent of the calls reach a saturated system and thus must be held in the dispatcher queue. In this case 0 percent of all calls for service are held in queue.

REGION-WIDE AVERAGE WORKLOAD (% TIME BUSY) = 0.01524

This is the average fraction of time that units are computed to be busy.

STANDARD DEVIATION OF WORKLOAD = 0.009

This is the standard deviation of the workload distribution, which is one measure of the imbalance in workloads among pumpers. The larger the quantity, the greater the imbalance would be.

MAXMUM WORKLOAD IMBALANCE = 0.02037

Subtracting the workload of the least busy pumper (pumpers in station 7) from the workload of the busiest pumper (pumpers in station 1) gives the maximum workload imbalance. A maximum workload imbalance of 0.02037 means the least busy unit has only 5 percent less work than the busiest unit, a very small imbalance.

FRACTION OF DISPATCHES THAT ARE INTER-DISTRICT = 0.02006

This says that 2.006 percent of all dispatch assignments (including those from a queue of calls) cause the assigned unit to travel to a reporting area not in its own district. Thus, for a randomly selected call for service, there is a 2.006 percent chance that the pumper which responds to that call will not be the unit whose district contains the call.

7.3.1.2 Unit-Specific Performance Measures

Table 24 provides the unit-specific performance measures generated by the Hyperucbe model.

TABLE 24
PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH STATION

STATION NUMBER	WORKLOAD OF STATION	FRACTION OF DISPATCHES OUT OF DISTRICT	AVERAGE TRAVEL TIME
1	0.031	0.0050	4.220
2	0.012	0.0512	4.084
3	0.011	0.0521	5.307
4	0.013	0.0120	6.844
5	0.010	0.0104	5.288

Examining the performance measures for station 1, we see the following:

> Pumpers from station 1 spend 3.1 percent of its time handling calls for service.

Only 0.5 percent of the dispatch assignments to pumpers in station 1 cause a pumper to leave its district.

The average time it takes for a pumper from station 1 to travel to the scene of an incident is 4.220 minutes.

7.3.1.3 District-Specific Performance Measures

Disrict-specific performance measures are presented in Table 25.

TABLE 25
PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH DISTRICT

DISTRICT	FADS	WORKLOAD OF FAD	FRACTION OF DISPATCHES INTER-FAD	AVERAGE TRAVEL TIME
1	01,64	0.035	0.0306	4.251
2	03,39	0.011	0.0116	4.018
3	04,05,06	0.011	0.0110	5.329
4	31,62	0.012	0.0128	6.873
5	32,63	0.010	0.0102	5.234

District 1 which contains Fire Alarm Disticts (FAD) 01 & 64 we see the following:

The District's workload is enough to cause one pumper to remain busy servicing calls 3.5 percent of the time (if that pumper handled all of calls for FAD 01 & 64).

The fraction of the district's dispatches that require an out-of-district pumper because pumpers in station 1 are unavailable is 3.06 percent.

The average travel time to incidents in FAD 01 & 64 is 4.251 minutes.

7.3.1.4 Estimated Travel Times Using Kolesar's Methodology

The estimated time it takes a unit to travel from the centre of a Fire Demand Zone to the centre of another Fire Demand Zone was input into the Hyperucbe Queuing Model. The results of using estimated travel times as input are provided below in the same format as that of the previous run. The interpretations are the same and therefore were not repeated.

AVERAGE SERVICE TIME = 16.81 MINUTES

AVERAGE NUMBER PER HOUR OF CALLS FOR SERVICE = 0.280

AVERAGE NUMBER PER 16.81 MINUTES OF CALLS FOR SERVICE = 0.078

AVERAGE UTILIZATION FACTOR (IN CASE OF UNLIMITED LINE CAPACITY) = 0.016

REGION-WIDE AVERAGE TRAVEL TIME = 2.293 MINUTES

AVERAGE TRAVEL TIME FOR QUEUED CALLS = 2.977 MINUTES

PROBABILITY OF SATURATION = 0

REGION-WIDE AVEARGE WORKLOAD (% TIME BUSY) = 0.01524

STANDARD DEVIATION OF WORKLOAD = 0

MAXIMUM WORKLOAD IMBALANCE = 0.02043

FRACTION OF DISPATCHES THAT ARE INTER-DISTRICT = 0.02007

Tables 26 and 27 provide the detailed performance measures that are specific to each station and specific to each district, respectively.

TABLE 26
ESTIMATED TRAVEL TIMES

PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH STATION

STATION NUMBER	WORKLOAD OF STATION	FRACTION OF DISPATCHES OUT OF DISTRICT	AVERAGE TRAVEL TIME
1	0.031	0.0063	1.941
2	0.012	0.0958	1.922
3	0.010	0.0078	4.123
4	0.013	0.0046	2.617
5	0.010	0.0079	1.758

TABLE 27
ESTIMATED TRAVEL TIMES

PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH DISTRICT

DISTRICT	FADS	WORKLOAD OF FAD	FRACTION OF DISPATCHES INTER-FAD	AVERAGE TRAVEL TIME
1	01,64	0.035	0.0307	1.957
2	03,39	0.011	0.0122	1.856
3	04,05,06	0.011	0.0105	4.122
4	31,62	0.012	0.0127	2.514
5	32,63	0.010	0.0102	1.762

7.4 MODEL VALIDATION

To validate the Hypercube Queuing Model for the City of Winnipeg, the output generated from the model was compared with the actual performance characteristics of the City of Winnipeg pumpers. Two separate data sets, the x and y coordinates of the centre of each FDZ and the estimated travel times based on Kolesar's methodology, were used as input to the Hypercube Model. The two sets of output generated from the Hypercube model executions were compared to the actual performance measures of the City of Winnipeg pumpers.

The first task of the validation process was to calculate the performance characteristics of the City of Winnipeg pumpers. Using the Computer Aided Dispatch dataset and Statistical Analysis System on the Unversity of Manitoba mainframe computer, performance measures were calculated and are presented in Table 28.

TABLE 28
PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH STATION BASED ON THE COMPUTER AIDED DISPATCH DATABASE

STATION NUMBER	WORKLOAD OF STATION	FRACTION OF DISPATCHES OUT OF DISTRICT	AVERAGE TRAVEL TIME
1	0.031	0.2370	2.103
2	0.011	0.2585	2.429
3	0.010	0.0000	3.325
4	0.013	0.2891	3.087
5	0.010	0.1791	2.812

The travel times generated from the two executions of the Hypercube model were compared with the actual travel times calculated from the Computer Aided Dispatch (CAD) System. The actual travel times calculated from the CAD System were compared with the travel times generated by the Hypercube Model, when the x and y coordinates were used as input. This information is presented in Table 29. From Table 29, it can be seen that for station 1 the actual average travel time was 129.8 percent smaller than the average travel time generated from the Hypercube Model.

TABLE 29

ACTUAL TRAVEL TIMES CALCULATED FROM CAD SYSTEM
VS
TRAVEL TIMES CALCUATED FROM X AND Y COORDINATES

	AVERAGE TRAVEL TIMES			
Station #	C.A.D.	Hypercube	Difference	% Difference
1	1.836	4.220	-2.384	129.8
2	2.596	4.084	-1.488	57.3
5	2.487	5.307	-2.820	113.4
6	2.948	6.844	-3.896	132.2
7	2.708	5.288	-2.580	95.3

TABLE 30

ACTUAL TRAVEL TIMES CALCULATED FROM CAD SYSTEM
VS
TRAVEL TIMES CALCULATED FROM ESTIMATED TRAVEL TIMES

	AVERAGE TRAVEL TIMES			
Station # Difference	C.A.D.	Hypercube	Difference	%
1	1.836	1.941	-0.105	5.7
2	2.596	1.922	0.671	25.9
5	2.487	4.123	-1.636	65.8
6	2.948	2.617	0.331	11.2
7	2.708	1.758	0.950	35.1

Through analysis of tables 29 and 30, it is clear that neither of the two input datasets generated Hypercube average travel times which fit the actual performance of the City of Winnipeg Fire Department pumpers perfectly. However, it can be concluded that using estimated travel times as input into the Hypercube Model generates average travel times that fit the CAD average travel times better than if the x and y coordinates were used as input.

To further establish this conclusion, the weigted average travel time from the CAD dataset was compared to the average travel time from the Hypercube Model for each input dataset.

The average weighted travel time from the CAD dataset was computed as ((1080*1.836 + 335*2.597 + 324*2.487 + 360*2.948 + 307*2.708)/2406). The final figure is listed below.

WEIGHTED AVERAGE TRAVEL TIME FROM CAD DATASET = 2.307 minutes

The region-wide average travel times for each set of input data was extracted from the output generated by the Hypercube Model. The figures are given below.

REGION-WIDE AVERAGE TRAVEL TIME = 4.882 minutes.
(FROM THE HYPERCUBE MODEL)
(Using x and y coordinates as the input dataset)

REGION-WIDE AVERAGE TRAVEL TIME = 2.293 minutes.
(FROM THE HYPERCUBE MODEL)
(Using the estimated travel times as the input dataset)

The difference between the weighted average travel time from the CAD dataset and the region-wide average travel time from the Hypercube Model, when the estimated travel times were used as the input dataset, was only 0.014 minutes versus 2.575 minutes, when x and y coordinates were used as the input dataset. For the estimated travel times input dataset the region-wide average travel time was 0.6 percent smaller than the weighted average travel time. For the x and y coordinates input dataset the region-wide average travel time was 111.6 percent larger than the weighted average travel time. Based on these percent differences, it seems reasonable to conclude that using the estimated travel times as input into the Hypercube Model generates performance characteristics which best fit the City of Winnipeg Fire Department Operations. Therefore for the remaining analysis only estimated travel times were used as input into the Hypercube Model.

CHAPTER 8

SENSITIVITY ANALYSIS

8.1 INTRODUCTION

Using the estimted travel times which are based on Kolesar's methodogoy as input into the Hypercube Queuing Model, various deployment strategies were analyzed.

1) The Hypercube Model was used to determine if the City of Winnipeg could meet future demands for fire services.

2) The effect the removal of a fire station would have on the operations of the fire department was analyzed.

3) Simultaneously, a fire station was removed and the demand for fire service was increased. The output for this scenario was examined.

The detailed anlaysis of these strategies are presented in this chapter.

8.2 INCREASE DEMAND FOR FIRE SERVICES

The Department of Environmental Planning has forecast that between 1986 and 2001 some 34,000 new dwelling units will be created, for a growth rate of 1 per cent per year. The present average workload for the Fire Department is approximately 0.28 calls per hour. Assuming the growth rate for the average workload is the same as the new dwelling growth rate, the average workload in 2001 would be 0.33 calls per hour, $(0.28 \times 1.01)^{15}$. This represents an increase in the demand for fire services of 5 percent.

The Hypercube Model was rerun using the an average workload of 0.33 calls per hour and the estimated travel time matrix. The following is the output generated from this run:

```
AVERAGE SERVICE TIME = 16.81 MINUTES
AVERAGE NUMBER PER HOUR OF CALLS FOR SERVICE = 0.330
AVERAGE NUMBER PER 16.81 MINUTES OF CALLS FOR SERVICE = 0.092
AVERAGE UTILIZATION FACTOR (IN CASE OF UNLIMITED LINE
CAPACITY) = 0.018
REGION-WIDE AVERAGE TRAVEL TIME = 2.295 MINUTES
AVERAGE TRAVEL TIME FOR QUEUED CALLS = 2.977 MINUTES
PROBABILITY OF SATURATION = 0
REGION-WIDE AVEARGE WORKLOAD (% TIME BUSY) = 0.01797
STANDARD DEVIATION OF WORKLOAD = 0
MAXIMUM WORKLOAD IMBALANCE = 0.02393

FRACTION OF DISPATCHES THAT ARE INTER-DISTRICT = 0.02361
```

TABLE 31
INCREASE DEMAND
ESTIMATED TRAVEL TIMES USED AS INPUT

PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH STATION

STATION NUMBER	WORKLOAD OF STATION	FRACTION OF DISPATCHES OUT OF DISTRICT	AVERAGE TRAVEL TIME
1	0.036	0.0075	1.941
2	0.015	0.1104	1.933
3	0.012	0.0097	4.121
4	0.015	0.0054	2.518
5	0.012	0.0095	1.760

TABLE 32
INCREASE DEMAND
ESTIMATED TRAVEL TIMES USED AS INPUT

PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH DISTRICT

DISTRICT TIME	FADS	WORKLOAD OF FAD	FRACTION OF DISPATCHES INTER-FAD	AVERAGE TRAVEL
1	01,64	0.041	0.0360	1.961
2	03,39	0.013	0.0146	1.857
3	04,05,06	0.012	0.0123	4.120
4	31,62	0.014	0.0149	2.514
5	32,63	0.012	0.0120	1.765

By comparing the average travel times from table 26 and table 27 it can be seen that an increase in demand for fire services does not increase the average service time or travel time. Therefore if the demand for fires increase at the same rate as the expected dwelling growth rate, there is no need to be concerned.

8.3 REMOVE A STATION

Fire Station 2 was removed and its Fire Demand Zones of primary responsibility were assigned to Fire Station 1 and Fire Station 6. The Hypercube Model was then executed to determine the effect the removal of this station would have on the remaining four stations' performance characteristics. The output from this run is presented below.

```
AVERAGE SERVICE TIME = 16.95 MINUTES
AVERAGE NUMBER PER HOUR OF CALLS FOR SERVICE = 0.280
AVERAGE NUMBER PER 16.81 MINUTES OF CALLS FOR SERVICE = 0.079
AVERAGE UTILIZATION FACTOR (IN CASE OF UNLIMITED LINE
CAPACITY) = 0.020
REGION-WIDE AVERAGE TRAVEL TIME = 2.425 MINUTES
AVERAGE TRAVEL TIME FOR QUEUED CALLS = 2.975 MINUTES
PROBABILITY OF SATURATION = 0
REGION-WIDE AVEARGE WORKLOAD (% TIME BUSY) = 0.01956
STANDARD DEVIATION OF WORKLOAD = 0.012
MAXIMUM WORKLOAD IMBALANCE = 0.02665

FRACTION OF DISPATCHES THAT ARE INTER-DISTRICT = 0.02007
```

TABLE 33
REMOVE STATION 2
ESTIMATED TRAVEL TIMES INPUT

PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH STATION

STATION NUMBER	WORKLOAD OF STATION	FRACTION OF DISPATCHES OUT OF DISTRICT	AVERAGE TRAVEL TIME
1	0.037	0.0062	1.925
5	0.011	0.0948	4.032
6	0.018	0.0035	2.822
7	0.011	0.0630	1.857

TABLE 34
REMOVE STATION 2
ESTIMATED TRAVEL TIMES INPUT

PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH DISTRICT

DISTRICT TIME	FADS	WORKLOAD OF FAD	FRACTION OF DISPATCHES INTER-FAD	AVERAGE TRAVEL
1*	01,64*	0.040	0.0375	1.966
3	03,39	0.011	0.0115	4.121
4*	04,05,06*	0.018	0.0185	2.819
5	31,62	0.010	0.0108	1.778

*Fire Demand Zones from station 2 were included in these areas.

Removing station 2 caused the averagae service time to increase from 16.81

minutes to 16.95 minutes. The average travel time for each station also increased, with the exception of station 5. Station 5's average travel time decreased from 4.123 minutes to 4.032 minutes. Station 6 had the greatest increase in average travel time, from 2.617 minutes to 2.822 minutes.

8.4 REMOVE A STATION & INCREASE DEMAND FOR FIRE SERVICE

If Station 2 were infact removed, then what would be the result on the performance characteristics if the average workload increase to 0.33 calls per hour?

This scenario was input into the Hypercube Model and the following results were generated:

AVERAGE SERVICE TIME = 16.95 MINUTES
AVERAGE NUMBER PER HOUR OF CALLS FOR SERVICE = 0.330
AVERAGE NUMBER PER 16.81 MINUTES OF CALLS FOR SERVICE = 0.093
AVERAGE UTILIZATION FACTOR (IN CASE OF UNLIMITED LINE CAPACITY) = 0.023
REGION-WIDE AVERAGE TRAVEL TIME = 2.426 MINUTES
AVERAGE TRAVEL TIME FOR QUEUED CALLS = 2.975 MINUTES
PROBABILITY OF SATURATION = 0
REGION-WIDE AVEARGE WORKLOAD (% TIME BUSY) = 0.02305
STANDARD DEVIATION OF WORKLOAD = 0.014
MAXIMUM WORKLOAD IMBALANCE = 0.03104

FRACTION OF DISPATCHES THAT ARE INTER-DISTRICT = 0.03087

TABLE 35
REMOVE STATION 2 & INCREASE DEMAND ESTIMATED TRAVEL TIMES INPUT

PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH STATION

STATION NUMBER	WORKLOAD OF STATION	FRACTION OF DISPATCHES OUT OF DISTRICT	AVERAGE TRAVEL TIME
1	0.044	0.0074	1.926
5	0.014	0.1093	4.017
6	0.022	0.0042	2.823
7	0.013	0.0736	1.873

TABLE 36
REMOVE STATION 2 & INCREASE DEMAND ESTIMATED TRAVEL TIMES INPUT

PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH DISTRICT

DISTRICT TIME	FADS	WORKLOAD OF FAD	FRACTION OF DISPATCHES INTER-FAD	AVERAGE TRAVEL
1*	01,64*	0.048	0.0439	1.975
3	03,39	0.013	0.0137	4.119
4*	04,05,06*	0.021	0.0217	2.818
5	31,62	0.012	0.0129	1.781

Again, an increase in demand of 5 percent does not result in significant changes in the average service times and travel times.

8.5 TIME RELATED DEPENDENCIES FOR FIRE DEMAND

Using a computer program called Statistical Analysis System (SAS) computations were performed to determine if there is a correlation between the demand for fire service and the day of the week, the demand for fire service and the month of the year, and finally the demand for fire service and the time of the day.

The χ^2 test of independence was used to test the following hypothesis:

1) The demand for fire service and the day of the week are independent.
2) The demand for fire service and the month of the year are independent.
3) The demand for fire service and the time of day are independent.

Tables 37 to 38 contain the computed chi square statistic for the three above hypothesis, respectively.

TABLE 37

x^2 STATISTIC FOR THE DAY OF THE WEEK AN INCIDENT OCCURS

DAY OF WEEK	TOTAL DEMAND FOR SERVICE	STATISTIC
SAT	419	15.94
SUN	401	9.14
MON	366	1.30
TUES	284	10.74
WEDS	314	2.76
THU	323	1.39
FRI	307	4.16
		45.42

$x^2_{0.0005,6} = 18.55$ (Critical Value)

Since 45.42 > 18.55 the hypothesis of independence is rejected. It cannot be concluded that the demand for fire service and the day of the week are independent.

TABLE 38
χ^2 STATISTIC FOR MONTH OF THE YEAR AN INCIDENT OCCURS

MONTH	TOTAL DEMAND	STATISTIC
1	168	5.47
2	161	8.02
3	179	2.44
4	235	5.69
5	214	0.82
6	234	5.36
7	208	0.23
8	209	0.31
9	217	1.25
10	204	0.04
11	177	2.90
12	208	0.23

		32.76

$\chi^2_{0.0005,11}$ = 26.76 (Critical Value)

Since 32.76 > 26.76 the hypothesis of independence is rejected. It cannot be concluded that the demand for fire service and the month of the year are independent.

TABLE 39
χ^2 FOR TIME OF DAY AN INCIDENT OCCURS

TIME OF INCIDENT	FREQUENCY	STATISTIC
24:00 - 1:00	56	0.80
1:00 - 2:00	77	3.05
2:00 - 3:00	57	0.59
3:00 - 4:00	47	4.12
4:00 - 5:00	43	6.42
5:00 - 6:00	26	21.83
6:00 - 7:00	41	7.75
7:00 - 8:00	36	11.66
8:00 - 9:00	45	5.20
9:00 - 10:00	59	0.27
10:00 - 11:00	64	0.01
11:00 - 12:00	59	0.27
12:00 - 13:00	57	0.59
13:00 - 14:00	62	0.02
14:00 - 15:00	74	1.87
15:00 - 16:00	74	1.87
16:00 - 17:00	75	2.23
17:00 - 18:00	61	0.07
18:00 - 19:00	81	5.06
19:00 - 20:00	86	8.29
20:00 - 21:00	81	5.06
21:00 - 22:00	79	3.99
22:00 - 23:00	92	13.21
23:00 - 24:00	83	6.26
		110.52

$\chi^2_{0.0005,23} = 44.18$ (Critical Value)

Since 110.52 > 44.18 the hypothesis of independence is rejected. It cannot be concluded that the demand for fire service and the time of the day are independent.

CHAPTER 9

CONCLUSIONS

9.1 INTRODUCTION

This chapter provides the conclusions of the analysis and recommendations for future research in the area of emergency services.

9.2 CONCLUSIONS

1. Given the available databases of fire incident information for the City of Winnipeg it was possible to implement the Hypercube Model. However, the data available was not without its problems. The integrity of the Computer Aided Dispatch System data is questionable. Based on my analysis it appears there are incident records in the Computer Aided Dispatch dataset which do not have the correct data. Additionally, it was very difficult to combine different sources of fire data because of the variety of ways of relating fire incident information to regions in the City. Historically data was recorded by Fire Demand Zones, Fire Alarm Districts, neighborhoods, and x and y coordinates. As a result, the process of preparing the data for input into the Hypercube Queuing Model was very time consuming and complicated.

2. Once the initial input data is established the Hypercube can be used to analyze various deployment changes fire administrators are contemplating. Deployment changes are easily integrated in the model input data provided the user has used proper documentation techniques. Failure to properly document the input data records would require tedious scanning of each record whenever a change was to be incorporated. Using the City of Winnipeg data various deployment changes were implemented; first, the demand for fire service was increased by five percent, then station 2 was removed, and last station 2 was removed and the demand for service was increased by five percent simultaneously. Other deployment alernatives which could be analyzed using the Hypercube Queuing Model include the relocation of a fire station, the addition of a fire station, or decreasing the demand for service.

3. Two distinct sets of input data were used to run the Hypercube Queuing Model, the estimated average travel time for a pumper to go from one fire demand zone to another fire demand zone, and the x and y coordinates of the centre of each Fire Demand Zone. The average travel times generated by the Hypercube Model, using the estimated travel times as input, fit the City of Winnipeg Fire Department Operations better than when the x and y coordinates of the centre of Fire Demand Zones were used as input. This conclusion is reasonable. Winnipeg has many rivers, one-way streets, and railways which would affect the time it would take a emergency unit to travel from a fire station to an incident. By simply calculating the sum of the x distance and the y

distance is too simplistic for city such as Winnipeg.

4. Statistical tests were conducted to determine if the demand for fire service was independent of day of the week, month of the year, and time of the day. For all three tests it could not be concluded that the demand for service is independent of seasonality. Intuitively it makes sense that a fire is more likely to occur during the times of the day when a family is home. As well, the types of activities people become involved in depend greatly on the month of the year, therefor so would the occurance of fires.

9.3 FUTURE RESEARCH FOR EMERGENCY SERVICE

1. The developer of emergency service models could incorporate the fluctuations in demand for service as a result of seasonality into future models. It is likely that most cities in North America would find the demand for emergency service is not independent of seasonality.

2. More effective management information systems should be designed for fire departments. These systems should be designed to ensure the integrity, availability, and confidentiality of emergency service data. The information system should maintain a database of information that would be flexible enough to allow a research team to implement a variety of emergency service models since most models have been designed to work in conjunction with other models.

3. The Hypercube Queuing Model should be rewritten using a Fourth Generation Language such as Focus, Natural, Oracle, or SQL. PL/1 is a Third Generation Language which was popular in the 1970s. The trend in computer service departments to move away from third generation languages and move toward fourth generation languages. This trend has occured because:

1) fourth generation languages produce applications that are closer to what the user wants,
2) previously developed applications are easily modified,
3) the maintenance costs associated with fourth generation languages is significantly better, and
4) fourth generation languages are more powerful than third generation languages.

As a result of these benefits, it is not likely that in the future computer services departments will have the skilled staff and/or the software to support third generation languages.

GLOSSARY

Aerial ladder
An extendable ladder anchored to a turnable base on a ladder deliver water though a detachable pipe. Typically, hydraulically operated and used in common sizes ranging from 65 to 100 feet or more.

Alarm
Any notification of the fire department that a situation that requires a response exists, or may exist. Following the response to the first alarm, the officer in charge of fireground operations at the scene may issue additional alarms: a "second alarm" making the incident a "two-alarm fire," a "third alarm" making it a "three-alarm fire," and so on.

Alarm rate
The average number of alarms per hour received by a fire department disptaching office. Only one alarm for each incident is used to compute the average, reguardless of how many notifications of the incident are recieved or of multiple alrms that my be issued by officers at the fireground.

Atom
See geographical atom.

Call for service
A communication to an emergency service originating from a citizen, an alarm system, a police officer, or other detector, reporting an incident that requires on-scene assistance by a response unit.

Command
An area or region comprising several districts that is administratively distinct, usually having a station-house or garage used as a base of operations. Often called precincts or zones. Disptach assignments are nearly always intra-command assignments.

Dispatch assignment
A directive by the dispatcher to a response unit assigning the unit to respond to the scene of a reported incident or call for service.

Dispatcher
An individual who has responsibility for assigning available radio-dispatchable response units to reported incidents.

District
A collection of geographical atoms that are primarily associated with a particular response unit. For certain dispatch strategies, the district's response unit always receives first preference in dispatching decisions. In police applications, a district (often called beat or sector) is the area in which the patrol unit can perform preventive patrol. Over the entire region, the set of districts need not be mutually exclusive nor collectively exhaustive.

Effective travel speed

That speed which, if constantly maintained over the path of a response journey, would result in the same travel time as that actually experienced by the dispatch response unit.

EMCM: Expected modified center of mass

A dispatch strategy that calculates the probailistic location of units, representing the best that nay disptacher could do without knowing the exact real-time position of available units.

ESCM: Expected strict centre of mass

A disptach strategy that estimates the statistically average travel distance from each of the unit's geographic atoms (weighed by the likelihood of the unit being located in that atom) to the atom of the incident (weighted by the likilihood of the incident being located in that atom).

False alarm

An alarm that is determined not to have required a response.

Fire demand zone (FDZ)

An area of the city sufficiently small that it may be assumed for computational purposes that all teh demand for fire service in the area arises from a single point, and that travel times to any place in the area will be the same as that point.

First-alarm assignment

The specification of which companies, officers, and special units are to respond to the first alarm received from a specific box or location.

First-alarm response

The actual response to a first alarm, potentially differing from the response specified in the first-alarm assignment as a function of dispatching policy, unit availability, or information in the alarm.

First-arriving

Arriving first in response to an alarm, whether or not first-due. Compare to first-due.

First-due

Assigned to arrive first in an area in response to an alarm. The first-due company is expected to the one first-arriving, the second-due company second-arriving, and so on. Arrivals may, however, be influenced by circumstances (availability, traffic) so that, for example, the first-arriving ladder might be the one that was third-due.

First-due area

The respone area in which a company is first-due, usually defined by the set of alarm boxes to which the company is closest (in time, not distance).

Geographical atom

A subarea within a command, typically no more than a few city blocks in size, that is used as the smallest geographical unit for aggregating statistics on the spatial distributions of calls for service and positions of the response units.

Interdistrict (or cross-district) assignment

A dispatch assignment to a district other than the unit's district.

Ladder

Any of various fixed or extendible devices used for climbing or descending, and characterized by parallel, equally spaced rungs securely fastened at right angles to each of two long structural members.

Ladder company

A fire company whose primary apparatus is the ladder and whose primary function is to extinguish fires. Also called and engine company.

MCM: Modified centre of mass

A dispatch strategy in which the exact location of the incident is used to make travel time (distance) estimates.

Neighborhood

Overlapping districts

Districts that have at least some areas in common; partially shared districts.

Preventive patrol

An activity undertaken by police response units, in which the unit tours an area, with the officer(s) checking for crime hazards (for example, open doors and windows) and attempting to intercept any crimes that are in progress.

Pumper

The basic piece of firefighting apparatus used to draw water from a hydrant, directly form a reservoir such as a lake, or from its own water tank, and pump it through a hose line for delivery to a fire. A common ladder configuration, the "triple combination," consists essentially of a large fire pump, a hose body carrying a supply of hose, and a small booster pump and tank with a capacity ao apporximately 500 gallons. Also called a fire engine.

Region

The entire collection of geographical atoms included in a particular set of runs of the model. Can be an entire city or part of a city.

Rescue company

A fire company trained, equipped, and provided with a special vehicle to perform rescues and render emergency medical services at both fire and nonfire incidents.

Response unit

A partol car, scooter, or wagon, and its assigned police officer(s); a radio-dispatchable footpartolman; an ambulance; a fire truck.

Response time

The elapsed time from the receipt of an alarm to the completion of setup of operations at the scene of a fire, including dispatching time, turnout time, travel time, and setup time.

SCM: Strict centre of mass

A dispatch strategy in which the dispatcher makes travel time estimates acting as if the unit were located at the statistical center of its district and the incident were at the statistical centre of its district.

Second-arriving

Arriving second in response to an alarm, regardless of the assigned order of arrivals. Compare to second-due and see first-due.

Second-due

Assigned to arrive second in an area in response to an alarm. Compare to second-arriving and see first-due.

Service time

The total "off the air" time per call for service for a response unit. Includes travel time, on-scene time, and possibly related off-scene time.

Third-arriving

Arriving third in response to an alarm, reguardless of the assigned order of arrivals. Compare to third-due and see first-due.

Third-due

Assigned to arrive third in an area in reponse to an alarm. Compare to third-arriving and see first-due.

Travel distance

The distance a fire company must travel from its firehouse (or wherever it is when told to respond) to the scene of a fire (or the location from which the original alarm was signaled).

Travel time

The time required for the dispatch response unit to travel to the scene of the reported incident.

Turnout time

The elapsed time between the notification of a company that it is to respond and its actual departure from quarters.

Utilization factor

The fraction of time a response unit is unavailable to respond to dispatch requests. In this model, it is assumed that a unit can only be unavailable because of call-servicing duties. Sometimes called utilization rate.

Workload

Same as utilization factor.

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